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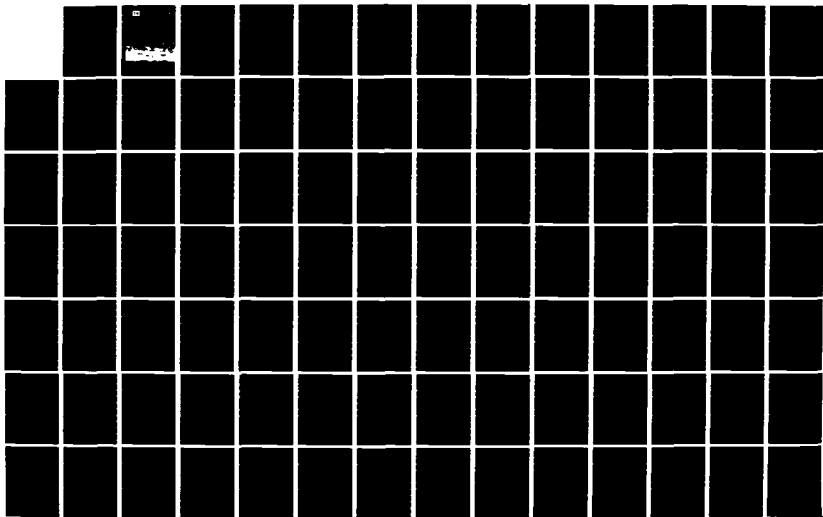
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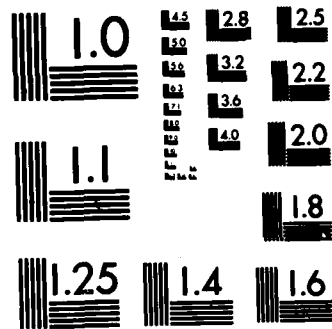
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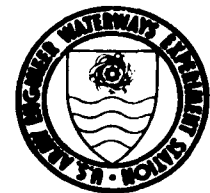
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TECHNICAL REPORT SL-82-9

# ANNOTATED BIBLIOGRAPHY: POLYMERS IN CONCRETE

by

James E. McDonald, Edward F. O'Neil

Structures Laboratory

U. S. Army Engineer Waterways Experiment Station  
P. O. Box 631, Vicksburg, Miss. 39180

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  → Included in this bibliography are 1211 annotated references on polymers in concrete. They cover articles written between 1922 and 1981 on four major areas of polymers in concrete: polymer concrete, polymer-impregnated concrete, latex-modified concrete, and sulfur concrete. A complete subject index and author index are provided. ↖		

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## PREFACE

This bibliography was prepared at the Structures Laboratory (SL) of the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Office, Chief of Engineers (OCE), U. S. Army, as a part of Civil Works Investigation Work Unit 31553. The study was authorized 16 February 1977 by first endorsement of a WES letter dated 3 January 1977. Mr. Fred Anderson of the Structures Branch, Engineering Division, OCE, served as technical monitor.

The study was conducted under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John Scanlon, Chief, Concrete Technology Division, SL, and under the direct supervision of Mr. James E. McDonald, Chief, Evaluation and Monitoring Group, SL. The report was prepared by Mr. McDonald and Mr. Edward F. O'Neil.

Commanders and Directors of the WES during the course of this study and the preparation and publication of this bibliography were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. The Technical Director was Mr. F. R. Brown.

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## ANNOTATED BIBLIOGRAPHY: POLYMERS IN CONCRETE

### INTRODUCTION

1. One of the largest duties of the Corps of Engineers in managing this nation's navigable waterways is the operation of over 6500 civil works projects. Many of these projects have associated with them one or more concrete structures such as dams, locks, flood walls, powerhouses, and bridges. A study conducted of these projects showed that 60 percent of these structures are over 20 years old and more than 25 percent are older than 40 years. With the declining emphasis on new construction projects within the Corps, a greater need to repair and maintain these concrete structures has emerged.

2. The development and evaluation of materials for potential use in the maintenance and repair of civil works structures is part of the objective of this research work unit. One of the efforts that has been made in fulfillment of the objectives of this work unit has been the compilation of an annotated bibliography on the subject of polymers in concrete. The use of this material in concrete has become accepted as a useful repair material during the past decade, and as such, much information has been written on its use and material properties.

3. The bibliography has been divided into four sections to group papers of a type together. Section A deals with papers that are grouped under the category of polymer concrete and polymer portland cement concrete. There are 615 abstracts in this section and the papers relate to the use of polymer materials to entirely replace the portland cement in the concrete (polymer concrete) and the use of polymer materials mixed with portland cement (polymer portland cement concrete). These papers range from 1954 to present. Section B has 248 references that range from 1967 to present and relate to the topic of polymer-impregnated concrete where monomers are saturated into hardened concrete and subsequently polymerized. Section C covers latex-modified concretes and has 256 abstracts on articles dating back to 1922. Section D describes 92 articles on sulfur concrete with articles as far back as 1924.

4. In the bibliography, each entry of literature appears only once in the section in which the title is most significantly identified, although the contents of some may be associated with two or more sections of subjects. Attempts were made to include all relevant references on the subject of polymers in concrete; however, considering the number of references in this broad field, many articles have been omitted.

5. As a guide for the users of this bibliography, a complete subject index and author index are provided.

SECTION A  
POLYMER CONCRETE

1954

- A1 *Rissel, E., "Patching of Concrete Pavements" (in German), Forschungsgesellschaft für das Strassenwesen E. B. Schriftenreihe der Arbeitsgruppe Beton-strassen No. 5, 1954, pp 58-61; Translation: PCA Literature Research Section Foreign Literature Study No. 147.*

This paper reviews earlier observations made on the Kassel and Frankfurt sections of the Autobahn and the results. The results provide a pattern for the appraisal of other tests, especially those which were wholly or in part negative.

The test evidence may be summarized as follows:

1. It is mandatory to thoroughly clean the old concrete surface; this was formerly considered to be only "necessary." For heavy traffic conditions sand blasting or similarly effective procedures cannot be avoided. Other methods of cleaning the old surface, including chemical methods, have not led to desired results.
2. For heavy traffic conditions, such as on the Autobahn, the patching mortar should be applied mechanically. The use of a parabolic screed with vibrating apparatus as proposed by Dr. Leins deserves special attention.
3. Mortar used in grouting (shotcreting) may be of wetter consistency than used otherwise.
4. Patches should extend only to cover damaged spots. Thin "coatings" extending over whole or parts of slabs are to be avoided for technical and economic reasons.
5. It seems particularly important that cement be allowed to harden a sufficiently long time to develop its full bond. To permit the cement to participate in the bond between patch and old surface, the latter should be saturated at least at the surface before patching begins. Rapid hardening cements are recommended for rush work.
6. Further treatment - according to experience at Frankfurt, Kassel, and in hydraulic structures - is needed only when patches are exposed to direct sunshine in the summer. Some authorities recommend an after treatment, others do not.

1956

- A2 *Michaels, A. S., "Surfactant-Treated Minerals as Reinforcing Fillers," Industrial and Engineering Chemistry, Vol 48, No. 2, Feb 1956, pp 297-304.*

The object of this investigation was to determine the effect of treatment of the surfaces of certain mineral fillers with selected surface-active compounds upon the physical properties of resinous or elastomeric compositions containing such fillers.

Mineral solids used were kaolinite and wollastonite. Surface-active agents employed were a fatty quaternary ammonium salt, and a fatty amine. Polymers used were GR-S, a poly(vinyl chloride) - vinylidene dichloride copolymer, plasticized polystyrene, and an epoxy resin.

Compositions were prepared by suspending the filler in water; adding the surface-active agent; adding the resinous material as an aqueous emulsion; coagulating the solids, filtering off the water, and drying; and compression-molding and/or -curing the product at elevated temperature and pressure.

The results of this study lead to the following conclusions.

Treatment of mineral fillers such as kaolinite or wollostonite with small controlled quantities of selected surface-active agents is accompanied by improvement in strength and stiffness of plastic or elastomeric products containing 50 percent by weight of filler, provided the untreated filler does not disperse readily in the resin with which it is compounded. Excess treatment of the filler is detrimental to physical properties. Surfactant treatment causes reduction in strength and stiffness of compounds based on resins in which the filler disperses readily without treatment.

#### 1958

- A3 *Morgenstern, E. A., and Stander, M., "Reinforced Plastic Protective Coatings," Bureau of Ships, Journal, Vol 7, No. 2., Jun 1958, pp 13-17.*

The purpose of this article is to present background information as well as the experience with reinforced plastics that led the Bureau to approve their use as protective coverings for wood decks.

Reinforced plastics, as known today, are synthetic resinous products combined with fibrous glass reinforcements. The resin most commonly used is the polyester type. Epoxy resins have certain advantages over the polyesters, but their use so far has been limited by higher cost and greater handling difficulties.

#### 1959

- A4 *Gaul, R. W., and Apton, A. J., "Epoxy Adhesives in Concrete Construction," Civil Engineering, Vol 29, Nov 1959.*

Epoxy adhesives have been used in both concrete and asphalt surfaces to bond new concrete to old, to bond precast concrete sections, to anchor traffic bars to road surfaces, to level chuckholes, to fill cracks, spalls, and depressions, to bond traffic buttons to the roadway surface, and to bond steel dowels into concrete pavement. In fact, for the past five years adhesives with an epoxy resin base, in liquid, paste, and grout forms, have been undergoing tests as bonding agents for concrete in highways, bridges, aircraft runways, buildings, streets, and sidewalks.

Results of the tests have been impressive. Epoxy adhesives have proved versatile and easy to use; they form bonds that are actually stronger than the concrete itself. Costs for materials and labor frequently are less than half those of conventional repair methods. In many cases the use of these adhesives will speed repairs so that traffic can move over a repaired area in about three hours.



- A5 *Pepper, L., "Epoxy Resins for Use on Civil Works Projects: Summary of Data Available as of 1 March 1959," Technical Report No. 6-521, Report 1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., Aug 1959.*

Epoxy-resin systems have been formulated, sold, and used for a wide variety of applications because of their strength, adhesion, stability at high temperatures, resistance to chemical attack, abrasion resistance, and electrical characteristics. This report reviews the available literature and manufacturers' publications to determine the potential uses of epoxy resins on Civil Works projects. These possible uses fall into three general categories: adhesives, fillers, and coatings. Specific applications that have proved successful are described.

1960

- A6 *Lawrence, J. R., Polyester Resins, Van Nostrand Reinhold Co., New York, 1960.*

The term polyester resins encompasses a variety of materials. However, technically, by virtue of usage, the compositions which are generally recognized by this designation are the unsaturated polyester resins, widely employed in reinforced plastics; and it is these compositions which are described in this book.

Polyester resins have attracted particular attention because of their ease of handling and fabricating. This processing ease has allowed them to pave the way in new areas of usage in many fields. Reinforced with fiber glass and other fibrous material they have been one of the leaders in bringing about the acceptance of reinforced plastics as structural materials, now widely used on the basis of their merits and not merely as substitute materials.

This book presents a review of polyester resins from the standpoint of chemistry, curing, and diversified applications. As with other books in this series, the presentation is aimed at giving a better understanding of the materials and how they are used, without becoming unduly involved in theoretical considerations. In this manner, the book is intended to serve as a guide to those directly or indirectly associated with fabricating or using articles fabricated from polyester resins.

- A7 *Tremper, B., "Repair of Damaged Concrete with Epoxy Resins," Proceedings, American Concrete Institute, Vol 57, Aug 1960.*

The use of adhesives and binders containing epoxy resins by California Division of Highways in repairing concrete is described. Illustrations of their use in repair work are given. The discussion includes possible variations in formulation to secure wanted properties for specific uses, methods of application that are necessary to obtain strong and durable repairs, and a typical formulation for general use.

- A8 Westall, W. G., "Bonded Resurfacing and Repairs of Concrete Pavement," Bulletin, Highway Research Board, Bulletins 258-260, 1960, Washington, D. C., pp 14-24.

For several years the Research and Development Division of the Portland Cement Association has investigated methods and materials for bonding relatively thin layers of concrete to old pavements or floors. The laboratory tests were designed to evaluate such factors as surface cleanliness; smooth and roughened surfaces; damp and dry surfaces; cement-sand mortars and neat cement grouts for bonding courses; concrete resurfacing mix designs; and methods of placing the resurfacing concrete, including surface and internal vibration, mechanical float compaction and pneumatic pressure application. Tests were made of the effectiveness of the bond as measured by the load required to shear the concrete along the plane of the junction of the two layers of concrete. These tests indicated that the most important single factor was the condition of the old surface - its cleanliness, texture, and strength or soundness. If the surface was clean and free of a weak outer skin, very good bond was generally obtained; otherwise relatively poor bond was obtained.

The purpose of this paper is to discuss bonded concrete construction and its various applications to pavements, to describe projects which have been accomplished, and to illustrate the essential steps in surface preparation and construction. All the jobs discussed were constructed at airports.

#### 1961

- A9 James, J. G., "The Use of Epoxy Resins in Road and Bridge Surfacing," Resin Review, Vol 1, No. 3, 1961, p 6.

The use of epoxy resins has become established in structural engineering, and in the last few years it has been experimentally applied to road engineering. The major applications that have been tried for road engineering are listed in this article. It is concluded that for some work, such as concrete repair on major roads, epoxies may prove useful, but that sufficient experience has not yet been acquired to establish the best formulations and techniques or to forecast the possible extent of their use in the future.

- A11 Minarik, W. L., "Use of Epoxy Resins," Public Works, Vol 92, Sep 1961, pp 116-118.

Epoxy resins are becoming widely accepted as new materials of construction and tools for maintenance. Architects and engineers are specifying them for new construction and reconstruction projects. Contractors and supply houses are recommending them for maintenance work and corrective applications. The Federal government and many state highway departments have written specifications for epoxy resin materials.

A large volume use of epoxy resins is for surfacing and repairing roadways and bridges. Epoxy road surfacing materials are also used as

waterproofing membranes on bridge decks and concrete roofs. Another important use for epoxy road surfacing material is for patching and repairing.

- A12 Murai, N., and Mizuno, S., "Thermosetting Plastics Swelled with Grainy Fillers (Plastics Concrete)," Review of the Electrical Communication Laboratory, Vol 9, No. 9-10, Nippon Telephone and Telegraph Public Corp., Tokyo, Sep-Oct 1961, pp 581-588.

Polyester resin swelled with grainy fillers is described in this paper. The fillers are different in size, i.e., powder of calcium carbonate of 2-5 $\mu$ , iron sand of 100-200 $\mu$ , sand of 300-400 $\mu$ , and stone of 3-5 mm. The mixing ratio for high workability and strength has been determined. The characteristics of the mixture thus obtained after curing, which is called Plastic Concrete (P.C.) are as follows:

Compressive strength - 12 kg/mm<sup>2</sup>; modulus of elasticity - 2000 kg/mm<sup>2</sup>; flexural strength - 3 kg/mm<sup>2</sup>.

#### 1962

- A13 ACI Committee 403, "Guide for Use of Epoxy Compounds with Concrete," Proceedings, American Concrete Institute, Vol 59, Dec 1962, pp 1121-1141.

Describes proper procedures for the use of epoxy resin compounds for skid-resistant overlays, waterproofing, patching, crack and joint sealing, bonding new concrete or hardened concrete to old concrete, grouting, coatings to prevent chemical attack and other uses. Methods of surface preparation of both concrete and steel, removing contamination prior to applying epoxy compounds, and for applying the epoxy resin compound are described. A test for appraising the soundness of the concrete surface and adhesion to it is suggested. Since epoxy compounds are often toxic, safe handling practice is extensively discussed.

- A14 "Those Wonderful Epoxies," Engineering News-Record, Vol 169, No. 12, Jul 1962, pp 28-34.

Because of their amazing properties, epoxies are being touted as the miracle materials of the age and a panacea for construction problems. They will do much that is claimed for them but they have limitations. This paper is a study of what epoxies are, what they will do and won't do, with suggestions for and about their use in construction.

- A15 Welch, G. B., et al., "Epoxy Resin Concrete," Civil Engineering and Public Works Review, Vol 57, Jun 1962, pp 759-762.

The paper presents details of experimental investigations into new concrete materials in which an epoxy resin replaces the usual cement-water paste as the binding constituent.

The epoxy concretes have generally very high strength characteristics, with particularly high tensile and bond strengths. Figures for

elastic modulus, Poisson's ratio, curing shrinkage, thermal movement, etc., are also given for typical epoxy concrete mixes, together with details of different aggregate gradings and resin formulations examined.

The important influence of varying the composition of the epoxy binder, by including a flexibilising modifier to increase flexibility is demonstrated by the results, and a satisfactory compromise which gives intermediate properties is indicated.

1963

A16 Jecic, D., "Resin Concretes," RILEM Bulletin No. 18, Mar 1963.

Resin concretes are a somewhat special extension of the very vast field of filler plastic materials. Some of the synthetic resins can in fact be used to bind the most varied materials. Products of the binding of materials generally used for the manufacture of concretes have quite special features: their mechanical properties and outer appearance are similar to those of ordinary concrete. In certain of their characteristics, however, resin concretes are superior to ordinary concretes and can in a sense complete them. Inasmuch as concrete is at the present time the most extensively used building material, a material which in a way characterizes our age in the field of construction, these characteristics of the new material acquire a special importance.

Resin concretes are markedly superior to ordinary concretes:

- in their tensile strength which, depending on the composition of the binder and the batching, can amount to several hundred kg/cm<sup>2</sup>;
- in their very strong bonding, which exceeds the tensile strength of ordinary concrete;
- in the speed with which they acquire their strength. The speed is greatly influenced by temperature, but there are types of resins which harden in 24 hours at ordinary temperature (18-20° C). If one is willing to work at moderately high temperatures (up to 100° for example), it is possible to obtain times of hardening that are as short as practical placing will allow (a few minutes);
- in their impact strength, which is the weak point of ordinary concrete;
- in their resistance to the effects of chemical agents;
- in the slighter shrinkage of concretes prepared with certain types of epoxy resins.

A17 Popava, O. S., "Creep of Polymer-Containing Concrete" (in Russian), *Sb. Tr., Lengrad, Inst. Inzh. Zheleznodorozh. Transp.*, No. 276, 1967, pp 113-27; Chemical Abstracts, 109561j, Vol 69, No. 26, 1963.

Cement was compounded with 2 or 6 percent of resin No. 89 (I) (epichlorohydrin-m-(H<sub>2</sub>N)<sub>2</sub>C<sub>6</sub>H<sub>4</sub> condensate) and aged for 28 days at 15-18° in air of 45-55 percent or 85-90 percent relative humidity. The concrete samples were then compressed with a pressure (P), which was 0.5-0.8 of their compressive strength at break ( $\sigma$ ). Curves were obtained showing the change of relative deformation ( $\epsilon$ ) with time, and  $\epsilon/P$  versus  $\sigma$ . The ratio  $\epsilon/P$  (in cm<sup>2</sup>/kg) was called the true measure of creep. In all cases

the additions of I decreased  $\epsilon/P$  and  $\epsilon$  of the concrete. Typically the addition of 6 percent I and aging the samples at 15-16° and 45-50 percent relative humidity gave  $\epsilon/P = 6.80 \times 10^{-6} \text{ cm}^2/\text{kg}$ .

A18 Riley, O., "Bridge Deck Repair Techniques on the New Jersey Turnpike," Public Works, Vol 44, No. 5, May 1963, pp 126-129.

Based on our experiences with the Passaic River Bridge deck, we have recommended revised standards for the Authority's new bridge deck design. At the Lincoln Tunnel Interchange, now under construction, this design is being used. It features an 8-in. reinforced concrete slab constructed in the light of modern concrete technology, a coal-tar epoxy resin waterproofing sealer applied to the slab surface, and a 1-1/2-in.-thick asbestos neoprene-asphalt wearing surface. This composite design of a structural concrete slab protected by an efficient sealer and a flexible wearing course is expected to produce a highly serviceable bridge deck that can resist weather attacks and sustain the tremendously increased traffic volumes on the New Jersey Turnpike.

A19 Rooney, H. A., "Epoxy Resins for Structural Repairs," The Fifteenth California Street and Highway Conference, Jan 1963, pp 126-129.

The phenomenal adhesion of the epoxies stimulated a research program to find adaptations of the epoxy resins as a structural repair material for use on concrete highways and bridges.

The California Division of Highways uses four basic epoxy formulations, in three of which the complete compositions are specified. The fourth type is a modified coal-tar epoxy type which is adequately defined by its physical and chemical properties. These formulations comprise:

1. An epoxy-polysulfide binder, unfilled, for use in epoxy mortars in areas not subject to subfreezing temperatures and for the bonding of new concrete to old concrete.
2. A slow-setting epoxy-polysulfide binder containing a relatively nonsettling and easily redispersed inert filler for use in bonding extruded portland cement concrete curbs to asphaltic concrete.
3. A two-component epoxy-curing paste in which the components are mixed 1 to 1 by volume prior to use. This type is of value in the making of small repairs or in the cementing of reflective pavement markers in place where a nonflowing product of buttery consistency is desired.
4. A two-component epoxy-coal tar formulation, corresponding to Shell Guardkote 140, for use in epoxy mortars in cold climates or in applications where a black color is not objectionable.

1964

A21 Bares, R., et al., "Practical Application of Synthetic Constructive Material as a Result of Exact Definition of Material Properties," RILEM Symposium on the Research and Reception Tests of Synthetic Materials for Construction, Liege, 9-11 Jun 1964, pp 465-477.

The Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences began its research into resin concrete in 1958 when the Czechoslovak building industry began to feel an acute need for a new, high-quality structural material resistant to various aggressive effects and characterized by high strength. Various aspects of selection of a suitable bonding agent on the basis of synthetic macromolecular materials were considered. Extraordinary chemical resistance, availability of raw materials, simple production and a consequently low price. Circumstances of particular importance for the building industry, decided in favour of furan resins. The criterion of strength was not decisive.

Among the furan resins we considered the furfurylalcohol or furfurylalcohol-furfurylaldehyde polycondensates as the most suitable for the given purpose. The material which resulted from the use of these resins as bonding agents for mineral aggregates was given the name of Berol. Our research in this respect was brought to certain practical applications, one of which, Berol pipes, is illustrated by a number of photos.

- A22 Brailsford A. D., and Major, R. G., "The Thermal Conductivity of Aggregates of Several Phases Including Porous Materials," British Journal of Applied Physics, Vol 15, 1964, p 313.

Expressions for the thermal conductivity of two-phase media are derived for various types of structure, and these are compared with the experimental results of Sugawara and Yoshizawa. The extension to the case of three phases is given. For porous media, such as sandstone, the structure plays a vital part in the determination of the thermal conductivity, and a model is proposed which allows this feature to be included and which provides a consistent explanation of experimental data.

- A23 "Lightweight Epoxy Resurfaces Bridge," Contractors and Engineers, Vol 61, No. 9, Sep 1964, pp 58-59 and 62.

The first step in resurfacing the upper deck of the San Francisco-Oakland Bay Bridge was to sandblast all surfaces and to repair potholes and cracks over 1/16-in. wide with a mortar of epoxy resin and sand aggregate. Then, just prior to surfacing, workers whipblasted the deck to remove any grease or oil.

To withstand the heavy traffic loads on the bridge, the aggregate was specified to be tough and highly abrasion-resistant. The aggregate used as a 12-30 mesh natural silica-type sand supplied by Pacific Cement Aggregates, Inc., San Francisco. The aggregate has a high percentage of material with a Mohs hardness in excess of 7.

#### 1965

- A24 Blake, L. S., and Pullar-Strecker, P., "Epoxy Resins for Repair of Concrete," RILEM Bulletin No. 28, 1965, Paris, pp 25-31.

Epoxy resins are being used in Great Britain for repair of

concrete but, because of their high cost, this use is generally limited to repair of small areas. For repair of larger areas, or on roads where it is possible to close traffic for 7 days, the alternative cheaper method of applying a concrete resurfacing is more frequently applied. In general, experience with epoxy resins has been satisfactory but some failures have occurred due to faulty application or to lack of knowledge of the properties of the resin and hardener. It is considered that the use of epoxy resins could be extended to a much wider field of repair work if more information was available on their physical and engineering properties; manufacturers of resins have little information on these properties. With these problems in mind, the Cement and Concrete Association has made a preliminary but systematic study of the properties of epoxy resin and a full report is being prepared.

A25 Johnson, R. L., "Cellular Concrete," U. S. Patent 3,211,675, (CL 269-29.6), 12 Oct 1965; Chemical Abstracts, 17673, Vol 63, No. 13, 1965.

A cellular concrete having a curing cycle comparable to conventional concretes, good acoustical properties, low thermal condition, low thermal expansion, resistant to freezing and thawing, fire resistant, and having a high compressive strength is made in the following manner: portland cement (Type 1) 1000 and H<sub>2</sub>O 324 containing CaCl<sub>2</sub> 6.3 and acrylamide 12.5 parts were mixed for 3 min. and allowed to stand for 1.5 hours. In a separate container the following mixture was prepared: epoxy resin 68.5, melamine-formaldehyde resin 3.1, Na  $\alpha$ -sodioacetate 9.4, ethylene sulfide polymer (mol. wt. of 1000) 25, dimethylaminomethylphenol 4.7, 2,4,6-tris(dimethylaminomethyl)phenol 4.7, and Al powder 6 parts. The latter mixture was blended with the cement mixture and poured into an open mold. When cured and dried, the resulting mixture had a bulk d. of 83 lb/ft<sup>3</sup> and a compressive strength of 2188 lb/in.<sup>2</sup>

A26 Krieger, P. C., "Concrete Connected to Concrete by Means of Resins," RILEM Bulletin No. 28, 1965, Paris, pp 45-59.

With an epoxy-glue, a reliable connection between two parts of hardened concrete could be made, which connection was not influenced by the type of curing of the connection, while also the long-time loading tests gave good results for loads of 70 percent of the fractural load in short-time testing. With a polyester-glue, no reliable connection between two parts of hardened concrete could be made. It is not known what the determining factor is in this connection.

Judgment of the behaviour of the glued connection may be done by bending, tensile or shear tests, which in each case all lead to the same conclusions.

A27 Mitchell, L. J., "Irrigation Operators' Workshop - 1965: Concrete Repair," Bureau of Reclamation, Denver, Colo., 1965.

Numerous kinds of repairs are possible with epoxy resin mortars. Epoxy resin mortars are made by adding sand fillers to fluid epoxy resin.

These mortars should be mixed as lean as possible to avoid excessive stickiness. A good rule for making epoxy mortar is to mix clean, thoroughly dry, well-graded sand into the mixed epoxy as long as it is possible to stir additional sand into the mix and still have it thoroughly coated with epoxy. If finishing difficulties are encountered, more sand should be added. The addition of more or coarser sand will usually increase the strength of the resulting mixture, which in all tested cases, is higher than that for concrete. Maximum size of sand used will depend upon the particular application. Sand should be the coarsest that can be properly finished or featheredged if the application involves featheredging. Applications may be ground by carbonundum wheels or disks to produce the final smooth edges or to correct surface imperfections.

A28 *Mlodecki, J., "The Application of Isobutoxysiloxane Resin to the Manufacturing of Resin Concrete," RILEM Bulletin No. 28, 1965, Paris, pp 67-73.*

It is possible to obtain resin concretes under the application of organic resins both epoxy and polyester with the addition of isobutoxysiloxane resin - with very good strength properties.

The addition of isobutoxysiloxane resin in the amount of 11 and 25 percent of the weight of the organic resin slightly lowers but does not essentially reduce the bending and compressive strengths of epoxy and polyester concretes.

The method of hardening the respective concretes seems to have an important influence on their strength properties.

The application of isobutoxysiloxane resin as addition to epoxy and polyester concretes would be advisable, should further tests confirm the rightness of the assumptions that this resin, as a silicone one, in view of its characteristic properties, should decrease creeping and increase the durability of these concretes, and should also improve other properties, essential for certain applications such as frost- and heat-resistance, electro-insulating properties, etc. Tests of a number of other properties of the said concretes are then necessary.

Under the application of the isobutoxysiloxane resin as binder as well as of asbestos as filler, it is possible to obtain materials of good strength properties, however considerably lower than concretes manufactured under the application of the organic resins tested. These materials may be applied in the cases when the strength requirements to be met are not very high; however, other properties of the material are important, particularly electro-insulating and thermic properties, frost-resistance, and durability which characterize materials made from silicone resins.

A29 *Okada, K., "Resins for Concrete in Japan," RILEM Bulletin No. 28, 1965, Paris, pp 73-81.*

This paper describes briefly the present status of studies on various resins used in the concrete works of both fields of Civil Engineering and Structural Engineering in Japan. In our country, like



other countries in the world, various resins, especially epoxy resins, and some polymers are trially used as admixtures, bonding of surface coating materials of concrete. But it may be said that these trials are just under way, though many researches have been made on the resins for concrete, and earnest efforts are devoted also by the manufacturers to produce them at lower cost and even to discover more useful ones in cooperation with the concrete researchers and engineers.

- A30 Palencar, Z., "Survey of the Techniques and Application of Mortars and Concretes Using Waste Materials from the Chemical Industry as a Base," RILEM Bulletin No. 28, 1965, Paris, pp 81-87.

The description of the mix indicates that a filled binder/weight ratio appr. 1:4 is concerned. We are afraid that shrinkage and creep of such material are too great to permit its use as constructional material. This paper shows how great the scatter of the obtained results is, especially regarding Young's modulus (the largest value almost ten times as large as the smallest value) and flexural strength (100 percent). This, in conjunction with the small absolute value of Young's modulus, only confirms how unsuitable the material is for constructional purposes. What does the change of modulus depend on, how great is the shrinkage, creep and long-term strength? What degree of curing of the material can be obtained at room temperature and high R.H.?

- A31 Periale, J. G., "Resinous Membrane Sealers for Bridges," RILEM Bulletin No. 28, 1965, Paris; pp 87-91.

The need for some type of protective membrane for bridge slabs has been clearly established in the United States.

Extensive field work has been performed with epoxy resin based membranes and at this time it appears that a high degree of protection is afforded to exposed concrete by such membranes.

Polyester resins will no doubt play an important role in future work with such membranes since they appear to yield protective properties comparable to epoxy resin based membranes and are about one-half the cost of epoxy resins.

- A32 Verzal, A. I., Ponomarev, M. A., Raetskaya, D. Ya., and Shreder, A. G., "Properties and Use of Polymer Concretes and Mortars" (in Russian), *Proizv Stroit-Izdelii iz Plast. Mass Sb.*, 1963, pp 218-239; Chemical Abstracts, 5050, Vol 62, No. 5, 1965.

The properties and areas of use of various types of concretes prepared on the basis of mineral and synthetic binders are described. Additions of low-mol.-wt. org. substances (surface-active substances and plasticizers) and polymers have considerable effect on structure formation in concretes and on their physical-mechanical properties. Thus, addition of the butadiene-styrene latex SKS-65 GP, a poly(vinyl acetate) emulsion, phenol-HCHO, melamine-HCHO, and phenol-furfural resins to  $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$  caused a change in the plasticity of the material, decreased water absorption, considerable increased strength, etc. The

mechanism of the effect of org. additives on the properties of plastic concretes is analyzed. E.g., the increase in strength and decrease in water absorption of polymer gypsum containing the heat-setting phenolformaldehyde resin is due to the filling of the pores of the gypsum with the latter, in addition to further reinforcement when the resin hardens. The properties of light polymer-silicate concretes based on an agloporite-silicate binder with additions of synthetic resins (furylaniline, urea-HCHO, and phenol-HCHO) and on the basis of silicate-org. binders (e.g., water glass and Et silicate, the silicate KS) are described. A review of investigations of polymer cement concretes and mortars, org.-mineral concretes (plastic concretes), and studies of their properties and construction uses is given.

A33 Warren, C. K., "Resin Bonded Concrete," RILEM Bulletin No. 28, 1965, Paris, pp 109-121.

It was decided at the beginning of this programme that the best approach would be to select a technique and suitable resin system which promised the highest strengths at low resin concentrations. Then, after a comparatively brief examination of the variables within the technique, to obtain the optimum conditions, the main course of the investigation would be directed towards determining the effect of variations in the aggregate gradings.

#### 1966

A34 Johnston, A. H., and Drewett, G. I. H., "The Use of Epoxy Adhesives with Concrete," New Zealand Engineering, Vol 21, No. 3, 15 Mar 1966, pp 126-132.

This paper deals briefly with the chemistry of epoxy adhesives, in somewhat greater detail with their uses and physical characteristics, the materials associated with their use, with experimental work done in the Ministry of Works Laboratory, Christchurch, and finally with their practical application.

A35 Nielsen, L. E., "Simple Theory of Stress-Strain Properties of Filled Polymers," Journal of Applied Polymer Science, Vol 10, 1966, pp 97-103.

By the use of simple models of filled plastics, approximate equations are derived for the elongation to break in the case of perfect adhesion between the phases and for the tensile strength in the case of no adhesion between the polymer and filler phases. By combining these equations with equations for the modulus (assuming Hookean behavior) all the stress-strain properties can be derived, including rough estimates of the impact strength, as a function of filler concentration. Among other things, the theory predicts a very rapid decrease in elongation to break as filler concentrations increases, especially for the case of good adhesion. It is also predicted for the case of good

adhesion that the tensile strength of a filled polymer can be greater than that of an unfilled polymer.

- A36 Olavi, G., and Nilsson, S., "The Addition of Plastic Materials to Cement and Concrete," Sep 1966, pp 452-456, Road Research Laboratory.

The technical advantages derived from the addition of synthetic materials to mortar are discussed. A comparison is made between the various types of synthetic products, their costs, and conditions of use.

- A37 Voinea, N., Velica, P., and Schiller, E., "Some Problems Concerning Concretes with Polymers" (in Romanian), Rev. Constr., Vol 19, No. 9-10, 1966, pp 506-511; Chemical Abstracts, 24358c, Vol 68, No. 6, 1968.

The physical properties of concrete samples containing various amounts of poly(vinyl acetate) were investigated. The compression strength decreased while the axial tensile strength and the bending strength increased with the amount of polymer. The strengths decreased following water exposure, but the effect was more marked in samples with high polymer content. Ir irradiation increased the strengths.

#### 1967

- A38 Bares, R., and Navratil, J., "Some Physical Properties of Resin Concretes," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

An important factor for the structure exploitation of resin concretes is their elasticity as a sum of the relations between stress and strain under short-term loading up to rupture in various external conditions. This contribution shows, in particular, the forms of longitudinal, lateral, and volume stress-strain diagrams, as well as the Poisson ratio courses of differently composed resin concrete of various kinds. A mathematical relation well approximating the strain diagrams of resin concretes is further introduced.

Attention is paid to limit strains, as well. Graphic representation of their relation to the mixture composition and prism strength illustrates coincident behaviour of all resin concrete kinds. More, there is emphasized the mutual connection of all the phenomena on the observation.

The creep has been followed up by long-term tests, and accordingly the long-term strength, both at various temperatures.

Attention is paid further to longitudinal changes of hardening resin concretes as well as of hardened ones under the influence of temperature or humidity variations. Finally, other properties of resin concretes are mentioned.

- A39 Bazant, Z. P., and Weiss, V., "A Method of Testing Relaxation and Durability Under Stress of Resin Concretes," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The effect of various aggressive media on loaded specimens is far more pronounced than that on the nonloaded ones; this holds particularly true about plastics and resin concretes. A simple method of measuring relaxation and durability under stress has been developed for materials with low extensibility, such as concretes and mortars. Circular C-shaped rings are expanded by a set screw placed in the gap between the rings ends to ensure time invariable strain. At the preset intervals the gap is enlarged with the aid of a dynamometer by small values  $\delta$  and  $2\delta$ , the force produced by the set screw calculated by extrapolation of the measured forces, and the rigidity of the ring determined. The deterioration of the specimen in time is examined by means of data on the force relaxation and the decrease of rigidity. Under a sufficiently intensive effect of the aggressive medium and stress the specimen fails after some time. However, the ring may be broken at an earlier time by a sudden enlargement of the gap and the lifetime of the specimen estimated on the basis of the short-term load-carrying capacity ascertained in the test.

- A40 Berka, L., "Determination of the Creeping and Relaxation Functions from the Results of the Creeping and Relaxation Tests," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The method of torsional vibrations (serving for the determination of elasticity coefficients and relaxation time) is not easily applicable to constructional materials based on synthetic resin. Especially for the resin concretes and in the technical practice, the creeping or relaxation test is more frequently used for the purpose of determining the rheological properties.

In the present paper, a method is given, using the results of the above tests for the determination of the rheological functions of deformation.

- A41 Brocard, J., and Cirodde, R., "Fundamental Properties of Resin Concretes" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, 4-6 Sep 1967.

After a reminder that synthetic resins in aqueous dispersions form are commonly used for modifying certain properties of hydraulic mortars, the authors explain different considerations which led to examining the case of concretes made up of mineral elements, agglomerated by a thermo-setting resin. The choice was made amongst the numerous compositions based on polyester and epoxy resins capable of cross linking at temperatures around those common in our climates. The size and nature of aggregates were examined so as to retain a minimum quantity of binder for maximum mechanical resistances. Essential physical and mechanical properties were fixed on the basis of two typical formulations (one

derived from polyester, the other from epoxy). Finally, an important part of the experiment was centred on the behaviour of resin in concretes in use and more particularly on creep and the influence of temperature on mechanical properties and creep.

A42 *Cirodde, R., "Techniques d'assemblages par collage," RILEM Bulletin, New Series 34-37, Series 37, Dec 1967.*

The experimental observations reported here result from the mechanical properties and the adhering properties of synthetic resins thermosetting at room temperature. They deal with jointing traditional materials by methods which, up to the present, have rarely been used for structural applications. After a survey of the criteria selected for judging a glue for concrete, the author describes laboratory techniques used for testing glues for metals, gives the values obtained for a certain number of products on the French market, and examines the efficiency of some surface treatments. The paper continues by stating some results of tests of glueing materials such as stone, brick, wood, etc. Mixed construction (concrete-steel, concrete-aluminium) for which experiments are described, is the first result of study of concrete reinforced with glued reinforcement. Apart from instantaneous features the ageing behaviour of composite units under shear and bending stress has been observed and has indicated some elementary values (creep for example).

A43 *Colonna-Ceccaldi, J., "Mortiers et bétons de résine," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.*

Usually, mineral fillers (powdered slate or mica, calcium carbonate) are added to thermosetting resins to save money, and to enhance the rigidity, without a decrease of easiness for high or low pressure molding.

If you select as fillers two granular or powdered minerals with two different crystal forms, but one identical parameter in the mesh of crystal lattice, you may obtain some new advantages as the improvement of mixture workability before jellification and the increase of the mechanical strength.

Between a product with one filler and a product with two fillers like that, the increasing factor of mechanical strength is 1,2 to 1,5 as a function of the kind of the fillers, the composition of the resin and the conditions of hardening.

The parameters of the mesh of crystal lattice are in respect of the laws about epitaxy according to Royer.

The phenomenon remains the same if you add fiber glass to the mixture; it is probably connected with a polymerization led by the associated crystals.

A44 *Franke, W., "The Employment of Epoxy Resin in the Sanitation of Prefabricated Bridge Members Made of Prestressed Concrete," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.*

Concrete cover margins ranging from 5 to 0 mm were discovered in hollow box-type members for road bridges made of prestressed concrete, fabricated according to a specified technology, with the entire series in danger of being rejected.

The exact spotting and inspection of the damage areas, which were reopened by chisel work and mended with epoxy resin mortar, resulted in the complete restoration of the prefabricated members, and their unrestricted applicability as prestressed girders. The bridge girders surfaces were also impregnated and primed with epoxy resin providing effective protection against corrosion for prestressed concrete girders mounted over steam railways or waterways. Aptitude records were kept of the various mortars, indicating that the most favourable strength values were obtained with sand of 0/1 mm and a fineness modulus, as low as possible, of approximately 45 to 50  $\text{cm}^2$ , and that mortars of these types were easily workable and particularly compact. Equations of mean value curves were defined empirically from graphic evaluations in order to obtain indications for calculating mortar masses and their characteristics.

A45 *Gamski, K., "Dilatation thermique des mortiers résineux," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.*

The dunes and Rhine sands are often used as fillers for preparing resin mortars. The results of tests described in this paper show the effect of fillers on the coefficient of linear thermal expansion of mortars in the interval from  $-10$  to  $+80^\circ\text{C}$ . The filler amount is such that it gives mortars, the apparent specific weight of which differs between 1.82 and 2.36  $\text{g}/\text{cm}^3$ . When the temperature is changing from  $-10$  to  $+80^\circ\text{C}$  during the repeated cycles, the mechanical performances of the mortars are decreasing.

The sand fillers notably decrease the flexural strength of the mortars, but the compressive strength remains the same as the one of a pure resin.

A46 *Gamski, K., "Quelques réflexions sur les circonstances susceptibles de stimuler l'utilisation judicieuse des mortiers résineux," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.*

The author analyses the part of consultant engineer in building, consulting scientist in chemistry and specialized laboratories in the organization of researches which must be done before the use of mortars resins. The intervention of these competences in this subject must be organized in order to stimulate the preparation of prescriptions based on the actual performances of mortars without taking into consideration the composition of resin mortars. In this way, a free competition will be open between the suppliers, stimulating the technical progress. The criteria of quality must be concerned together with the resin regarded as matrix material and mortar before and after setting, and concerned with the interaction between mortar and support.

- A47 Hahamovic, J., and Knezevic, N., "Propriétés du béton de résine de polyester et de déchets de'asbeste," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Asbestos halde obtained from the mines in the form of particles of 1 mm, or asbestos waste, practically unusable in industry, can be used as puzzolane. It has been demonstrated in numerous tests that with a slight addition of this halde the strength of portland cement increases to a certain extent, in other words that the cement, in a proportion of 20 percent, can be replaced by halde without any loss in the strength of the basic material.

By adding polyester resin to this asbestos halde, in a proportion of 14.7 percent, great strengths, both compressive and tensile, were obtained in materials shortly after. Thus, after 5 days, the compressive strength ( $R_c$ ) was 835 kp/cm<sup>2</sup> and the tensile strength ( $R_t$ ) 212 kp/cm<sup>2</sup>. We are trying to improve these results in order to obtain  $R_c$  1000 kp/cm<sup>2</sup> and  $R_t$  250 kp/cm<sup>2</sup>, and it is probable that this can be done without increasing the quantity of resin. It is believed that this artificial stone can very well be used for the manufacture of various prefabricated elements, because this material also possesses other favourable physical and mechanical qualities, especially impermeability, frost and heat resistance, as well as a good modulus of elasticity.

- A48 Hallquist, A., "An Investigation on Epoxy and Polyester Resin Mortars as a Jointing Material," RILEM Bulletin, New Series 34-37, Series 37, Dec 1967.

The Norwegian Building Research Institute has undertaken as a research project a study of the possibility of joining prefabricated concrete building components by means of synthetic resins. The first part of the program is a study of different mortars from which we hope to be able to evaluate their structural properties. This paper deals with an investigation on 45 different mixes of resin mortars. Three epoxies and two polyesters were used as binder in varying proportions in the mix - 15, 20, and 25 percent by weight. Three types of aggregates were used and of the nine 25-mm × 25 × 170 mm test specimen cast, three were cured at 20°C and either 30, 65, or 85 percent RH for 7 days. Bending-, compressive-, and splitting tensile strength were determined for all the test specimens. Using each mix, concrete cylinders, beams, and cubes were jointed together with a 5-mm joint. The test specimens were cured 7 days at 20°C and 65 percent RH and then tested for bond-, bending-and shear strength. To test the bond between the different mixes and reinforcing steel, mortar was filled in a steel pipe and deformed steel bars 20 mm were pushed into the pipe butting together 10 cm from the end of the pipe. When the mortar had cured for 7 days at 20°C and 65 percent RH, the strength of the joint was tested.

- A49 Hop, T., and Miodynski, Z., "Polymer-Mineral Mixtures as New Building Materials," Building Science, Vol 2, No. 2, 1967, pp 147-163.

The technology of mineral-polymer mixtures, their most important properties proved by testing, and their application in the building industry are discussed. The first part of the paper deals with the mortars and concretes to which the proper polymer has been introduced for the optimum change of their specified properties. After surveying the polymers used for the modification of mortars and concretes, the working of these chemical additions is shown, their influence on features of mortars and concretes, mode of preparation of proper mixtures, results of some tests, and the application of a variety of polymer mortars and polymer concretes are discussed.

The second part deals with those mineral polymer mixtures in which the sole binding medium is the appropriate synthetic resin. The authors' test results are given and the uses of these mixtures for variety of building structures discussed.

A50 Kofalt, J. A., "Investigation of Synthetic Resins and Synthetic Resin Pavement Properties," Jul 1967, Bureau of Materials, Testing, and Research, Pennsylvania Department of Highways.

The objectives of the study were to compare the properties and characteristics of synthetic resins with asphalt cements and synthetic resin pavement with asphalt pavement in order to determine the durability and practicality of using synthetic resins in highway construction.

The scope of these experiments includes:

1. The various resins supplied by two producers and two asphalt cements were tested. Conventional and Department tests were employed in testing and evaluating the resins and asphalt cements.
2. Synthetic resin and asphalt concrete specimens were compounded and tested following Pennsylvania Department of Highways design and control methods for bituminous concrete. Evaluations were based on comparative resin and asphalt test results.
3. Several projects were constructed using synthetic resin as the binder to evaluate mixing, placing, and durability of the resin concrete.

A51 Ionescu, I., and Enculescu, M., "Bétons à base de résines synthétiques sans liants minéraux," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

This paper shortly presents some of the results of the researches made for obtaining mortars and concretes containing organic binders based on furfural acetone, phenol-formaldehyde and epoxy resins and the combinations of them, showing the influence of their nature and of the relations existing between the components of the concrete batch on the basic properties of concretes without mineral binders.

Then, it analyzes the variation of the mechanical strengths of the concretes without mineral binders in time till 2 years, and the evolution of the experimental works for a period of 2-1/2 years of working conditions.

In conclusion, it presents assessments of the fields indicated for the application of the new type of concrete, in building construction and in the technological equipment, taking into account the technical



characteristics and the cost of the synthetic resins used as organic binders.

- A52 Ionescu, I., and Facaoaru, I., "Quelques résultats des recherches de laboratoire et semi-industrielles concernant les bétons à base de résine furfurol-acétonique "FA", " RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

This is a presentation of the results of laboratory and semi-industrial research on the properties of concretes having a furfurol-acetone base during the interval elapsing between their manufacture and the age of 2 years, namely:

- the influence of the composition and the medium in which the test pieces have been cured on the final properties of mortars and concretes and the increase in mechanical strengths in relation to time - compressive, tensile, and flexural strength, resistance to mechanical shock, to wear by mechanical abrasion; permeability in water and resistance to repeated frost-thaw;

- the variation of the dynamic modulus of elasticity in time, the contraction and the swelling of concretes. The behaviour of experimental works executed with concretes having FA monomers under conditions of industrial operation for more than 2 years and recommendations concerning the use of these concretes in the execution of construction works and technological installations.

- A53 Kreijger, P. C., "Use of Resins in the Repair of Concrete Structures," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.

Preliminary results are given of an inquiry held in the Netherlands on the repairing of concrete structures situated in- and outdoors. The several types of repairing mortars - based on cement, on cement with addition of polymers or purely on base of resin - do show an evident shifting in the direction of the use of repairing mortars purely on base of resins during the years of the execution of the reparings (before 1950 towards 1966).

- A54 Lavie, M., et al., "Composite Beams Made of Resin Concrete and Conventional Concrete," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.

A limited series of tests aiming at the investigation of the bending performance of resin-concrete cement-concrete composite beams, carried out at the Technion, Israel Institute of Technology, is described. Preliminary tests with a variety of resins (PVA, Acrylate, Polyester, and others) led to the choice of Epoxy resin as the most suitable for the purpose, and determined the fundamental structural properties of the concrete made with the chosen resin: axial load strength, bond with cement-concrete, etc. Formulae for predicting stresses and deflections are stated.

A55 Nielsen, L. E., "Mechanical Properties of Particulate-Filled Systems," J. Composite Materials, Vol 1, 1967, pp 100-119.

The science of mechanical behavior of filled systems is in a poor state. The theory, even of elastic moduli, is not exact and for most other properties is practically nonexistent. Experimental work has done little to clarify the situation since, in nearly all cases, the various variables affecting mechanical behavior have not been clearly separated. Thus, the individual effects due to interfacial adhesion, dispersion, particle agglomeration, and particle shape are not clearly known because of poorly characterized systems which do not allow one to properly separate these variables in most experimental work. There is a pressing need for better ways to characterize filled systems so that the mechanical tests can be properly interpreted.

Areas of research especially needing attention (both theoretically and experimentally) include:

(a) Methods of characterizing type of dispersion, particle agglomeration, and flocculation in suspensions and the effect of these variables on different mechanical properties. (b) Effect of particle shape and particle orientation on mechanical properties and methods of characterizing orientation in systems filled with nonspherical particles. (c) A theoretical understanding of the effects brought about by the size of filler particles. (d) Better methods of measuring the adhesion between the filler and matrix phases along with the effects of adhesion on mechanical properties, especially stress-strain and strength properties.

A56 Okada, K., Sakamura, A., Murai, N., and Sate, Y., "Resin Concrete," Journal of the Society of Materials Science, Japan, Vol 16, No. 167, Aug 1967, pp 667-676.

In its use as a civil engineering structural material the major problems associated with resin concrete are concerning the manufacturing technique of large molds, its durability and fire resistance, and the high cost of the materials.

Resin concrete is superior to cement concrete in mechanical strength, chemical resistance, quick hardening and in many other respects. With the cooperation of NTT (Nippon Telephone and Telegraph), we are now testing the utility of resin concrete as materials for making manhole covers for communication cables, and are carrying out research and development projects of its application to many other practical uses.

In this paper we will show mainly the results of our research in polyester resin concrete.

A57 Palencar, Z., "Quelques problèmes concernant la structure des bétons et mortiers de résine," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The paper deals with some problems concerning the structure of resin concrete and mortars based on epoxy or unsaturated polyester resin. The problems of the course of hardening for the material system depending

on the conditions and the milieu, were examined, first by the determination of the degree of the resin hardening, and then by the investigation of the physical properties of the material system referred to. The report points out the importance of determining the degree of the binder hardening as it is influenced by several factors, e.g., by layer thickness, binder concentration in the resin concrete, the chemical nature of the binder, the moisture, the temperature and so on, which cannot be defined in an explicit way, and single cases cannot be compared mutually.

A58 Podgorski, D., "Evolution dans le temps des caractéristiques mécaniques des résines époxydes," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

It was realized that the epoxy resin based on coatings generally became brittle when aging and that this brittleness is particularly large at low temperatures.

In view of securing their durability, the problem is to find formulations which assign, even after aging, a certain flexibility in the cold state (-20°C) and, at the same time, leaving a sufficient toughness at about +65°C.

Three formulations were considered:

- a standard formulation epoxy resin cured with polyamid,
- the above formulation modified by adding a polysulfide liquid polymer,
- the same standard formulation modified by adding coaltar.

Samples were tested, some after a normal aging (storage at 20°C), others, after accelerated aging (storage at 80°C).

In order to try to establish a relation between these two types of aging, we have observed the evolution of some of their mechanical properties (modulus of elasticity, flexural strength).

The tests realized in different temperatures have shown off the thermal sensitiveness of each of those mixtures.

A59 Podgorski, D., "Influence de l'eau sur les caractéristiques des produits à base de résine époxyde," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Water, in solid, liquid, or gaseous state, generally exerts an unfavourable effect upon epoxy resin products, which can appear in different ways and at various times.

Several formulations have been studied in the presence of moisture and their comportment was compared with the corresponding waterless formulation, taken as a reference.

It was considered the following cases where the properties of the poly-additionned products, are modified by:

- water brought in one of the components of the formulation, whether by adding just before the mixing, or by an absorption during an extended exposure in a high relative humidity room.
- a component which absorbed water has been evaporated from, by a stay in a ventilated drying-oven.

- the curing of waterless mixtures in a high relative humidity room or under water.
- the coat of waterless mixtures on wet or immersed supports.
- The evolution of the properties is controlled by bending and adhesive tests, after a curing of 7 and 28 days.

A60 Pollet, H., "Bétons à liant de résine avec agrégats artificiels," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

In the Laboratoire de Plastiques de l'ICAM à Lille research is being conducted to reduce the cost of resin as a binder so that this material may be used for heavy concrete work.

The first condition to obtain this result is to use polyester resins rather than epoxy resins. The compressive strength will be somewhat lower, but polyester resins are much cheaper.

In order to reduce the required percentage of resin, we use artificial aggregates (cubic shape) instead of natural aggregates; in such a way, the required percentage of resin is 4 percent by weight instead of 12 percent in the case of natural aggregates.

Then, in order to make these cubes at a reasonable cost, we use a mixture of clay and lime. The cubes are made by a machine for preforming and we use a compaction of 300 kg/cm<sup>2</sup>. After a heat treatment in an autoclave at a temperature of 200°C and a pressure of 16 atmospheres during five hours, their compressive strength is nearly 1000 kg/cm<sup>2</sup>.

A61 Rechner, L., "Contribution à l'étude de plaques minces en béton de plastique à liant économique thermodurcissable, et réalisation d'une installation pilote de fabrication en continu," RILEM Symposium on Synthetic Resins in Building Construction, Paris Vol 1, 4-6 Sep 1967.

Different results concerning a study of plastics concretes with an economical thermohardenable binder base are presented. A comparison of different methods of manufacturing thin plates brings out the influence of the conditions of elaboration. A pilot facility for the continuous manufacture of such plates was designed and various types of plate elements with or without support were turned out.

A62 Rioufol, M., "Utilisation de polyesters en émulsion comme liants de mortiers et de bétons," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The use of polyester resins as binders in substitution of cement makes it now possible to obtain concrete and mortars with outstanding mechanical properties.

However, the processing of such materials is quite a difficult job and sets a certain number of precise requirements, i.e., the use of perfectly dry aggregate, work in low-moisture content areas, etc., along with the fact that cost price of the materials obtained is often prohibitive.

On the other hand, the use of polyesters under the form of emulsions avoids most of these inconveniences and leads to cheaper materials with good mechanical properties.

Emulsification of polyesters is a well-known technique and may, for instance, be brought about by rapid agitation of the components in alkaline medium. Emulsions obtained are of the oil-in-water type having interesting properties, one of which being that they can be polymerized at room temperature with suitable catalyst, as used for polyesters.

In conclusion, this is a definition of the interest of using polyester emulsions in the preparation of mortars and concrete with organo-binding compounds.

- A63 Rowlands, J., *"The Formulation of High-Polymer Compounds for the Surfacing, Repair, Protection and Decoration of Concrete Structures," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.*

The paper deals with those shortcomings of concrete structures which can be usefully overcome or assisted by the application of synthetic resin compounds, and then goes on to outline briefly the relevant properties of epoxy resins, unsaturated polyester resins, isocyanate resins (including polyureas and polyurethanes), acrylic resins and furane resins. The paper suggests that these basic materials require sophistication at the hands of a Formulating Company. It is further postulated that the general acceptance of these types of materials by the Civil Engineering and Building Trade is dependent upon the supplier offering a reasonable and effective guarantee of their efficiency in use and, at this stage in the development of their technology, this presupposes the provision of adequate supervision on site.

- A64 Satalkin, A. V., et al., *"The Influence of Watersoluble-Resin Additions on the Principle Qualities of Mortars and Concretes," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.*

The injection of watersoluble resins into concretes and mortars help to heighten their watertightness capacity as well as lower their creep and shrinkage without any decrease of their compressive strength and tension resistance.

The injection of resins, when comparing to polyvinyl acetate emulsions and latexes, has good influence on hardening processes in concretes and mortars when in humid medium.

The changes of the material properties arise from the resin influence on the structure formation processes. Additions of watersoluble resins give the best effect when cements have a high percentage of C<sub>3</sub>A.

- A65 Satalkin, A. V., and Popova, O. S., *"Effect of Polymer Additives on the Strength and Degree of Deformation of Concrete" (in Russian), Sb. Tr., Leningrad Inst. Inzh. Zheleznodorozh, Transp., No. 276, 1967, pp 101-12; Chemical Abstracts, 109560h, Vol 69, No. 26, 1968.*

SKS-65GP (a latex based on butadiene-styrene copolymer), stabilized with OP-7 (a wetting agent prepared from ethylene oxide and alkyl phenols), water-soluble resin No. 89 (prepared by condensing  $m\text{-(H}_2\text{N)}_2\text{C}_6\text{H}_4$  with epichlorohydrin), or epoxy resins DEG-1 and TEG-17 were added to cement mixes and physical properties of the obtained concrete were studied. The additions caused some plastification of cement and made it possible to reduce the water/cement ratio to 0.23 without affecting workability. The compressive strength ( $\sigma$ ) and tensile strength ( $\sigma'$ ) of concretes containing the latexes depended on aging conditions and the amounts of latexes. Aging in dry air could decrease  $\sigma$  and  $\sigma'$ , while aging in the moist air or in the contact with water considerably increased  $\sigma$  and  $\sigma'$  in comparison with concretes containing no additives. The optimum amount of latexes was 1.5 to 2.5 percent. The elongation at break (E) and  $\sigma'$  increased with time during aging. Thus, concretes containing 2 percent resin No. 89 after 7-days cure had E = 325 percent and  $\sigma' = 207$  percent of concretes containing no additives. The deformation of concretes containing latexes was not considerably different from that of the untreated concretes.

A66 Valenta, O. and Kucera, E., "What Properties of Epoxies are Important When Used as Admixtures to Concrete" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The bond between cement and aggregate grains is of the utmost importance for the most important properties of concrete (tensile strength, durability). The use of certain plastics may lead to the improvement of these properties. The analysis of mechanical properties of hardened cement paste, aggregates, concrete and of certain plastics shows how we could make best of this combination. The concrete frozen in wet state is a good model of it from the qualitative point of view. The use of epoxy resin in water emulsion is facing many problems as to the choice of emulsifier, stabilizer, hardener, other agents, technology suitable for effective application of epoxy resin into the concrete texture and for hardening of cement and resin in the same conditions. The results of the tests are positive as to the increased tensile strength and the shrinkage. It is necessary to make better use of the excellent properties of epoxy or other resin of properties appropriated to the task to be fulfilled in the improvement of concrete properties. And here the word should be also given to research in plastics.

A67 Voina, N., et al., "Experimental Investigations Concerning the Use of Synthetic Resins in the Concrete Technique in Rumania," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The present paper gives a synthesis of experimental investigations concerning the use of synthetic resins made in Rumania in order to improve the physicomechanical and the chemical properties of mortars and concretes.

The first part shows the results obtained on normally hardened

mortars and concretes with PVA addition. Several compositions were investigated where the mechanical resistances, the water stability, the elasticity moduli, the deformations under lasting load, etc., were determined.

Taking into account some disadvantages of these concretes, as water instability, great contractions, reduced hardening rates, the improvement of their properties by treatment with ultra-red rays was investigated.

The last part shows the results obtained on mortars with phenol-formaldehyde, epoxy and monomer furfuralidene-acetone resins. Based on the characteristics, the utilisation fields as layers of impermeability and of protection against abrasion of hydrocyclones of the glass industry, and as anticorrosive layer in sugar industry as well as in that of lacteous products, are rendered.

A68 *Werse, H. P., "The Repair of Fissures in Concrete Structures," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.*

The paper describes methods for closing cracks occurring in the concrete by the aid of synthetic resins. This is done by either cutting a groove and filling it with plastic mortar, or by covering the surface with a film of epoxy or polyester resin strengthened by fibre glass, or by filling the cracks with fluid epoxy resin; the advantages and disadvantages of the individual methods are discussed.

Preparation and qualities of plastic mortar are described, special stress being laid on the features which are essential for the choice of the binding agent. The application of "repair mortar" is shown by some examples; even facade lining plates have already been made of plastic concrete.

The last part of the paper treats with paintings which were applied to the concrete surface as protective coating or for aesthetic reasons. The possibilities of application are described on the basis of similar works executed. Besides the rigid duro-plastic materials, also gum elastic materials were applied.

#### 1968

A69 *Auskern, A., "The Strength of Concrete Polymer Systems," BNL-12890, Sep 1968, Brookhaven National Laboratory, Upton, N. Y.*

The analysis of the modulus and the tensile and compressive strength of concrete and concrete-polymer is, of course, limited by the validity of the assumptions made, by the lack of extensive experimental data, and by the limited theoretical treatments of compressive strength of composite materials. In spite of this, the simple models used gave fairly good agreement to the experimental results. Two conclusions emerge from the investigation:

Surveys of the rebonded areas, two years after rebonding, showed that only 15 percent of the areas rebonded were again hollow. This is in contrast to a 130 percent average yearly increase in the size of the hollow areas over a five-year period in the nonbonded areas.

This technique holds promise for hollow plane repair in bridge decks. Better results could possibly be obtained with more refined injection equipment, other epoxy types, or different liquid adhesives such as certain elastomers more suited to this purpose.

A71 Estrada, N. S., "Polyester Overlays for Road and Bridge Protection and Repairs," Highway Research Record No. 242, Highway Research Board, Washington, D. C., 1968.

Sealing of deteriorated concrete surfaces and the provision of a new, durable wear surface cannot readily be accomplished through the use of conventional paving materials, such as concrete or asphaltic-concrete. Various synthetic resin systems have been evaluated as sealers and as binders for wear courses in attempting to resolve this problem. Epoxy resin systems have been widely investigated and have the longest history of satisfactory use. This paper describes the performance of a system based on polyester resins, over a wide variety of exposures and use conditions. The polyester system is basically quite simple and versatile, involving application of a catalyzed resin to a clean, dry, sandblasted road surface at a rate of 3 lb/sq yd. Clean, dry, round-grain silica is broadcast in excess onto the wet resin. After the resin has cured in 30 to 60 min the excess sand is brushed off. Three such coats are generally recommended, giving a final thickness of at least 1/4 in. The system cures rapidly over a variety of temperature conditions, 40 to 110°F, so that traffic can be allowed over the surface within an hour after application.

A72 Gaul, R. W., and Smith, E. D., "Effective and Practical Structural Repair of Cracked Concrete," Epoxyes with Concrete, SP-21, pp 29-36, 1968, American Concrete Institute, Detroit, Mich.

After reviewing briefly why cracks should be repaired, the authors discuss the feasibility of repair, how effective structural repair is accomplished, and limitations of repairs. Examples are given of typical applications of a method which consists in injecting an epoxy-resin adhesive into cracks to "weld" the concrete back together into monolithic form.

A73 Ishai, O., and Cohen, L. J., "Effect of Fillers and Voids on Compressive Yield of Epoxy Composites," Journal of Composite Materials, Vol 2, No. 3, Jul 1968, pp 302-315.

Two series of epoxy composites, filled and porous, were loaded in compression up to yield under several constant strain rates. Results indicate a linear relationship between yield stress and log strain rate, characterized by a constant slope for the different compositions, and almost linear dependence of yield stress on filler content. A simplified empirical formula was derived for the yield stress of filled composites as function of filler content and strain rate. Similar dependence was found for porous composites.

The strain-rate dependence indicates non-Newtonian viscoplastic



behaviour obeying the corresponding Eyring equation. The filler content was found to have almost no effect on the activation volume terms, and its main effect is apparently with regard to the activation energy characteristics of the yielding process.

A74 Ito, K., "Pre-Cast Resin Concrete Manhole," Japan Telecommunications Review, Vol 0, No. 1, 1968, pp 230-234.

This article describes the properties and structure of precast resin concrete manholes, which are now under trial use by NTT.

The precast manhole serves to reduce the time required for manhole construction. Polyester resin concrete has been adopted as the material for precast manholes instead of conventional cement concrete. Precast resin concrete manholes feature reduced weight, simplified installation work, less excavating and require less repairs to road surface areas.

A75 Johe, C. H., and Thery, C. H. R., "Static Studies on the Behavior of Homogeneous Resin-Concrete Under Constant Loading; Comparison with the Results of Dynamic Tests in a Shock Tube," p 25, 30 Dec 1968, Institu Franco-allemand de Recherches, St. Louis, France.

Concrete plates with epoxy or polyester resins as binders were subjected to static loads that were increased to the point of crack initiation and fracture. Deformation and flexing up to fracture were measured. Parallel with these experiments, dynamic control tests were performed in a shock tube. Results obtained by the various tests are compared with predicted theoretical values. Tensile crack initiation was found to set in at loads of approximately 200 bar, while fracture occurred at loads considerably higher.

A76 Kampf, L., "Repair of Concrete Bridge Pavements," Epoxies with Concrete, SP-21, pp 53-66, Oct 1968, American Concrete Institute, Detroit, Mich.

The mechanism of concrete failure is discussed. Concrete in a bridge deck is subjected to stresses resulting from six dimensional changes. There is a shrinkage of the concrete, in the transition from the plastic to the rigid state, when it dries and when the temperature drops. Chemical effects and the freezing and thawing effect can cause expansion. The most difficult stress is caused by vertical deflections. A repair material must therefore withstand these stresses. It must have strength, flexibility, adhesiveness, and a low susceptibility to temperature change. Epoxies can be formulated to have all these properties. The various materials available for the repair of concrete are discussed as well as the epoxies. The epoxies discussed are straight epoxies, polysulfide and polyamide epoxies, and coal-tar epoxies. Test results are given on these materials and on the effect of formulation on their properties. The use of epoxies as a surface treatment, as an adhesive, and as a binder is discussed. For deep repairs a polysulfide or polyamide adhesive with a high-strength, quick-setting concrete is

preferred. For shallow repairs an epoxy mortar is favored. Surface treatments are questionable.

A77 McElroy, J. A., "Rehabilitation of Bourne Highway Bridge," *Epoxies with Concrete*, SP-21, pp 79-92, 1968, American Concrete Institute, Detroit, Mich.

This paper discusses the various applications of epoxy adhesives and waterproofing materials used to effect a major rehabilitation of the Bourne Highway Bridge which spans the Cape Cod Canal at Bourne, Massachusetts. Discussion concerns the evaluation-of-condition survey to estimate extent of deterioration; preparation of plans and specifications to accomplish repair; phasing of the operations to cause the least amount of disruption to Cape access; and use of epoxy-resin materials to bond old concrete to new, waterproof the concrete deck with a bituminous-epoxy and glass-fabric membrane, and surface-coat concrete and steel. Satisfactory accomplishment of the rehabilitation stresses the fact that utilization of epoxy-resin materials can provide effective and economical repairs and protection to concrete.

A78 Rooney, H. A., "Epoxies in Concrete Construction and Maintenance," *Epoxies with Concrete*, SP-21, pp 5-8, 1968, American Concrete Institute, Detroit, Mich.

This article describes the work done by the Materials and Research Department of the California Division of Highways, since 1954, in adapting epoxy resins to the maintenance and repair of concrete highways and bridge decks. It discusses how the high coefficient of thermal expansion of cured epoxy mortars, which causes portland-cement concrete over which the epoxy mortars are applied to rupture in tension, may be neutralized by the formulation of epoxy mortars having high creep values at sub-zero temperatures.

A79 Steinberg, M., et al., "Concrete-Polymer Materials, First Topical Report," BNL-50134 (T-509), Dec 1968, Brookhaven National Laboratory, Upton, N. Y., and USBR General Report No. 41, Dec 1968, U. S. Bureau of Reclamation, Washington, D. C.

Activities are reported in a program established between the U. S. Bureau of Reclamation and BNL to investigate and develop concrete-polymer composites as improved building materials. Information is presented concerning concrete formation, polymer formation, concrete-polymer preparation, measurement of composite specimens, basic research, and applications development.

A80 Steinberg, M., "The Effect of High Velocity Projectiles on Concrete-Polymer," BNL-12681, Jul 1968, Brookhaven National Laboratory, Upton, N. Y.

The two tests on the effect of ammunition on concrete-polymer material clearly indicate, in a qualitative manner, the marked

improvement of the impact and antifragmentation properties of concrete-polymer compared to concrete alone. This suggests some interesting possible applications as low cost armor plate. These preliminary qualitative tests thus reveal that it would be well worthwhile pursuing a program which would further investigate and evaluate the preparation and properties of concrete-polymer for impact and antifragmentation resistance.

- A80(1) Solntseva, V. A., "Effect of Polymer Additives on the Water Permeability of Cement Mixtures" (in Russian), Journal, Sb. Tr., Leningrad. Inst. Inzh. Zheleznodorozh. Transp., Vol No. 276, 1967, pp 87-100; Chemical Abstracts, 109540b, Vol 69, No. 26, 1968.

Latexes were added in small amounts to cement pastes and the pastes were allowed to harden and age. Water was then forced under pressure through the concrete slabs to test their permeability. For example, the untreated cements let water through the 2-ton pressure after 7 days aging, while cement containing 33 wt. percent resin No. 89 (prepared by the condensation of epichlorohydrin with  $m\text{-(H}_2\text{N)}_2\text{C}_6\text{H}_4$ ) withstood 20-ton pressure without leaking. The cement pastes containing latexes had somewhat increased compressive strength ( $\sigma$ ) and less water was required for their preparation. Increasing the amounts of latexes beyond ~30 percent decreased  $\sigma$  of the resulting concretes. The following latexes were used: SKS-65GP (butadiene-styrene copolymer), DBKbB-70 (butadiene-vinylidene chloride copolymer), MF-17 (a urea-HCHO resin), and epoxy resins DEG-1 and TEG-17. The properties of concrete containing latexes are best, when it is aged in moist air to provide the most favorable conditions for the chemical bonding of the inorganic entities, followed by aging dry air to form the films of latexes, which impact resistance to water penetration.

1969

- A81 Auskern, A., "A Model for the Strength of Cement-Polymer and Concrete-Polymer Systems," BNL-13493, R-2, Mar 1969, Brookhaven National Laboratory, Upton, N. Y.

Using simple semi-empirical models for the compressive strength of cement as a function of porosity and filler content, a model for the strength of cement-polymer was developed. The strength of cement-polymer can be expressed by the equation

$$s_c = (120,000 V_m)(1 - P)^6$$

where  $s_c$  is the compressive strength in psi,  $V_m$  is the volume fraction matrix (cement), and  $P$  is the real porosity of the cement-polymer composite. The model predicts strengths as high as 40,000 to 50,000 psi are theoretically attainable in this system.

The model was extended to the concrete-polymer system. It was necessary, in order to compute the strengths of concrete and concrete-polymer, to assume that in addition to strengthening the cement, the

presence of polymer improved the bonding between the cement and aggregate. This had been concluded in an earlier report. Reasonable agreement between predicted and observed concrete-polymer strengths are achieved.

A82 Berman, G. M., and Moshchanskii, N. A., "Corrosion of Steel Reinforcement in Polymer Concrete" (in Russian), Beton I Zhelezobeton, No. 5, May 1969, USSR, pp 6-8.

In polymer concrete with a furfural-acetone monomer base and a 5 to 6 pH, reinforcement is not subject to corrosion in a dry atmosphere. When polymer-reinforced concrete samples are preserved in an acid environment, especially in reheated acids, corrosion of the reinforcement shows a marked increase. A thicker protective layer slows down the corrosion process. When porous aggregates are used, they must be of small dimensions. Polymer concrete (furfural-acetone, granitic aggregates, quartz sand) cured in hot acids has a low chemical strength and gives insufficient protection to the reinforcement.

A83 Davydov, S. S., et al., "Two-Layer Beams of Reinforced Concrete and Steel-Polymer Concrete," Beton I Zhelezobeton, Vol 15, No. 5, 1969, USSR, pp 3-5.

Concrete slabs, 10 by 20 by 120 cm in size were cast by using 1:1.45 cement-river sand mixture and water-cement ratio of 0.48. The slabs were reinforced with steel rods. Some of the samples were coated with a mixture of polymer film shortly after pouring and compacting by vibration. In some cases the reinforcement was prestressed before pouring. The polymer-clad slabs had much higher resistance to cracking and in most cases they did not require prestressing. The thickness of the polymer layer is dictated by the construction requirements and economic factors. It is in the 6- to 20-mm range.

A84 Geymayer, H. G., "Use of Epoxy or Polyester Resin Concrete in Tensile Zone of Composite Concrete Beams," Technical Report C-69-4, Mar 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report describes the results of an investigation into the feasibility of combining the high compressive strength of portland-cement concrete and the superior tensile strength of epoxy or polyester resin concrete into a composite beam. This would increase the beam's flexural strength and improve the corrosion protection for the reinforcement at large deflections by eliminating tensile cracks.

The report describes in detail the development of high-strength resin concrete mixtures and summarizes the most important engineering properties of the selected mixtures. Also included are the results of third-point loading tests of 12 reinforced and unreinforced composite beams with 1-1/2- and 3-in.-thick layers of epoxy and polyester resin concretes. These results are compared with results of tests of two reference beams without resin concrete layers and with analytical results.

The study led to the following principal conclusions:

- a. Properly designed resin concrete layers at the tension face of concrete beams can be used to moderately increase the strength and rigidity of reinforced concrete beams, or to upgrade the flexural strength of unreinforced beams by a factor of two to three.
- b. More important than their influence on strength is the ability of resin concrete layers to provide a noncracking moisture barrier or corrosion protection practically up to beam failure.
- c. The epoxy resins appeared to be more suitable for this application than the polyester resins investigated due to lower shrinkage and exotherm as well as higher tensile strength and tensile strain capacity.
- d. In proportioning resin concrete mixtures, early attention should be directed to properties other than strength (such as shrinkage, exotherms, coefficient of thermal expansion, creep, sensitivity to environmental factors, etc.).

A85 *Goretskaya, E. A., "Strength and Deformation Ranges of Coarse-Grained Polymer-Concretes Based on Poly(vinyl) Acetate Emulsions" (in Russian), Stroit. Mater., No. 8, 1967, pp 201-209; Chemical Abstracts, 33119q, Vol 71, No. 8, 1969.*

Mechanical properties of concretes containing  $\leq 20$  percent poly(vinyl acetate) emulsion (I) were tested. The concretes were prepared by using a 1:1.71:2.91 cement-sand-gravel ratio and varying amounts of water. Testing lasted  $\leq 180$  days. The tensile strength at break and the compressive strength of the concretes containing I were lower at first than those of the unfilled concrete; but after 180-days aging, the compns. were 1.5 to 2 times as strong as the unfilled concretes. The elasticity modulus was decreased; the tendency toward plastic deformation of the compns. was increased by addition of  $\sim 5$  percent I. For this reason, the compns. were more resistant to cracking than ordinary concrete.

A86 *Knab, L. I., "Polyester Concrete: Load Rate Variance," Highway Research Record No. 287, Highway Research Board, Washington, D. C., 1969.*

The effect of the variance of load rate on the engineering properties of a plain polyester concrete system was investigated. Both the tensile and compressive phases of the system were evaluated. In the tensile phase, the load rates ranged from slow static through the dynamic range; whereas in the compressive phase, the load rates varied from very slow static through very high static. Tests were conducted using one type of a polyester resin combined with a feasible gradation of a standard reproducible aggregate. Wherever possible, standard ASTM tests for portland-cement concrete were used with each load rate held constant throughout the testing time of each specimen.

Ultimate stress, modulus of elasticity, and the strain at ultimate stress were the basic engineering properties considered. Significant variation of these three properties in both the tensile and compressive phases was obtained by varying the load rate. This investigation

conclusively showed that the polyester concrete system studied will withstand both slow and fast static loading conditions in both tension and compression.

A87 Lindeman, R. A., "Dynamic Tensile Strength of Polyester Concrete," (unpublished), Nov 1969, Construction Engineering Research Laboratory, Champaign, Ill.

This report presents the results of 22 impact tests performed on 2.0- by 33.0-in. cylindrical test specimens of high-strength synthetic polyester concrete. The results of the tests on polyester specimens are compared with the results of previous tests on specimens of plain concrete and steel wire fibrous-reinforced concrete.

Basic properties of the polyester concrete test specimens, such as static tensile strength, static unconfined compressive strength, specific gravity, mass density, seismic velocity, attenuation coefficient, and complex Young's modulus of elasticity are established.

Test results revealed that the critical normal fracture strain of the polyester concrete is dependent on the initial straining rate of the pressure pulse, but that the critical fracture strain energy is relatively constant over the strain rates employed.

The comparison of polyester concrete to conventional concretes showed that the dynamic tensile strength of the former is superior to either plain or fibrous-reinforced concrete.

A88 O'Neara, J. W., Savage, W. F., Evans, R. H., "Indexed Bibliography on Corrosion and Performance of Materials in Saline Water Conversion Processes-2," p 50, Mar 1969, Oak Ridge National Laboratory, Tenn.

Abstracts are given for 45 reports issued by the Office of Saline Water relating to the corrosion and performance of materials of construction used in saline water conversion processes. The body of the report is a copy of information stored in a computerized storage and retrieval system for the Materials Information Center of the Laboratory. The publication contains also a summary of a recently issued report on concrete-polymer materials. An author index and a keyword index to the reports referenced are given. This bibliography is a quarterly listing dated March 1969.

A89 Steinberg, M., Kukacka, L., Colombo, P., and Auskern, A., "Concrete-Polymer Materials--Second Topical Report," BNL-50218 (T-506), Dec 1969, Brookhaven National Laboratory and REC-OCE-70-1, Dec 1969, U. S. Bureau of Reclamation.

Activities are reported in a program established between the U. S. Bureau of Reclamation and BNL to investigate and develop concrete-polymer composites as improved building materials. Information is presented concerning monomer selection, polymer formation, preparation and properties of concrete-polymer composites, basic research, process and quality control, and applications development.

- A90 Abd-El-Bary, M., Manson, J. A., and Goldstein, J. I., "Electron Microprobe Investigation into the Diffusion of Ions Through Polymers," Journal of Materials Science, Vol 5, 1970, pp 898-900.

The objective of this investigation is to study the mechanism of ion diffusion through polymeric films and coatings. A better understanding of this phenomenon should aid progress with problems such as corrosion protection and desalination membranes. The authors wish to report some preliminary results obtained by means of electron microprobe analysis.

Salt diffusion through polymeric materials have been studied by several methods, e.g., chemical analysis, radioactive tracer techniques, and neutron activation analysis. Although such methods yield useful information about average diffusion parameters, they provide no insight into details of diffusion on a localized and microscopic scale. The electron microprobe, on the other hand, can be used to determine the presence of specific ions in a volume element as small as 1  $\mu\text{m}$  in diameter. Therefore, microprobe analysis should be useful in determining local concentrations of diffusing ions and in examining the details of the diffusion process in polymers.

- A91 Berman, G. M., and Moshchanskii, N. A., "Corrosion Resistance of Polymer Concretes," Beton I Zhelezobeton, No. 11, Nov 1970, p 14-16.

Results of the corrosion resistance tests of concretes. Basic principles and mechanics of the strength reduction of polymer concretes in aggressive liquid media are given. Quantitative values of performance coefficients of polymer concretes in sulfurous and hydrochloric acids and in water are obtained.

- A92 Bezler, P., et al., "Design Studies on Multistage Flash Distillation Vessels: Jan-June, 1970," Report on Polymer Concrete Applications Development for the Office of Saline Water, BNL-15138, Aug 1970, Brookhaven National Laboratory, Upton, N. Y.

A preliminary survey of vessels for multistage flash distillation units using concrete-polymer materials has been completed. These studies were carried out in the period January-June, 1970. A summary of the effort and the pertinent results are given in this report.

The design basis for the vessel study consisted of a horizontal cylinder with hemispherical heads. The inside diameter was 30 ft and the cylinder was 90 ft long. All the vessels are designed to withstand 50 psig and 15 psig design pressures as well as full vacuum. They were designed with a distributed load corresponding to 2 ft of brine with supporting fill of light aggregate. They were supported at every 15 ft along the cylinder.

Concrete-polymer material properties were assumed to be those currently reported from other areas of the development program. In

particular, the compressive strength was taken as 18,000 psi and the tensile strength as 1,600 psi. Variations of up to 15 percent in the assumed compressive and tensile strengths would not affect the results of these design studies. Young's modulus values used were  $7.5 \times 10^6$  psi in the first sets of calculations and  $6.5 \times 10^6$  psi in the final sets. Reference should be made to the concrete-polymer topical reports for other properties.

The types of vessel construction considered in the design studies were:

1. Standard reinforced construction.
2. Prestressed construction.
3. Concrete-polymer lined (coating in depth) ordinary concrete construction.
4. Ferro-cement construction.
5. Premix ferro-concrete polymer construction.

A93 Bloss, D. R., Hubbard, S. J., and Gray, B. H., "Development and Evaluation of a High-Strength Polyester Synthetic Concrete," Technical Report M-2, 1970, U. S. Army Construction Engineering Research Laboratory, Champaign, Ill.

This report presents the results of the selection and subsequent testing of a high-strength synthetic concrete. The program was initiated to select a material of maximum compressive strength (20,000 psi desirable) using conventional aggregate with synthetic binders and to obtain its optimum characteristics by testing.

The selection of materials program used a number of resin types with varying aggregates. It was found that the strength of concrete was limited to about 15,000 psi using conventional aggregates. The most promising material, PPG 5119 in combination with Type III cement, was found to be the only concrete to exceed the 20,000-psi compressive strength goal. The resin-cement ratio was found to be optimum at about 1:2 by weight.

This investigation revealed that the high-strength synthetic concrete's value lies in its compressive strength of 20,000 psi and above. The nominal modulus of elasticity after two days and at room temperature is about  $1.4 \times 10^6$  psi. Direct tension values are in excess of 2000 psi.

Major drawbacks of this material include extreme reduction of strength with temperature (6000 psi at 210°F). Costs are in excess of \$250 per cubic yard for materials alone, plus high placement costs due to special handling requirements. Handling is difficult because the material has a short pot life and must be mixed in small batches. It also has a very high exothermic reaction. This causes considerable shrinkage in large pours and acquires pouring in layers not to exceed 4 or 5 in. The potential application of this synthetic concrete is therefore limited to specialized use where these qualities would be advantageous.

A94 "Concrete Beckons Polymers," Chemical Engineering, Vol 77, No. 5, Mar 1970, pp 70-72.



Unlike plastics' seizure of markets once held by wood, metals, and paper, the move into civil engineering is being done by alliance: in most instances, this is with concrete, but there are a few cases with materials such as rock, soil, or even sewage and garbage. Researchers are grooming ways to either incorporate cured polymers with these materials, or else impregnate the material with the monomer and then polymerize in situ. The polymer contributes to such properties as strength, durability, and water resistance. A broad range of polymers and monomers is being studied, including methyl methacrylate, polyesters, styrene, epoxies, and nylon.

A95 Davydov, S. S., et al., "Epoxy Polymer Concrete: Rationalization and Experience," Hydrotechnical Construction, Sep 1970, pp 849-852.

Polymer concretes, which are cementless and anhydrous and based on synthetic polymer binders, are becoming popular in construction industry. The department of civil engineering structures of the Moscow institute of railway transport engineers has made a thorough study of the properties (primarily resistance to water, creep, long-term strength, and adhesion) of epoxy polymer concrete, and has erected efficient and economical structures using this material. In hydraulic-engineering structures epoxy polymer concrete should be used for bonding heavy-duty joints, for ensuring watertightness of tunnels, galleries, pipes, and underwater structures for protecting structures in aggressive media, and for other special purposes.

A96 "Experiments With Additives for Underwater Concrete," Cement, Amsterdam, Mar 1970, pp 103-110.

Research was conducted into the efficiency of additives in preventing the washing out of cement under water and into the strength attainable. Laboratory tests were carried out on concrete mortar with and without additives. Each batch was used for the casting of two test cubes, one above and the other below water. The tests were conducted in four stages, the favorable results of which were again used as a basis for subsequent tests. Although favorable results were obtained with a number of additives, preference is given to bentonite, since in addition to other advantages, this additive is relatively cheap. The influence of bentonite will be verified in actual practice.

A97 Ghosh, R. K., "Concrete Repairs with Epoxy and Polyester Resins," Highway Research Record No. 327, pp 173-182, 1970, Highway Research Board, Washington, D. C.

This paper reports results from laboratory investigation and field trials on concrete repairs using epoxy and polyester resins with particular reference to outdoor works such as repair of concrete pavement.

A study was conducted at the Central Road Research Institute, New Delhi, with heat-convertible synthetic resins such as epoxy and polyester resins to determine their efficacy in concrete repairs with particular

reference to concrete pavement. Although both of these resins, particularly the epoxy resin, have been in use for concrete repairs for sometime past, more information is needed to establish satisfactorily their different engineering properties in relation to environmental and job conditions.

A98 Holliday, L., "Inorganic Polymers," Inorganic Macromolecules Review, Vol 1, 1970, pp 3-16.

This paper does not seek to provide a synoptic view of the vast field of inorganic polymers. Instead it contains a few speculations about future progress, as seen from a strictly personal viewpoint. These speculations revolve around three important points. These are:

- (1) The distribution of the network bonds in space.
- (2) The nature of the network bonds.
- (3) Mixed networks.

A99 Kalandiak, M., "Polymer-Containing Cement Compositions," S. African Patent 68 05,949, 27 Nov 1969; Chemical Abstracts, 28476r, Vol 73, No. 6, 1970.

Dry hydraulic cement mixtures with excellent storage stability and which may be hydrolyzed to yield floor coverings, plasters, grouts, and adhesives with excellent tensile, compressive, and flexural strength were prepared by blending portland cement with 3 to 20 percent metal salts of water dispersible polymers with glass transition temperatures  $>30^{\circ}$ , Na citrate setting retarder and sequestering agent for the metallic ions, 1 to 5 percent trimethylolethane or trimethylolpropane, 5 to 25 percent  $\text{Na}_2\text{CO}_3$ , and various defoaming agents, fillers, aggregates, and pigments. Water-dispersible polymers used were the Ca salt of 46:49:5 (wt. %) Et acrylate-Me methacrylate (I)-methacrylic acid (II) copolymer, the Al salt of 30:20:40:10 Bu acrylate-acrylonitrile-I-acrylic acid copolymer, or the Zn salt of a 25:55:12:8 2-ethylhexyl acrylate-styrene-vinyl acetate-II copolymer.

A100 Knab, L. I., Preliminary Investigation of Shear Failures in Conventionally Reinforced Polyester Concrete Beams, M.S. Thesis, University of Cincinnati, Cincinnati, Ohio, Jan 1970.

Shear failures in a conventionally reinforced polyester concrete beam system were investigated. Twenty-seven beams, with tension reinforcement and without shear reinforcement, were tested and their strength characteristics were evaluated and compared to portland-cement concrete shear beam data.

Portland-cement concrete shear beam research and data were used as an aid in statistically designing this experiment. Hypotheses concerning the effects of two independent variables on three dependent variables were stated and tested. The two independent variables were the span length to depth of steel ratio and the depth of steel. The horizontal cracking shear stress, the ultimate shear stress, and an ultimate shear moment stress parameter were the three dependent variables studied. Held

constant in this experiment were the unconfined compressive strength, the percent steel and the width of the beams.

With one exception, both the span length to depth of steel ratio and the depth of steel were shown to affect significantly the three shear and moment stress parameters studied. It was concluded that the polyester concrete used was compatible with conventional reinforcement in the shear failure range. Further, it was concluded that portland-cement concrete beam design procedures can be used as a guide in the shear design of polyester beams, with the resulting design being conservative.

A101 *Krottinger, R. L., Pence, S. A., and Eilers, L. H., "Polymer Cement Composition," U. S. Patent No. 3,493,529 (Cl 260-29.6: C08f), Feb 1970; Chemical Abstracts, Vol 72, 93080a, No. 18, 1970.*

Sealant slurries useful for sealing off wells and which are compatible with both polymer slurries and hydraulic cement slurries were prepared by blending a hydraulic cement with 0.2 to 10 percent cross-linked acrylamide polymer and 40 to 75 percent of a mixture of alkylene glycols and water. Thus, a mixture comprising 100 lb Class A portland cement, 1 lb polyacrylamide crosslinked with methylenebisacrylamide and 5.52 gal of a liquid mixture comprising 87 vol. percent ethylene glycol and 13 vol. percent water had compressive strength 94 psi and 234 psi after aging 24 hr at 100°F and 140°F, respectively, and had compressive strength 261 psi after 72 hr at 140°F. A polymer prepared by polymg. acrylamide with 4600 ppm methylenebisacrylamide and catalyzed by a peroxide catalyst (60 parts) was mixed with 175 parts BaSO<sub>4</sub> and 101.8 parts ethylene glycol and poured into an upright cylindrical bottle (well-bore model) to one-third the capacity. A second compn. prepared from the polymer >1, portland cement 100, and a 91:9 vol. ethylene glycol-water mixture 453.5 parts, was poured onto the first compn. to fill the bottle to two-thirds of its height. The bottle was completely filled with the first compn. and the sandwich sealant compn. was set 24 hr at 140°F to yield a hard solid with excellent adhesion between the three layers.

A102 *Newland, E. A., "Radiation-Induced Polymerization; Part II: Concrete-Polymers, An Improved Type of Concrete Obtained by Using Radiation to Combine Conventional Concrete and Plastic, A Bibliography," p 6, Nov 1970, Australian Atomic Energy Commission Research Establishment, Lucas Heights.*

Thirty-one references are listed, covering the period 1964 to July 1970. Arrangement is alphabetical by author within each year. Abstract references for each article are also given, where applicable.

A104 *Reich, M., and Hendrie, J. M., "Design Studies on Highway Bridge Decking and Luminaire Supports," BNL-1513S 116, Jan 1969-Jun 1970, Brookhaven National Laboratory, Upton, N. Y.*

A preliminary survey of the use of concrete-polymer materials for luminaire support structures has been completed and a study of highway

bridge decking has been started. These studies were carried out in the period January 1969 to June 1970. A summary of the effort and the pertinent results are given in this report.

A105 Reich, M., and Hendrie, J. M., "Report on Polymer Concrete Applications Development for the Bureau of Public Roads; Design Studies on Highway Bridge Decking and Luminaire Supports," BNL-15139, p 113, Aug 1970, Brookhaven National Laboratory, Upton, N. Y.

Results of research on properties of concrete-polymer materials are reported. Design studies related to overall applications and to applications in roads were carried out during the period. It was found that concrete luminaire structures can be advantageously used along highways. Such structures will safely withstand wind forces of 120 mph and should in the event of a collision, cause a change in automobile velocity well within the prescribed safety limits. Experimental determinations of the cyclic loading values based on the risk of rupture concept, together with evaluations of the energy absorption indices for concrete-polymer materials are necessary prerequisites before detailed design work is undertaken. Results of highway bridge decking studies are also reported in which the technique used was to study crack formation phenomena in concrete and to develop better analytical methods than have been used in the past.

A106 Rotario, G. J. and Miller, L. A., "The United States Program on Concrete-Polymer Development," Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, Oct 1970.

This paper discusses the United States' program on concrete-polymer development. Government offices participating in this effort include the U. S. Department of the Interior through its Bureau of Reclamation, Bureau of Mines, and the Office of Saline Water; the U. S. Department of Agriculture; the Departments of the Army and Navy as well as the Department of Transportation's Bureau of Public Roads.

Apart from governmental activities, private industry in the United States has under way selected efforts directed to commercialization of the concrete-polymer product for various uses including building block.

Areas of potential application include high-pressure piping, conduit and sewage piping, highway and bridging construction, improved structures for increased mine safety, low-cost housing, underwater containment vessels and habitats, as well as multistage flash distillation plants.

Past and current work is focused on characterization of properties of concrete-polymers as well as assessment of various monomers for use in the process. The testing and characterization program includes determination of abrasion resistance, effects of corrosive materials, cavitation resistance and compressive strength.

A107 Singer, K., et al., "Cost Evaluation of Radiation-Cured Concrete-Polymer Materials for Pipe Manufacture," Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, Oct 1970.

Experimental work on radiation-cured concrete-polymer materials has been started as a joint program between the Concrete Research Laboratory, Karlstrup, and the Research Establishment Riso of the Danish Atomic Energy Commission.

Preliminary investigations have included a number of material combinations: lightweight concrete, normal-strength concrete and high-strength vibropressed concrete, different hard-compressed cement-sand mortars, sand-lime bricks and plaster of Paris impregnated with methylmethacrylate, styrene/acrylonitrile and unsaturated polyesters. Large increases in compressive strength and splitting tensile strength were obtained. Thus, compressive strengths of more than 2000 kg/cm<sup>2</sup> were reached in some cases.

A108 Steinberg, M., et al., "Concrete-Polymer Materials Development," Nuclear News, Sep 1970, pp 48-54.

This paper reports on the objectives of a joint program under way at Brookhaven National Laboratory that concerns development of concrete-polymer composites as new materials of construction.

The program includes the development of techniques for the preparation of the concrete-polymer material, the measurement of the physical and chemical properties, the preparation of full-scale concrete products, and the conceptual design and evaluation of various specific applications.

A109 Steinberg, M., Manowitz, B., Kukacka, L. E., and Colombo, P., "Concrete-Polymer Materials and Polymer-Concrete Composites," BNL-14746, p 4, Feb 1970, Brookhaven National Laboratory, Upton, N. Y.

The compressive strength of concrete-polymer materials with different aggregates is presented. The aggregate materials include: sand, rock, soil, sewage, solids, and refuse.

A110 Towler, R. J., and Williams, R. I. T., "Resin Concrete," Construction Research and Development Journal, Vol 1, No. 1, 1970, pp 107-109.

Resin concrete may be defined as concrete in which resin, rather than portland cement, is used as the binder. The resin serves the same function as the paste in portland-cement concrete, initially providing a fluid medium around the aggregate particles so that the mix may be compacted and finally determining to a large extent the properties of the hardened material. Various types of resin have been used but so far the main emphasis has been placed on the use of epoxy resins and of polyester resins.

#### 1971

A111 Akhverdov, I. N., and Lavrega, L. Ya., "Effect of Water-Soluble Resins on the Structure Formation of Polymer Concrete" (in

Russian), Dokl. Akad. Nauk. Beloruss. SSR, Vol 14, No. 12, 1970, pp 1071-74; Chemical Abstracts, 67293u, Vol 74, No. 14, 1971.

The addition of ~2 percent water-soluble epoxy resin DEG-1 or epoxy-amine resin E-89 to portland cement increases the rates of its hardening and strength increase. The additives modify the concrete structure by lowering the d., increasing porosity, and increasing the final compressive strength. The polymers form insoluble networks in the concrete which decrease the water evaporation rate and increase the contact time between water and lime causing its more complete hydration.

A113 Backstrom, J. E., and Dikeou, J. T., "Polymer Concrete: A Potential Construction Material for Desalination Plants: Part I," Desalination, Vol 9, 1971, pp 97-125.

Experiments were conducted to determine the feasibility and techniques for impregnation and in situ polymerization of liquid monomers in preformed concrete, and the inclusion of monomers directly into the fresh concrete mix, followed by polymerization. Polymerization by both gamma radiation and chemical reaction in the presence of heat was studied. Studies include monomer screening tests, development of process technology, and development of applications.

A114 Bazhenov, Yu. M., and Martsinchik, A. B., "Investigations of the Dynamic Strength of Polymer Concretes," Structural Chemically Stable Polymer Concretes, pp 59-61, 1971, Israel Program for Scientific Translations, Jerusalem.

The features and the laws governing the dynamic strength of polymer concretes were investigated at the Military Engineering Academy im. V. V. Kuibyshev. This work was carried out in two directions: The behavior of samples subjected to single impacts causing failure and to pulsating impact loads (endurance) was studied. The principal material selected for these studies was finely granular polymer concrete based on FA monomer as binder.

The material was prepared in a 150-liter mortar mixer. The samples were compacted through manual tamping, and hardened by being held at 100 to 110°C for 1 hr.

A115 Berman, G. M., and Sazonova, L. M., "Adhesion of Polymer Concretes to Reinforcements, and the Corrosion Resistance of the Latter in Various Environments," Structural Chemically Stable Polymer Concretes, pp 75-83, 1971, Israel Program for Scientific Translations, Jerusalem.

Investigations, carried out at the Voronezh Institute of Civil Engineering by L. M. Zalan and Yu. B. Potapov under the guidance of Prof. A. M. Ivanov, Ph.D., have shown that polymer concretes based on FA and FAM monomers exhibit decreasing creep under compression. These studies have proved the feasibility of using polymer concretes based on furfurool-acetone resins in load-carrying structures, including those

subjected to the long-time action of constant loads. The ratio of the tensile to the compressive strength is higher for polymer concrete than for ordinary concrete, but nevertheless polymer concrete is a brittle material which requires reinforcements in the tensioned zones of structures. The large creep of polymer concrete subjected to compression or bending may in this case be an advantage, since it reduces the width of the cracks formed in the reinforced tensioned zones of components subjected to bending.

Use of reinforced polymer concrete in load-carrying structures necessitates investigating the adhesion of polymer concrete to the reinforcements and the corrosion resistance of the latter in various environments.

1. Polymer concretes of the compositions investigated exhibit strong adhesion to reinforcements:

polymer concrete based on FA monomer to plain steel rods of various diameters, 45 to 200 kg/cm<sup>2</sup>; to rods of helical contour, 140 to 200 kg/cm<sup>2</sup>;

polymer concrete based on PN-1 resin or FA monomer to fiberglass rods of helical contour and 6- [sic] mm diameter, 100 to 160 kg/cm<sup>2</sup>;

polymer concrete based on PN-1 resin to plain steel reinforcement rods of 6-mm diameter, 100 to 120 kg/cm<sup>2</sup>.

2. The surface layer (braiding) of fiberglass reinforcement rods of helical contour was sheared off in all adhesion tests with polymer concrete.

A116 Billmeyer, F. W., Jr., *Textbook of Polymer Science*, 2d ed., Wiley-Interscience, New York, 1971.

Chapters 1 to 4 comprise Part I, dealing with introductory concepts and the characterization of macromolecules. Important additions in this section include discussion of solubility parameters, free-volume theories of polymer solution thermodynamics, gel permeation chromatography, vapor-phase osmometry, and scanning electron microscopy, with extensive revision of many other sections.

Part II (Chapters 5 to 7) deals with the structure and properties of bulk polymers, and includes considerable revision of parts of Chapter 5, where a few of the concepts of crystallinity in polymers, new in 1962, have had to be modified as our knowledge in this area has grown.

The format and content of Part III, concerned with polymerization kinetics, have been revised primarily for the citation of recent advances and new references. The exception lies in Chapter 10, whose topic is ionic and coordination polymerization, in which field many of the concepts new in 1962 have now reached a stage of further elucidation and acceptance.

The chapters of Part IV describe the polymerization, structure, properties, fabrication, and applications of commercially important polymers, including those used as plastics, fibers, and elastomers. Of particular note are new sections in Chapter 15 on aromatic heterochain, heterocyclic, ladder, and inorganic polymers.

Part V, dealing with polymer processing, has been revised primarily by the addition of new references.

A117 Furr, H. L., "Bond and Durability of Concrete and Resinous Overlays," Report No. 130-5, 1971, Texas Transportation Institute, College Station, Tex.

Research Study No. 2-18-68-130, Bridge deck deterioration.

A118 Chebanenko, A. I., "Investigations of the States of Stress and Strain of Load-Carrying Polymer-Concrete Structures by Means of Enveloping Diagrams," Structural Chemically Stable Polymer Concretes, pp 39-49, 1971, Israel Program for Scientific Translations, Jerusalem.

Polymer concretes possessing long-time strength and subjected to loads of constant sign can be assessed comprehensively by means of enveloping  $\sigma - \epsilon$  diagrams. Such diagrams in the form of nets were used by the author of this paper in investigations of concrete based on cement. The net method makes it possible to combine the theoretical and experimental diagrams and thus recognize certain properties, characteristics, and parameters which are of considerable importance in the practical assessment of the technical qualities of materials used in load-carrying structures.

A119 Cherkinskii, Yu., Gornov, V. N., and Slipchenko, G. F., "Performance Properties of Polymer Concrete Floor Coatings" (in Russian), Stroit. Mater., No. 10, 1970; Chemical Abstracts, 15498v, Vol 74, No. 4, 1971.

The addition of butadiene-styrene latex SKS-65 or poly(vinyl acetate) latex PVAE to cement gave compositions useful for coating floors. The optimum latex/cement ratio is 0.15. Lower ratios gave coatings of decreased water resistance as measured by detg. the thickness ( $\delta$ ) of the coating abraded in a std. test. The coatings required 2 months to complete hardening:  $\delta$  decreased rapidly during first month after the application, slower thereafter, and it became const. after 2 months. The wear resistance of coatings kept under water or petroleum increased a little with time, but for coatings based on SKS-65 under oil  $\delta$  increased from 337 to 1145  $\mu\text{m}$  in 28 days.

A120 Davydov, S. S., "On the Prospects of Perfecting Reinforced-Concrete Construction," Structural Chemically Stable Polymer Concretes, pp 3-5, 1971, Israel Program for Scientific Translations, Jerusalem.

Concrete based on cement has certain serious shortcomings, such as low resistance to cracking and to corrosion, and insufficient increase in strength during aging. Addition of polymers to the cement, or the use of polymeric binders in polymer concrete without cement can increase the strength of concrete two- to threefold and its resistance to cracking five- to tenfold, and render the material chemically stable in any corrosive environment.

The continual appearance of new polymers and the improvement of



their properties offers large prospects of raising the quality of concrete by enriching it with polymers.

New types of nonmetallic reinforcements will also appear. Parts are already being made of fiberglass which has a specific strength exceeding that of steel. Particularly strong and corrosion-resistant synthetic materials are now being produced, which may be used for reinforcements.

Reinforced polymer concrete may in its properties approximate either reinforced concrete or metal, depending on the manner and extent to which it is filled with reinforcements. It will, however, always be better than the latter materials, since it will have a longer service life in any corrosive environment. It will, of course, always be more expensive than ordinary reinforced concrete; its use in structural shapes will be economical only in special constructions, primarily in corrosive environments. New, more suitable structural shapes must be developed in order to use it efficiently in large-scale building. It may be advisable to distribute this high-quality material as a thin wall along the circumference of a section and thus obtain hollow lightweight elements. By combining them with the aid of an adhesive it will be possible to create highly efficient structures of large load-carrying capacity and small weight, which may be used as supports in industrial buildings and structures.

A121 *Fraint, T. M., "Protecting Concrete by Means of Polymer Concrete Against the Actions of Caterpillar Tracks," Structural Chemically Stable Polymer Concretes, pp 120-123, 1971, Israel Program for Scientific Translations, Jerusalem.*

The aim of this research was to develop compositions and methods of applying wear-resistant coatings protecting reinforced-concrete ships, quays, and concrete motorways subjected to the action of caterpillar tracks. The coatings were to withstand grouser pressures of up to 100 kg/cm<sup>2</sup>.

1. The possibility is demonstrated of using polymer concretes based on epoxy resins for wear-resistant coatings of reinforced-concrete floors which have to withstand the action of caterpillar tracks.

2. The resistance to wear of polymer concrete hardened with polyethylenepolyamine is tens of times higher than that of Grade 400 concrete, depending on the linear speed of the grousers.

A122 *Ivanov, A. M., "Furfurol-Acetone Polymer Concrete - A Structural Building Material," Structural Chemically Stable Polymer Concretes, pp 25-38, 1971, Israel Program for Scientific Translations, Jerusalem.*

This paper deals with the results of creep tests carried out on furfurol-acetone polymer concretes at the Voronezh Institute of Civil Engineering (VISI) and at the Lipetsk branch of the Moscow Institute of Steel and Alloys (LfmISiS) between 1962 and 1967.

Small samples were tested for creep at the beginning. The method used remained unchanged also later when larger samples and parts

approaching full size were tested. The procedure employed was the same as for plastics and concrete based on cement.

Furfurol-acetone polymer concrete is a structural material suitable for use in the load-carrying parts of buildings, which take up compressive forces acting for long periods and are subjected to various corrosive environments.

Parts made of polymer concrete, subjected to tension and bending, must be reinforced. Reinforcing polymer concrete with steel rods yields qualitatively the same effect as in the case of concrete based on cement.

A123 Khozin, V. G., Sokolova, Iu. A., and Voskresenskii, V. A., "The Dependence of the Physico-Mechanical Properties of Epoxy Resin on the Degree of Hardening," Structural Chemically Stable Polymer Concretes, pp 124-129, 1971, Israel Program for Scientific Translations, Jerusalem.

Extensive use of polymer concretes in self-contained structures is largely prevented by the lack of data on the hardening of polymeric binders and on the changes in the properties of polymer concretes during short- and long-time actions of mechanical loads and corrosive environments. It was shown that creep of the polymer concretes in use is considerable, which is inadmissible in structural materials. The high deformability of polymer concretes, particularly at elevated temperatures, is largely due to the properties of the polymeric binders. Clarification of the relationships between the physical properties of binders and their structures will thus obviously make it possible to obtain polymer concretes with optimum properties.

Promising binders for polymer concretes are epoxy resins which have spatial structures. Their properties have been less investigated than those of linear polymers. The properties of polymers with spatial structures depend on the density of the three-dimensional network. However, this relationship has been fairly accurately determined only for vulcanized rubbers having flexible and widely spaced spatial structures.

Epoxy resins, like other rigid thermosetting polymers, have very dense and rigid structures whose Mack-elastic properties are one to two orders of magnitude less than those of vulcanized rubbers, and appear only at elevated temperatures.

The extremal relationship between the degree of hardening of ED-5 resin and the polyethylenepolyamine content is demonstrated. A maximum is observed at a polyethylenepolyamine content of 20 to 25 percent of the resin weight.

Heat treatment, especially at below-optimum polyethylene-polyamine contents, greatly increases the degree of hardening; this improves the physicomaterial properties of the material.

Most physicomaterial, in particular the thermomechanical, properties, which characterize the thermostability and deformability of a polymer exhibit extremal dependences on the degree of hardening of the epoxy resin. It was found that excess hardener acts like a plasticizer, increasing the mobility of the spatial structure of the hardened epoxy resin.

A124 Krivopolenov, V. M., and Belov, A. V., "Thermal and Moisture Strains of Polymer Mortars," Structural Chemically Stable Polymer Concretes, pp 62-67, 1971, Israel Program for Scientific Translations, Jerusalem.

Corrosive environments and temperatures cause thermal and moisture strains in structures in which polymeric materials are used. The nonuniform distribution of these strains over the bulk of the structure, and the constraints imposed on its free deformation lead to the simultaneous appearance of internal stresses. Premature failure of the structure may occur if these stresses are not allowed for. Investigation of the nature, magnitude, and features of the thermal and moisture strains of polymer mortars based on thermosetting resins is therefore of great practical importance. Furthermore, corrosive environments and temperatures cause changes in the physicomaterial properties of the material, which must also be taken into account in the design stage.

This paper presents the results of tests of comparatively small samples based on phenolic, furan, and epoxy resins with finely ground filler. However, the relationships obtained are, with some corrections, valid also for polymer concretes containing coarse aggregates.

A125 Lamba, K. D., "Accelerated Hardening and Rapid Checking of the Strength of Polymer Concrete by Means of High-Frequency Currents," Structural Chemically Stable Polymer Concretes, pp 139-143, 1971, Israel Program for Scientific Translations, Jerusalem.

This paper describes a method of accelerated hardening of polymer concrete by means of high-frequency heat treatment.

This method is advisable because the material, in particular if a poor heat conductor, is heated over its entire volume. The principal advantage of high-frequency heat treatment, however, is the shortening of the hardening duration to tenths or hundredths of the time required otherwise.

A126 Mamatov, Yu. M., Mukhamedov, Kh. U., and Vanifat'eva, A. A., "Some Properties of Lutes and Polymer Concretes Based on Furfurol-Acetone Monomers," Structural Chemically Stable Polymer Concretes, pp 104-108, 1971, Israel Program for Scientific Translations, Jerusalem.

The compositions of polymer concretes, understood to be materials consisting mainly of a synthetic binder, a mineral aggregate, and a hardener, vary within wide limits.

The choice of the composition depends on the purpose and hardening conditions of the polymer concrete and the components made from it.

Some laws governing the properties of polymer concretes are presented in diagrams. The diagrams indicate the strength of polymer concrete as functions of its age at different polymerization conditions. The ordinates represent percentages of the maximum strength and not absolute magnitudes. This permits a better comparison of strength values.

A127 Mlodecki, J., "Application of 'Vinacet' Polyvinyl Acetate Emulsion to the Production of Polymeric Concretes," Building Review, Vol 43, No. 5-6, 1971, pp 72-84.

The effect was studied of the "Vinacet" emulsion on the properties of mortars and concretes. Its usefulness was assessed, and its principles and range of application were determined. Vinacet D5 polyvinyl acetate emulsion (contains no plasticizer) was used in the investigations as well as cement mortar of plastic consistency. Vinacet emulsion causes a significant increase in the liquidity of fresh mortar and the possibility of lowering the amount of batch water by 15 to 40 percent. Two hundred and fifty (250) grade concrete (with a cement content of 350 kg per cu m, water-cement index of 0.48, and plastic consistency), portland cement (350), and natural aggregate of up to 20-mm grain size were also investigated. The resistance to the bending tensile effect was studied as well as the influence of various storage conditions on polymeric concrete resistance. The crossed brick method was employed in the adherence test. The adhesive power of the connecting mortar was determined by fracturing by means of special apparatus. In the experimental floor lining of polymeric concretes, concretes of 5 to 10 percent polymer content of the cement weight were used. Conclusions based on the investigations are presented.

A128 Moshchanskii, N. A., and Paturoev, V. V., eds., Structural Chemically Stable Polymer Concretes, Izdatel'stvo Literaturny I O Stroitel'stvu, Moskva 1970; Translated from Russian by the Israel Program for Scientific Translations, Jerusalem, 1971.

The collection deals with the work, carried out in recent years by leading scientific research organizations, on polymers containing large amounts of filler such as polymer mortars without cement and polymer concretes. The collection contains extensive information on the technology and experience relating to the use of polymer mortars and polymer concretes, as well as on the design of structures built with polymer concretes in highly corrosive environments.

A129 Nutt, W. O., "Polymer Cement Surfaces for Concrete," Composites, Vol 2, No. 3, Sep 1971, pp 176-177.

Polymer cements are composites containing both inorganic and organic structures, and they were developed to overcome some basic deficiencies of portland cement. Their cost restricts widespread use to thin coatings for concrete, particularly for industrial floors. The two most significant factors affecting performance of polymer cements as floor surfacings are adhesion to the concrete substrate and strength reduction on water absorption.

A130 Parker, H. W., Semple, R. M., Rokhsar, A., Febres-Cordero, E., and Deere, D. U., "Innovations in Tunnel Support Systems," p 263, May 1971, Illinois University, Department of Civil Engineering, Urbana, Ill.

Innovations in the design and construction of tunnel support systems and applications of new materials for tunnel supports are presented in the report. Medium-to-large transportation tunnels in both soil and rock are considered. While primary emphasis is given to support systems for machine-bored tunnels, improvements in conventional tunnel supports are also included. The Extruded Liner System, which can place a lining by slipform methods immediately behind a boring machine, is described in detail. The lining material which now makes such a system practical is wire-fiber reinforced concrete made with high, very-early strength regulated-set concrete. Modifications of segmented-type linings are suggested to extend their range of applicability, and better ways of erecting them are indicated. Polymer concrete is the most promising new material for segmented linings. Square tubular and circular pipe sections are shown to be structurally superior to wide flange sections for steel frame tunnel supports subjected to a complex set of loads from directions largely governed by the joint pattern in the rock mass. New materials for sprayed support systems and semiautomatic mechanization of sprayed support systems are evaluated. Guidelines for selection of the most economical tunnels are presented.

A131 Paturiov, V. V., "The Long-Time Strength of Polymer Concretes," Structural Chemically Stable Polymer Concretes, pp 14-23, 1971, Israel Program for Scientific Translations, Jerusalem.

This article discusses the influence of certain factors on the physicomechanical properties of polymer concrete.

The special features of the molecular structure of polymers cause their relaxational properties to be noticeable already at temperatures of 18 to 20°C.

Physically the effect of "resting" for a polymer is as follows:

Creep in a polymer during the action of a static load is accompanied by elongation of the polymer chains and stress relaxation. This induces structural changes and a more uniform stress distribution in the sample. Periods of "resting" thus not only interrupt the action of the load but, due to relaxation, also interfere with the structural changes in the material, which occur under load.

Polymer concretes and polymer mortars are materials with conglomerate structures, in which the polydisperse fillers are bonded by synthetic resins into strong monolithic systems. The properties of artificial conglomerates, in contrast to those of natural ones, may be varied within quite wide limits by changing not only the type of the binder but also the type and quantity of the filler.

A132 Paturiov, V. V., and Zhukova, L. A., "Heat Release by Polymer Concretes," Structural Chemically Stable Polymer Concretes, pp 84-89, 1971, Israel Program for Scientific Translations, Jerusalem.

One of the most important properties of polymer concretes and various putties based on thermosetting synthetic resins is the temperature increase during their preparation and subsequent molding, which is due to exothermic polymerization reactions of the binder.

Thermograms make it possible to assess the completeness of hardening and thus the strength of the composition investigated. This is of great importance in selecting the formula and controlling the hardening process.

Some synthetic resins (PN, FA, FAM, etc.) have a strong tendency to react. This prevents mixing large amounts of these resins with hardeners without introducing fillers first, since otherwise the reaction would be so rapid and such quantities of heat would be released that spontaneous combustion and thermal destruction of the material would occur.

Investigation of the temperature curves and the heat released by polymer concretes were carried out with an automatic vacuum-flask calorimeter designed by NIIZhB and others.

The NIIZhB calorimeters are designed for the determination of the heat released by cements during hydration, but they may also be used for determining the heat released by polymer concretes and mortars during hardening.

Investigations of the heat released by polymer concretes and mortars included development of a method of determining the maximum polymerization temperature and computing the amount of heat released. They also comprised studies of the effects of the type and quantity of filler added, and of the ambient temperature on the maximum polymerization temperature, of the influence of the composition mass on the maximum polymerization temperature, and of sub-zero ambient temperatures on the extent of hardening and the strength.

Analysis of the temperature curves leads to the following conclusions: The bending point on the temperature curve corresponds to transition of the composition from the liquid to the gelatinous state, while the inflection point corresponds to solidification. The temperature attains its maximum value when transition of the composition from the gelatinous to the solid state is terminated, after which the temperature decreases smoothly.

Four phases may therefore be distinguished on the temperature curve.

A133 "Plastics in Building and Construction," Plastics Conference, Washington University, Jul 1971.

Proceedings of 15 papers delivered at the conference related to the various aspects of the use of plastics in construction including modular engineering; use in airplane construction; use of PVC; support of coal mine structures with plastics; polymer concrete; pollution aspects of plastics disposal; and urethane spray foams in roofing. Bibliography data are included with some individual papers.

A134 "Polymer Concrete," Concrete Construction, Vol 16, No. 5, May 1971, pp 173-175.

The article discusses the process by which the ordinary concrete has been impregnated or loaded with a monomer material and then polymerized by radiation, or by heat and catalytic ingredients, or by a

combination of these two techniques. The result is a composite material with improved characteristics. It is reported that polymer concrete can increase compressive strength of concrete four times and freeze-thaw resistance by 300 percent.

A135 Putliaev, I. E., "Shrinkage Kinetics and Internal Shrinkage Stresses in Polymeric Materials Based on Thermosetting Plastics," Structural Chemically Stable Polymer Concretes, pp 50-58, 1971, Israel Program for Scientific Translations, Jerusalem.

The present paper deals with the method of computing the strains and stresses of polymeric materials in practice.

An important characteristic of structures or coatings of polymeric materials based on thermosetting plastics is their ability to undergo elastic or plastic deformations. However, a very important property of a polymer is also shrinkage in the viscous and elastic state. The internal stresses in the polymer may in these states become relaxed, or may cause elastic strains. It is therefore very important to know not only the absolute magnitude of the shrinkage (although it is decisive), but also the shrinkage strains at the beginning of hardening of the polymer.

Thermosetting plastics may be divided into two groups according to their shrinkage behavior, namely low-shrinkage plastics (epoxy resins) and high-shrinkage plastics (polyester, furan, and phenolic resins).

The shrinkage kinetics are expressed by an exponential law and differ both qualitatively and quantitatively for the various thermosetting resins.

Shrinkage of a resin decreases when a filler is added, and thus represents an attenuated process.

The most dangerous period as regards cracking of reinforced structures or seamless coatings begins after 30 days of polymerization.

A136 Read, H. E., and Maiden, C. J., "The Dynamic Behavior of Concrete," p 61, Aug 1971, *Systems, Science, and Software*, La Jolla, Calif.

Particular attention is given in this review to rapid, impulsive loading of concrete resulting from mechanical impact and sudden exposure to radiation. Shock wave propagation and spallation phenomena are discussed. The coefficients for an existing constitutive model of a porous material are determined for a particular concrete. Numerical results based on this model and on an existing elastic-perfectly plastic model are given for several shock loading problems, and comparisons with corresponding experimental data are presented.

A137 Shapiro, A. I., "The Use of Polymer Concrete in Underground Mining Construction," Structural Chemically Stable Polymer Concretes, pp 130-138, 1971, Israel Program for Scientific Translations, Jerusalem.

Monolithic and assembled structures of polymer concrete and steel-reinforced polymer concrete may be used in various kinds of underground

construction. Polymer concrete is at present still 3 to 4 times more expensive than reinforced concrete; we therefore selected structures in which polymer concrete can compete with conventional materials not only from the technical but also from the economical aspect.

The following works were carried out in recent years:

1. Single-layer annular linings for drains, installed by driving rings. One hundred and fifty-five steel-reinforced polymer-concrete rings of 1450-mm diameter, weighing 1120 kg each, were made.

2. Lightweight steel-reinforced polymer-concrete timbering for mine workings in coal pits. A plant for such timbering was built, which is capable of producing 40,000 elements per year, from which 21,000 pit props and ceiling plates were made.

3. Timbering for pit shafts in potash mines. Two experimental stretches of drainage shafts were encased with watertight timbering; the volume of polymer concrete used in this case was 130 m<sup>3</sup>.

Underground polymer concrete structures having a total volume of 2500 m<sup>3</sup> were built under the supervision of TsNIIPodzemshakhtostroi. All the polymer-concrete structures enumerated were tested successfully and are now being tried in continuous service. Periodic inspection of the underground polymer-concrete and mining structures showed that the choice of the material has been correct.

A138 Solomatov, V. I., "Mass Transfer in Polymer Concretes and Putties," Structural Chemically Stable Polymer Concretes, pp 68-74, 1971, Israel Program for Scientific Translations, Jerusalem.

Polymer concretes and putties containing thermosetting synthetic binders are often called practically impermeable to liquids. This valuable feature, together with the high physicochemical stability, strength, and other favorable properties of these new materials lead to their increasingly wide use in structures subjected to the action of liquid and gaseous, often corrosive mediums in which pressure and temperature differences exist.

However, the impermeability of polymer concretes and putties is far from being perfect. Although the flow rate of liquids is far smaller in polymer concretes than in ordinary concretes, it is nevertheless, as shown by experience, sufficiently high to affect the shielding capacity of coatings and structures decisively. Moreover, the moisture field, which varies over the thickness of the component and is due to changes in the humidity of the environment, may cause internal stresses in the polymer concrete, which may be critical as regards the safety of the structure.

1. Mass transfer in polymer concretes and putties is a diffusion process.

2. Transfer of matter in polymer concretes is characterized by high values of the Biot number and small values of the Fourier number. Mass transfer in a polymer-concrete component may be considered as taking place in a semi-infinite body.

3. The mass content in the cross section of a polymer-concrete component may be expressed quantitatively as a function of the time if specific and reliable data on the mass transfer in polymer concretes are



available. This refers in particular to the diffusion coefficient and to the coefficient of mass exchange with the surrounding medium.

A139 Solomatov, V. I., "Strengthening a Furfural-Acetone Polymer Concrete with Fluorides," *Soviet Plastics*, No. 8, 1971, pp 52-53.

The strength and durability of polymer concrete, as an artificial conglomerate, is determined by the nature and properties of its components, and also by the physicochemical processes taking place at the interface of the organic and mineral phases. The use of quartz fillers gives polymer concrete with low strength and water resistance. The hydrophilic nature of the surface of the quartz, and the envelopment of its particles with water, prevent the formation of strong bonds and inhibit the polymerisation of the binder resins in the contact zone. As a result of this there is a loosening of the structure at the polymer-filler interface.

A strengthening and compaction of the structure of the polymer concrete, and also an increase in the water resistance, may be achieved by rendering the surface of the quartz particles water-repellent or by chemical changes in the hydroxyl sheath.

The increase in compression strength of the polymer concrete with the fluorinated quartz microfiller was round about 40 percent as compared with a similar composition using unmodified quartz, the strengthening being achieved by the addition of 0.5 percent of fluorite. The "coefficient of water-resistance" of the polymer concrete containing fluorite was 0.80, which is 25 percent more than for polymer concrete filled with quartz.

The treatment of silica-containing fillers with fluorides and other fluorine compounds is an exceptionally effective and promising method of strengthening and improving the physicochemical characteristics of polymer concretes.

A139(1) "Polymerbetong, Polymer Concrete Materials, Field Test Using Polymerized Curbstones," Report No. 3, Dec 1971, Technical University of Norway, Trondheim.

A research program to develop concrete-polymer composites and to investigate their strength as compared to ordinary concrete was initiated at FCB, Technical University of Norway in 1969. Results from this program have been described in two FCB reports: "Foreløpig rapport," 20 Oktober 1969, and "Polymerbetong, Concrete Polymer Materials," 15 January 1971.

A field study has also been initiated to investigate the use of concrete-polymer material in curbstones. This field test is being carried out in cooperation with the Oslo Road Division. Preliminary tests, production, laboratory testing, and placement of the curbstones are described in this report.

A139(2) Sople, B., "Polymerbetong, Concrete Polymer Materials" (in Norwegian), Project C149, Report No. 2, Jan 1971, Cement and

Concrete Research Institute, Technical University of Norway,  
Trondheim.

A research program to develop concrete-polymer composites and look into their strength compared to ordinary concrete was initiated at FCB, Technical University of Norway in 1969. Results from this first pilot tests were described in "Foreløpig rapport pr. 20.10.1969." The present report describes work accomplished through November 1970. The program is sponsored by NTNf (Norges Teknisk-Naturvitenskapelige Forskningsrad).

The pilot tests from 69 were run using 7-cm cubes as test specimens and the main purpose of the series was to gather information with respect to the test procedure and with respect to the new material's strength in direct compression and splitting and also get some idea with respect to its freeze-thaw durability, resistance to chemical attack, water absorption, and so on. The results from the pilot test were promising and created a base for further research. Both radiation and thermal-catalytic techniques were used. The radiation treatment was difficult, however, since we did not have the necessary equipment and therefore had to send the specimens to Sweden. The thermal-catalytic method appears to be best suited for the production of those field test specimens which have been planned to be prepared (curbstones, sidewalk pavements, and smaller pipes).

The report is divided into several main series that take up problems in connection with each step in the process of developing concrete-polymers. In addition, the report covers a few other topics that are of interest like long- and short-term effects upon concrete polymers, lightweight polymer concrete, and reinforced polymer concrete.

#### 1972

A140 Akhverdov, I. N., and Lavrega, L. Ya., "Structure and Strength of Fine-Ground Polymer Cement Concrete" (in Russian), Dokl. Akad. Nauk Beloruss. SSR, Vol 15, No. 12, 1971, pp 1059-98; Chemical Abstracts, 89588n, Vol 76, No. 16, 1972.

A significant structural property of concrete appears to be its porosity. Polymer cement stone has a distinctive texture compared with that of normal cement stone. The method of testing, materials used, mech. treatments, and added reagents are discussed in detail. Amine resin and two water-soluble resins were used in testing. During three-layer centrifuging there is a considerable decrease in capillary porosity due to increase in closed pores, contributing to formation of a uniformly close texture in the concrete. The tensile strength of concrete with addition of resins is increased but it remains considerably lower than that of polymer cement of three- and single-layer centrifuged samples. Without adding polymers it is essentially impossible to increase the tensile strength of concrete, and only the uniformity can be increased. By introduction of an optimum quantity of water-soluble resins it was possible to improve considerably the structural character and durability of concrete, and also by centrifugation. It could be assumed, in the

case of adding polymers, when impermeability to water is required in manufacturing reinforced concrete pressure pipe, it can be obtained with a single-layer centrifugation.

A141 Akhverdov, I. N., and Lavrega, L. Ya., "Mechanism of the Solidification of Polymer Concrete on Water-Soluble Resins" (in Russian), *Dokl. Akad. Nauk. Beloruss. SSR*, Vol 15, No. 10, 1971, pp 916-19; *Chemical Abstracts*, 89587m, Vol 76, No. 16, 1972.

The effect of water-soluble resins on structure-formation of polymer concrete was studied. The epoxyamine resin E-89 quickly coagulates with alkalies forming a dense resin-like substance. The formation of gel-like polymeric compounds around the cement grains is due to the interaction of E-89 with alkalies. For this purpose a certain amount of  $\text{OH}^-$  is required, i.e., a certain "electrochemical equivalent" of the polymer must exist. At high E-89 concns. there is a vigorous interaction with free lime and flocculation of nonhydrated cement grains. This leads to thickening of the polymer-cement mix. With increasing dispersion of the cement the surface of the ionic deposit increases. E-89 accelerates structure formation. The resin DEG-1 hardens in cement stone if a polyethylenepolyamine is presented as a hardening agent. The resin is adsorbed on the surface of the cement grains with formation of gel-like layers of various thicknesses. This causes peptization of the cement floccules and stabilization of the cement grains.

A142 Akhverdov, I. N., and Podmostko, I. V., "Variation of Deformative Properties of Pre-Stressed Concrete," p 10, Jun 1972, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio.

The shrinkage effect on concrete is a significant factor in solving the problem of using flexible prestressed ferro-concrete columns and other constructions. This article describes experimental studies of the effect of pre-shrinkage on the stability of concrete columns. The shrinkage of No. 500 concrete specimens was produced by prestressing glass-plastic reinforcement with a modulus of tensile elasticity  $E_{\text{sub}}$  a 500,000 kg/sq cm and a nominal strength of 13,000 kg/sq cm.

A143 Batrakov, V. G., "Increasing the Durability of Concrete by Additives of Silicon Organic Polymers," p 169, 1972, Bureau of Reclamation, Washington, D. C.

The durability of concrete was studied with additives of silicon organic polymers under the complex action of cyclic freezing and thawing, wetting and drying, capillary suction and evaporation of salt solutions, and also the prolonged continuous action of an aggressive liquid medium. The physicomachanical properties of concrete with silicon polymer additives were studied. The physicochemical aspects of the interaction of silicon-organic polymers of the polyhydrosiloxane and sodium silicate type with the minerals of portland cement, clinker, and cements were investigated.

A144 Birulya, A. R., et al., "Manufacture of Chemically Resistant Structures from Steel Polymer Concrete," Soviet Plastics, No. 12, 1972, p 25-27.

A description is given of the production of slabs of steel polymer concrete (incorporating a furfural acetone resin) for use as structural elements in factories where corrosive media are involved.

A145 Davydov, S. S., et al., "Polymer Concrete Building Components" (in French), RILEM, Vol 5, No. 26, Mar-Apr 1972.

In the first part of the article are described the most original examples of application of polymer concretes to building in industrial fields, where the physicommechanical properties and the chemical stability of polymer concretes make themselves most evident. There follow considerations on the characteristic properties and main advantages, preceding the elaboration of the practical methods of determining the strength and the deformation of polymer concretes under sustained force.

The authors propose one of the possible approaches to the solution of such a problem, an approach based on the use of the diagrammes of the limit states.

The construction of the diagrammes of the limit states offers the possibility of expressing the strength of polymer concretes in terms of temperature and time with a sufficient precision for practical purposes, by diagrammes having two variables. With these, the load-bearing force of the polymer concrete may be assessed not only in terms of the first limit state which is the strength, but likewise by the second state which is the deformation. The method proposed has made it possible to work out a method of calculation of combined steel and polymer concrete structures.

A146 Dennard, J. E., Jr., "Resin Concretes; A Literature Review," Miscellaneous Paper C-72-21, Sep 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Although there seems to be widespread interest in resin concretes, there have been only a limited number of publications on this subject, in contrast to the numerous publications on the specific resins (bonding agents). The publications on resin concretes have mainly been reports of specialized investigations.

Some workers found that by carefully controlling the particle size of the aggregates (or the volume of the voids) and by using special blending techniques, a strong cohesive mix can be obtained using approximately one-tenth the usual amount of resin (approximately 4 percent by weight versus the normal 40 to 50 percent), thus decreasing the cost of the concrete. Other workers investigated the use of special resins (i.e., furan and silicone resins) to form resin concrete. Still other workers investigated particular characteristics of resin concretes (i.e., the effect of curing on strength, the temperature dependence of strength, the effect of load rate variance, and the maximum strength using various aggregates and mineral fillers). Several authors compared

the characteristics of epoxy, polyester, furan, silicone, and portland cement concretes.

The major advantages are high strength, bonding ability, and resistance to wear, moisture, and abrasives. The major disadvantages are high cost of materials, difficulty of handling, and reduction in strength due to temperature increase. The major applications are for joining, repairing, lining, and coating portland cement concrete and for special applications where certain characteristics are needed (i.e., high strength, bonding ability, or chemical resistance).

A147 Doyle, H. G., "An Investigation of the Structural Properties of Lightweight and Normal Weight Polymer Concrete," p 145, May 1972, The University of Texas at Austin, Austin, Tex.

Concrete cylinders were prepared from mixes designed to produce both low strength and high strength lightweight and normal weight concrete specimens. The cylinders were prepared using Type III cement, natural silica sand, and the appropriate coarse aggregate material. A commercial air-entraining agent was used in varying quantities to provide varying degrees of air entrainment. All cylinders to be treated were oven dried, placed into a vacuum chamber and evacuated for times varying from 1 to 5 hr. They were then soaked in methyl methacrylate monomer for times varying from 2 to 5 hr, wrapped and placed into water in an oven for thermal-catalytic polymerization. One group in each series of cylinders was not treated and was used as a basis of comparison of results. The investigation was limited to determination of compressive strength, splitting tensile strength, and modulus of elasticity for the lightweight concrete specimens and compressive strength for the normal weight concrete. Laboratory testing produced the following results.

(a) Compressive Strength: Compressive strength of lightweight aggregate concrete increased from an average of 3,500 psi for the lower strength concrete to an average ultimate strength of 16,500 psi for the maximum vacuum and soak times used. The highest ultimate strength obtained was 18,200 psi from a higher strength lightweight concrete mix with a control strength of approximately 6,000 psi. These results represented strength ratios varying from 2.88 to 5.01 for the lightweight concrete series. Overall these ultimate strengths proved to be virtually independent of the initial concrete strength. Normal weight concrete compressive strengths increased from an average of 3,350 psi for the lower strength series and 5,200 psi for the higher strength series to an average of 10,900 psi for both after maximum vacuum and soak times. This represented strength ratios varying from 2.00 to 3.5 times initial concrete strength.

(b) Splitting Tensile Strength: Splitting tensile strength ratios fell an average of one below the increases for the same specimens in compressive strength for lightweight concrete. Initial control strengths of an average of 500 psi for the lower strength concrete increased to an average of 1350 psi. Higher strength concrete initial control strengths were approximately 50 psi higher than those for the lower strength concrete, but the polymerized strengths were lower than those of the lower strength concrete, increasing to an average of only 1400 psi.

(c) Modulus of Elasticity: Modulus of elasticity increases for the specimens with maximum vacuum and soak times varied from 1.27 to 2.2 times those for the untreated concrete specimens, from approximately  $1.51 \times 10^6$  psi to an average of  $2.56 \times 10^6$  psi.

(d) The effects of air entrainment and polymer loading on the properties of the materials were studied. Generally, it was found that strengths increased with increased polymer loading. The modulus of elasticity showed only slight trends of this nature.

As a result of this investigation, it was concluded that the impregnation of concrete with a polymer such as polymethyl methacrylate produces significant improvements in the strength characteristics in both lightweight and normal weight concrete, and that the increases seem to be almost independent of initial strength. As air entrainment percentages, amount of vacuum and soak times, and polymer loading percentages increased, so did strength characteristics improve.

A148 Goodall, P. D. and Husband, H. C., "Grouting in Structural Engineering and the Application of Epoxy Resins," The Structural Engineer, Vol 50, No. 12, Dec 1972, pp 495-505.

The paper briefly describes typical grout applications where the grout properties can be of critical importance, and these properties are summarized. The properties of grouts based on portland cement, polyester resins, and epoxy resins are examined and compared. The paper then describes the methods used and the results obtained.

Additionally applications of epoxy resin grouting to the main bearings of the new Britannia Bridge and to the carriageway expansion joints of the Weaver Viaduct are described, together with an account of a case of failure of an epoxy mortar used to underpin a large precision bearing on a satellite communications aerial.

A149 Heins, C. F., "Consultation and Research on Polymer-Concrete Composites," p 23, 26 Jun 1972, Denver Research Institute, Colo.

Cement pastes incorporating furfurool-aniline mixtures and two commercially available polymer emulsions possessed significantly lower compressive strengths than cement paste controls. Differential thermal analysis indicated these organic admixtures retarded cement hydration. The rate of absorption of low viscosity liquids into concrete was found to be strongly dependent on viscosity. Relatively rapid uptake was observed only for liquids with a Brookfield viscosity of close to 1.0 centipoise. An unambiguous correlation between rate of absorption and hydrogen bonding capability of the liquid was not established. Oven dried concrete was observed to absorb styrene-polyester mixtures (Brookfield viscosities of 10.0 and 28.4 cp, respectively) more rapidly than undried specimens. A test designed to measure the flammability of two types of polymer impregnated concrete resulted in a conclusion on 'nonflammable by this test.'

A150 Howdysshell, P. A., "Creep Characteristics - Polyester Concretes," Technical Report M-23, 1972, U. S. Army Construction Engineering Research Laboratory, Champaign, Ill.

The purpose of this project was to determine the nature, magnitude, and factors influencing the creep of particle-filled polyesters, and to what extent creep affects the usefulness of the material in concrete-type applications.

Tests were conducted on an aggregate- and a cement particle-filled polyester to determine compressive creep characteristics. The evaluation consisted of using laboratory test techniques that directly relate to the evaluation of creep in portland-cement concrete.

Results indicated that particle-filled polyesters are visco-elastic in nature and creep when subjected to sustained loads. While the creep strains of the filled polyesters were similar in nature and magnitude to what could be expected from equivalently-loaded portland-cement concrete, the creep characteristics of the polyesters appeared to be very sensitive to small temperature variations. Also, the polyesters exhibited creep failure tendencies at lower stress-to-strength ratios than would be expected from portland-cement concretes.

A151 "Improved Thermal Stability for Polymer Concrete," Composites, Vol 3, No. 4, Jul 1972, p 147.

This article reports on a very urgent problem in the use of ordinary concrete that is attacked by sulphates and other chemicals in sea water environments, in sewage treatment plants, and in many of the chemical processing industries. There has been considerable interest in improving the resistance of concrete to such attack by impregnating the concrete with various polymers. In order to achieve good penetration, the polymers are applied in the monomer stage when they still have low viscosity, and are then cured in place. The U. S. Bureau of Reclamation pioneered this concept in the mid-sixties. This organization impregnated concrete with methyl methacrylate monomer under a vacuum and then cured the monomers in place using heat or radiation. The resulting composites exhibited good resistance to chemicals, and also have about four times the strength of ordinary concrete. Some work has also been done in Switzerland on polymers which are simply brushed on concrete to achieve surface penetration. This method is being advocated as a means of protecting concrete highways against salt attack.

A152 Knab, L. I., Flexural Behavior of Conventionally Reinforced Polyester Concrete Beams, Ph. D. Dissertation, University of Cincinnati, Cincinnati, Ohio, 1972.

The purpose of this dissertation was to investigate the flexural behavior of conventionally reinforced polyester concrete beams for both short- and long-term loading. The duration of the short- and long-term loadings were about 1 hr and 40 days, respectively.

To evaluate the effects of short-term, monotonic loading, 18 simple beams with varying length to depth ratios, were tested. The beams, which

failed in flexure, exhibited relatively high strength accompanied by very large deflections. A moment stress parameter was statistically shown to be independent of both the span to depth of steel ratio and the depth of steel. The flexural beam behavior investigated in this dissertation was correlated with the shear beam behavior of a previous study by the author. A numerical method was presented which used strain distribution data from the beams to determine the concrete compressive, flexural stress-strain curve. A fourth degree polynomial was chosen to represent the concrete compressive, flexural stress-strain curve. By using the beam moment and strain distribution data in conjunction with the governing beam equations, the coefficients of the polynomial were determined. Using only the concrete stress-strain curve and an assumed bilinear steel stress-strain curve, a mathematical model was developed which predicted the stress and strain distributions, the ultimate moment capacity, and the deflected shape of the beams for short-term loading. Theoretical ultimate moment capacity, load deflection and load-strain relations, based upon the theory presented, agreed well with the observed data. The method presented, then, represents a general flexural theory for short-term loading, which can be applied to any polymer concrete.

Stress and strain distributions and deflected shape as functions of time for long-term sustained loading were predicted using Sackman and Nickell's model. A nonaging, linear visco-elastic matrix material was used in their model for a cracked, reinforced beam. Also used and compared with Sackman and Nickell's model was the effective modulus method. A typical beam was analyzed and the deflection due to long-term, sustained loading was shown to be significant.

It was concluded that the polyester concretes studied should function well in both short- and long-term structural loading applications requiring high compressive strength, large energy dissipation, and good dampening characteristics. In structural applications, however, where deformation is a critical factor and adequate support is not provided, the polyester concretes would not be suitable.

A153 Kukacka, L. E., "Perlite-Polymer Concrete," BNL-16931, May 1972, Brookhaven National Laboratory, Upton, N. Y.

Techniques for producing lightweight insulating-type composites with uniform polymer distributions have been developed. Three lightweight aggregates, perlite, vermiculite, and foamed glass, were evaluated and perlite was selected for continued evaluation. Two monomers, methyl methacrylate (MMA) and polyester-styrene, were used in these studies. Structural properties equivalent to or greater than those of high quality normal weight concrete have been obtained with perlite-concrete composites containing 50 to 60 vol percent polymer. The densities of these materials range between 60 and 75 lb/cu ft. Samples impregnated with polyester-styrene have lower strengths than MMA-impregnated specimens. Preliminary designs for breakaway luminaires constructed with impregnated perlite concrete have been made and a 5-ft prototype section constructed. Based upon this work the fabrication of larger sections appears to be technically feasible.



A154 Moshchanskii, N. A., and Paturiov, V. V., "Development of Polymer Concrete Technology in USSR," (*Razvitie tekhnologii polimerbetonov v SSSR, American Concrete Institute Symposium, "Polymers in Concrete," Atlantic City, New Jersey, Mar 1973, p 7*), Translation No. 866, Dec 1972, U. S. Department of Interior, Bureau of Reclamation, Engineer and Research Center.

In recent years, technology is developing in the USSR with small quantities of water-soluble resins introduced into the mixture. This usually increases the strength somewhat, particularly for tension, as well as the density and crack resistance.

The technology for preparing polymer concretes is very simple and, in general, corresponds to the technology for the ordinary cement concrete. The cost of polymer concretes is lower than that of concrete polymers.

In recent years, along with the study of polymer cement compositions and concrete polymers, a detailed development of the technology for preparation of polymer concretes was carried out in the Soviet Union, and studies were conducted on their physicomachanical properties and the most effective areas of their use.

A155 "Polymer Concrete," Precast Concrete, Vol 3, No. 4, Apr 1972, p 228.

The basis for preparing concrete-polymer material is the fact that concrete made with portland cement and air-entraining agents contains approximately 13 percent of voids, which are interconnected and distributed through the concrete. Thus, if a sample of concrete is heated to drive out the chemically unbound moisture, then evacuated and soaked in a liquid chemical monomer such as methyl methacrylate (MMA) and finally irradiated with gamma rays, a material is obtained in which the MMA is present as a solid plastic in most of the voids and is interconnected. The concrete/polymer material finally produced contains up to 6 to 7 percent by weight of MMA polymer, which exists within the original concrete as a three-dimensional filigree network or matrix.

A157 Popova, O. S., "Effect of Polymer Additives on Concrete Life" (in Russian), *Sb. Tr., Leningrad. Inst. Inzh. Zheleznodorozh. Transp.*, No. 330, 1971, pp 83, 91; Chemical Abstracts, 155960h, Vol 77, No. 24, 1972.

SKS-65GP (a latex based on butadiene-styrene copolymer), stabilized with OP-7 (a wetting agent prepared from ethylene oxide and alkyl phenols), water-soluble resin No. 89 (prepared by condensing  $m-(H_2N)_2C_6H_4$  with epichlorohydrin), or epoxy resins DEG-1 and TEG-17 were added to cement mixes and physical properties of the obtained concretes were studied. The additions caused some plastification of cement and made it possible to reduce the water/cement ratio to 0.23 without affecting workability. The compressive strength ( $\sigma$ ) and tensile strength ( $\sigma'$ ) of concretes containing the latexes depended on aging conditions and the amounts of latexes. Aging in dry air could decrease

$\sigma$  and  $\sigma'$ , while aging in the moist air or in the contact with water considerably increased  $\sigma$  and  $\sigma'$  in comparison with concretes containing no additives. The optimum amount of latexes was 1.5 to 2.5 percent. The elongation at break (E) and  $\sigma'$  increased with time during aging. Thus, concretes containing 2 percent resin No. 89 after 7-days cure had E = 325 percent and  $\sigma' = 207$  percent of concretes containing no additives. The deformation of concretes containing latexes was not considerably different from that of the untreated concretes.

A158 Reich, M., et al., "Finite Element Approach to Polymer Concrete Bridge Deck Designs Analysis," BNL-16890, May 1972, Brookhaven National Laboratory, Upton, N. Y.

The goal of this investigation was the development of analytical techniques to guide the design of crack-free concrete-polymer bridge decks and to aid in better understanding of the crack phenomena occurring in present-day concrete bridge decks. It was considered desirable to extend the analytical techniques to include also the prediction of crack patterns for the total range of loading from zero to ultimate. This report deals only with the bridge deck elastic analysis and design.

A159 Shah, S. P., et al., "New Materials in Concrete Construction," Proceedings, New Material in Concrete Construction Conference, Dec 1972.

New materials for concrete construction which incorporate two types of matrices: expansive cement and regulated-set cements, two types of reinforcements: fiber-reinforced concrete and ferro-cement, two types of polymeric additions: polymer latex modified mortar and polymer impregnated concrete, are described. The use of artificial aggregates and waste products is also covered.

A160 Selander, C. E., Causey, F. E., Hickey, M. E., and Howard, A. K., "Evaluation of Reinforced Plastic Mortar Pipe, Government-Industry Cooperative Study," REC-ERC-72-26, (PB 213 675), Aug 1972, Engineering and Research Center, Bureau of Reclamation, Denver, Colo.

A Government-Industry Cooperative Study conducted over a 3-year period (1968-1971), evaluated reinforced plastic mortar (RPM) pipe for water resources applications and was comprised of laboratory and field programs, and preparation of specifications and design data. Results indicate the RPM pipe will perform satisfactorily as pressure pipe for irrigation distribution and water conveyance systems. Changes in physical properties resulting from environmental exposures of solutions of sulfuric acid, sodium hydroxide, synthetic soil extract, and to tap and distilled waters are of an acceptable magnitude; the major effect being attributed to wetting action rather than to chemical action. Laboratory buried pipe tests showed that RPM pipe deflects more than steel pipe of similar stiffness under external load; however, field tests indicate that the recommended maximum deflection (5 percent of pipe dia) will not be exceeded when the pipe is properly installed. Disadvantages

of RPM pipe are: adverse changes in physical properties with service age, and less deformation resistance than some other pipe; advantages are: high corrosion resistance, good chemical resistance, no inherent cracking, and light weight, greatly facilitating handling and installation operations.

A161 Sliwka, W., Vestner, S., Peterhans, J., Teichmann, H., and Petri, R., "Polymer Dispersions for Refinement of Hydraulic Binders," Ger. Offen. Patent 2,051,569 (Cl C08f), 27 Apr 1972; Chemical Abstracts, 65870t, Vol 77, No. 10, 1972.

Hydraulic binders, e.g., cement, mortar, or concrete, were refined, their physical properties improved, without neg. influencing workability or increasing setting times, by addition of a polymeric emulsion obtained by copolymer. of styrene (I) acrylic acid or Bu acrylate (II), 2-buten-1-ol (III), and acryla (IV) in the presence of emulsifiers, initiators, and an H<sub>2</sub> amide group containing copolymer, e.g., 70:27.5:2.5 parts acrylamide-vinylpyrrolidinone-vinylimidazole copolymer. Thus, four parts emulsifying 50:1 mole ethylene oxide-p-iso-C<sub>6</sub>H<sub>4</sub>OH reaction product (VI) in 230 parts H<sub>2</sub>O was under N to 78°; 100 parts of a solution from 2.5 parts K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> parts H<sub>2</sub>O added; an emulsion from I 280, II 220, 50:1 mole VI 16, Na salt of sulfonated mixture of equal parts 8:1 and 50:1 mole VI 10, III 2, IV 10, V (K value 136) 0.15, and H<sub>2</sub>O 230 was added within 1.5 hr; the remaining aq. K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> added within 2 hr, the emulsion kept 2 hr at 80°; cooled; and its pH adjusted to 5-6 to give a thin, even dispersion free of coagulated material. A cement mixture from sand 600, cement 200, 50 percent above dispersion 40, H<sub>2</sub>O 70, and antifoaming agent 0.8 part had flexural tensile strength (28-days weathering test) 110 kg/cm<sup>2</sup>, compressive strength (28-days weathering test) 404 kg/cm<sup>2</sup>, porosity 3.5 percent, beginning of setting 196 min, and end of setting 344 min as compared with 64 kg/cm<sup>2</sup>, 384 kg/cm<sup>2</sup>, 7.5 percent, 220 min, and 275 min for cement containing no dispersion.

A163 Strel'nikova, M. P., "Crack Resistance of Reinforced Concrete Railroad Ties Containing a Polymer Additive," 1972; Chemical Abstracts, 155900 (see also abstracts 155901 and 155902), Vol 77.

The resins DEG-1, TEG-17, and No. 89 have a favorable effect on the sp. impact viscosity, watertightness, frost resistance, and deformation of high-strength concrete used in railroad ties. The compn. of the cement was: 3CaO, SiO<sub>2</sub> 52, 2CaO·SiO<sub>2</sub> 25, 3CaO·Al<sub>2</sub>O<sub>3</sub> 7, 4CaO·Al<sub>2</sub>O<sub>3</sub>·Fe<sub>2</sub>O<sub>3</sub> 14 percent. The ties withstood a load that was 23 to 6 percent higher than normal. The highest crack resistance was observed with resin No. 89. The resin hardens in the alk. medium of the cement rock, becomes water-insoluble, and forms strongly crosslinked polymeric chains. The polymers formed on the hydrate neoformations form spatial structures and penetrate the rock in the contact zone between the crystallites.

A164 Baker, C. A., Polymer Concrete: A Chemically Inert Structural Material, Humes Limited, Melbourne, Australia, Presented at the Institution of Engineers' Symposium on Concrete Research and Development, Sydney, Australia, 20 Sep 1973.

This paper presents a study of the physical and chemical properties of an ultra low binder content polymer concrete, particularly in relation to its usage for underground pipe.

The development of the material is described, in particular the means adopted to ensure complete chemical inertness and to overcome loss of strength caused by bond failure in an aqueous environment.

The importance of stress-time dependence of strength of polymer concrete is emphasised and a study of long-term strength characteristics of a typical polymer concrete is presented. Extrapolation techniques are briefly discussed.

Chemical resistance data of 2-years duration is tabulated, as are other physical properties relevant to the structural use of polymer concrete.

It is concluded that this material is suitable for structural use in environments normally destructive to portland-cement concretes and that design data applicable for polymer concrete underground pipe have been established.

A165 Beller, M., and Steinberg, M., "Glass-Polymer Composites," BNL-17555, Jan 1973, Department of Applied Science, Radiation Division, Brookhaven National Laboratory, Upton, N. Y.

The Concrete-Polymer Materials Development Program at Brookhaven National Laboratory has led to the use of urban solid waste components as aggregates in the development of structurally strong and durable composite materials. A glass-polymer composite (GPC) is produced by mixing crushed waste glass with monomer (either methyl methacrylate or polyester-styrene) and polymerizing by chemical initiation techniques. With ungraded crushed bottle glass, monomer concentrations are 13 to 16 percent by weight; graded sieved glass results in monomer loadings of 9 to 10 percent. The strength of GPC is 2 to 4 times higher than ordinary concrete. The durability, especially the resistance to chemical attack, far exceeds concrete. The application of GPC for sewer pipes is attractive because of the availability of waste glass in urban communities. Ten lengths of 8-in.-dia, 3/4-in. wall, 42-in.-long GPC pipe were produced and installed in a municipal sewer line on Long Island for a field test. For the same wall thickness, the three-edge bearing strength of a polyester-styrene GPC pipe is more than two times higher than the ASTM C 14-70 requirements for concrete pipe. Cost estimates indicate that GPC is potentially competitive with asbestos cement, vitreous clay, concrete and plastic pipe in the 8- to 24-in.-dia pipe size range.

A166 Chen, W.-F., and Dahl-Jorgensen, E., "Stress-Strain Properties of Polymer Modified Concretes," Polymers in Concrete, SP-40, pp 347-358, 1973, American Concrete Institute, Detroit, Mich.

This experiment was designed to investigate some of the structural properties of polymer modified concrete. Three- by six-inch (7.6- by 15.2-cm) cylindrical specimens were prepared and tested in simple compression and split tension to obtain the entire stress-strain relationship for this concrete.

For the polymer-impregnated concrete (PIC), the monomer methyl methacrylate was used. Polymerization was done by the thermal-catalytic method with benzoyl peroxide and azobisisobutyronitrile to initiate polymerization. The concrete used in the experiment was dense and of high strength. With the use of 3 percent benzoyl peroxide complete polymerization was not achieved, leaving a central core in the specimens containing unpolymerized monomer; 0.5 percent azobisisobutyronitrile, however, gave full polymerization. The results obtained for PIC are comparable and confirm the improvements in properties of concrete observed by many researchers in this field.

For the Polymer Cement Concrete (PCC), the monomer diacetone diacrylamide was mixed in the fresh concrete and followed by polymerization. The specimens responded negatively both to heat treatment and moisture curing and it was apparent that the polymerization and hydration processes react unfavorably and are incompatible simultaneously.

A167 Clear, K. C., and Hay, R. E., "Effect of Mix Design and Construction Parameters," Time-To-Corrosion of Reinforcing Steel in Concrete, Vol 1, Interim Report No. FHWA-RD-73-32, Apr 1973, Federal Highway Administration, Washington, D. C.

The purpose of this investigation is to provide administrators and designers with factual data on which to base decisions on the type of protection to provide to bridge decks constructed in corrosive environments. Specifically, the objective is to determine the relative time-to-corrosion of reinforcing steel embedded in concrete slabs, fabricated from various mix designs and construction procedures when the slabs are subject to periodic wetting with a 3 percent NaCl solution.

One hundred and twenty-four 4-ft by 5-ft by 6-in. reinforced concrete slabs were fabricated, cured, and placed in the outdoor exposure yard on elevated stands. Concretes covering the feasible range of mix designs were investigated. Clear concrete cover over the reinforcing steel was varied from 1 to 3 in. Finishing methods studied included wood floating and brooming, compacting with a steel trowel, the use of absorptive form liner, and vacuum processing of the fresh concrete. Surface revibration and the use of chromate and silicone admixtures were included. Surface protective treatments included boiled linseed oil and stearate. Special treatments studied were polymer-impregnated concrete, permanent steel bridge deck forms, galvanized reinforcing steel, latex-modified concrete, epoxy-modified concrete, a low water-cement ratio portland-cement concrete overlay, an expanded pumice additive, and ferro-cement.

An evaluation of the electrical half-cell corrosion detection technique was also performed.

A169 Hilado, C. J., "An Overview of the Fire Behavior of Polymers," Fire Technology, Vol 9, Aug 1973, pp 198-208.

Concern with the fire behavior of plastics has shifted emphasis from the individual polymers to the final products, which often involve two or more polymers. Therefore, product design may be as important a factor as polymer selection.

Numerous studies have been made of the various stages of combustion - heat flux and accumulation, preheating, degradation, pyrolysis, diffusion, and ignition. Our understanding of why polymers behave the way they do in fires has been improved, but much is still to be learned.

A170 Keeton, J. R., and Alumbaugh, R. L., "Polymer Strengthened Concrete for Military Facilities," Technical Note N-1319, Dec 1973, Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Mixtures of polymer-cement-mortar and polymer-cement-concrete were formulated with (1) epoxy, polyester, and epoxy-acrylate resins; (2) acrylic, vinylacetate, styrene-butadiene, and polyvinylidene chloride latices in varying proportions in relation to the weight of the cement. Both Type 3 portland and regulated-set cements were used. Curing methods included low pressure steam, high pressure steam, dry heat, and ambient laboratory air. Compressive strengths of concrete with and without polymers were studied.

A171 Kukacka, L. E., et al., "Concrete-Polymer Materials for Highway Applications," Report No. FHWA-RD-74-17, Progress Report No. 3, Dec 1973, Federal Highway Administration, Washington, D. C.

Experimental work on the use of concrete-polymer composites for highway applications has progressed in three general areas: material properties of polymer-impregnated concrete, the repair of deteriorated and delaminated bridge decks, and the partial in-depth impregnation of new decks.

The structural and durability properties of impregnated normal weight and structural lightweight concretes have been measured. The effect of temperature and cyclic loading was investigated and bond pull-out strength of reinforcement measured. Process variables studied include monomer type, method of polymerization, and air content of the concrete. The results from these tests are summarized in Table 1. Compared to the controls, MMA-impregnated samples had improvement factors ranging from 2.6 to 4.5. The use of polymer-impregnated concrete as a means of preventing chloride penetration into bridge decks has been demonstrated. This offers a potential solution to the bridge deck deterioration problem.

The feasibility of repairing highly deteriorated and delaminated bridge decks by monomer impregnation has been demonstrated and field

testing is in progress. Results to date indicate that highly deteriorated concrete can be reconstituted and bonded to the sound concrete beneath. Compressive and shear strengths of 8000 and 1100 psi, respectively, have been obtained. No deterioration of the repaired sections has been observed after exposure to traffic for 6 months.

Field evaluation of the use of polymer concrete as a rapid means for filling large holes in major arterial highway bridges is in progress in New York City. The polymer concrete containing 13 wt percent monomer was mixed and placed using conventional equipment. Curing was completed within 1 hr, at which time the forms were removed and compressive strengths varying between 5400 and 8000 psi were measured.

A172 Kukacka, L. E., "Perlite Polymer Concrete," Polymers in Concrete, SP 40-8, pp 173-191, 1973, Detroit, Mich.

Techniques for producing lightweight insulating-type composites with uniform polymer distributions have been developed. Three lightweight aggregates, perlite, vermiculite, and foamed glass, were evaluated and perlite was selected for continued evaluation. Two monomers, methyl methacrylate (MMA) and polyester-styrene, were used in these studies.

Structural properties equivalent to or greater than those of high quality normal weight concrete have been obtained with perlite-concrete composites containing 50 to 60 vol percent polymer. The densities of these materials range between 60 and 75 lb/cu ft. Nonair-entrained 1:8 perlite concrete specimens impregnated with MMA exhibited average compressive, tensile splitting, and flexural strengths of 7800, 1440, and 1700 psi, respectively. Samples impregnated with polyester-styrene have lower strengths than MMA-impregnated specimens.

Freeze-thaw tests of impregnated lightweight materials are in progress but data are not yet available. Testing of a perlite concrete sewer pipe in 5 percent  $H_2SO_4$  has indicated no attack after exposure for 120 days.

Preliminary designs for breakaway luminaires constructed with impregnated perlite concrete have been made and a 5-ft prototype section constructed. Based upon this work the fabrication of larger sections appears to be technically feasible.

A173 Kukacka, L. E., "Perlite-Polymer Concrete," Concrete, Vol 7, No. 7, Jul 1973, pp 28-32.

The structural and durability properties of impregnated insulating-type concretes are measured. The purpose of the study is to attempt to improve the properties so that the materials can be used for a variety of highway applications. Techniques were developed for preparing lightweight insulating-type concrete composites with uniform polymer distributions and with hard, continuous polymer coatings. Lightweight concrete-polymer composites with high strength and durability have been produced by impregnating insulating-type perlite concrete with MMA and polystyrene.

A174 Levitt, M., "The Applications of Polymerized Concrete," Resins and Concrete Symposium, The Plastics Institute and Institution of Civil Engineers, University of Newcastle upon Tyne, Paper 8, Apr 1973.

This report describes the various methods of polymerizing concrete, the economics involved, and the various applications the process may have in both in situ and precast concrete. High strengths are considered to be an advantage in high stress applications such as prestressed concrete, but the advantage of high chemical resistance can be utilized to a much larger extent. Viable processes can only be entertained when there is a saving in concrete weight, turnover time; lifetime, storage time, efficiency or a combination of these properties.

A175 Lizzio, A. M., "Status of Concrete-Polymer Composites in the United States and Abroad," Public Roads, Vol 37, No. 4, 1973, pp 129-135.

This article discusses the upsurge of interest in mortars and various polymers after the improvements were obtained when the monomers, methyl methacrylate and styrene were added to conventional concrete and mortars and polymerized to form entirely new products. These products have increased strength, durability, abrasion resistance, resistance to chemical attack, and have reduced permeability, absorption and creep.

A176 Lott, J., and Howdyshell, P. A., "Polymer Concrete-Reinforced Concrete Composite Beams," Polymers in Concrete, SP 40-14, pp 295-319, 1973, Detroit, Mich.

Composite beams consisting of reinforced concrete and a layer or cap of polyester concrete in the region of high compressive stress are tested and evaluated. The creep characteristics of polyester concrete were evaluated using 1000-hr creep tests, and the effect of sustained load on the ultimate compressive strength was also determined. Composite beams which were 6 by 6.5 by 64 in. (15.2 by 16.5 by 162.6 cm) were fabricated by capping precast reinforced concrete beams with a layer of fibrous polyester concrete of various given thicknesses. The composite beams were subjected to third-point loads on a simply supported length of 57 in. (145 cm). Load-deflection behavior and ultimate strength were determined for various combinations of reinforcement and depth of fibrous polyester concrete cap. Experimental and analytical results indicate that the fibrous polyester concrete composite beams are performance and material cost effective relative to reinforced concrete beams with the same percentage of tensile reinforcement.

A177 Mattiotti, P., "Highly Wear Resistant, Polymer Containing Concrete Surfaces," Fr. Patent 2,115,618, (C1 C04b)(Eo4b), 11 Aug 1972; Chemical Abstracts, 75473a, Vol 78, No. 12, 1973.

A concrete with high abrasion-resistant surface is produced by mixing sand (0.2- to 2.0-mm particles) 750, gravel (5- to 25-mm diam.) 1100, portland cement 450 kg, and H<sub>2</sub>O to a H<sub>2</sub>O/cement ratio of 0.5 and pouring to a 10-cm-thick layer, which is vibrated at 1 min/m<sup>2</sup>, which



causes sepn. of H<sub>2</sub>O on the surface. A 1- to 2-mm layer of portland cement 100, sand 300, and vinyl polyacetate 15 kg is added onto the concrete surface. The concrete thus obtained has an abrasion resistance 15 times greater than the normal concrete.

A178 Ohama, Y., "Mix Proportions and Properties of Polyester Resin Concretes," *Polymers in Concrete*, SP 40-13, pp 283-295, 1973, Detroit, Mich.

Polyester resin concrete is a type of concrete that is prepared by binding aggregate with polyester resin (as a binder) without inorganic cements. The mix proportions of polyester resin concrete have not been studied systematically until now.

In this paper, a summary of the method used to obtain the most satisfactory mix proportion of polyester resin concrete and a discussion on the properties of this concrete.

A179 Parker, H. W., Deere, D. U., Peck, R. B., Birkemoe, P. C., and Semple, R. M., "Testing and Evaluating of Prototype Tunnel Support Systems," p 338, Aug 1973, Illinois University, Urbana, Department of Civil Engineering, Urbana, Ill.

The report presents the results of engineering studies related to the development of new and improved tunnel support systems. Steel fiber reinforced regulated-set concrete has been proposed for use as a slip-formed concrete lining which can be placed immediately behind a tunnel boring machine. Mix design studies and field pumping tests for this new concrete are described. The results of a cooperative research effort carried out with the U. S. Bureau of Reclamation on precast polymer concrete segmented tunnel support systems include an evaluation of the structural aspects of the system, an analysis of potential heat and fire hazards, and an evaluation of the cost of the promising new support system.

A180 "Polymer Cement Concrete With Furfuryl Alcohol Resins," Report No. 73/20-8-33, Apr 1973, U. S. Bureau of Reclamation, Washington, D. C.

The polymerization of pure FA occurs very rapidly when catalyzed with strong acids, but polymerization rate can be reduced by the use of weak acid catalysts and lower temperature. The problem involved in catalyzing FA in portland cement is to obtain an acid catalyst that can work in the presence of the alkaline portland cement. Antonova's solution to this problem was the use of aniline hydrochloride which in theory slowly releases hydrochloric acid to catalyze the FA after the portland cement had set.

In order to improve the usefulness of FA in PCC, the goals for this study as outlined in the proposal are: (1) increase in curing rate to be attempted by replacing aniline hydrochloride catalyst with other amine hydrochlorides, with weak acids, or with other similarly hydrolyzable compounds, such as acid chlorides (aliphatic or aromatic), or with the

chlorides of Sn, Ti, or Al; (2) strength improvements to be attempted by combining FA with Jet-Kote X3M (Furane Plastics, Inc.), a partially polymerized FA resin, under variation in the proportions and absolute amounts of these two, and of the other additives [CaCl<sub>2</sub> and aniline hydrochloride, or its substituents developed under (1)]; (3) those concretes with outstanding compressive strength properties and optimum curing rates developed under (1) and (2) to be tested for resistance to distilled water at a temperature of about 212°F, and for resistance to aqueous sulfate solutions and acids, by standard procedures.

A181 Pomeroy, C. D., "Evaluating Modified Concretes," Concrete, Parts 1 and 2, May and Jun 1973.

It is shown that in terms of the properties by which concrete is conventionally judged the improvements that result from the addition of polymers or fibers may be no greater than those that result from optimum mix designs using normal cements and aggregates. Therefore, to be of commercial interest the polymer concrete must have benefits to offer other than strength. This is true of all forms of modified concrete, and a list of the principal features that can be used to compare different forms of concrete is given.

A182 Proshin, A. P., "Improvement of the Properties of Polymer Concrete by Additions of Synthetic Surfactants," Soviet Plastics, No. 1, 1973, pp 67-68.

The investigation relates to the use of synthetic surfactants on the wetting and adhesion of a furfural-acetone monomer in relation to the surface of quartz sand and other mineral fillers. It is found that the addition of synthetic surfactants, in particular those of cation-active type, improves the wettability and increases the strength of adhesion to the surface of mineral fillers, perceptibly plasticizes the polymer concrete mixture in the initial stages of hardening, reduces shrinkage deformation and abrasion, and also increases the strength of the polymer concrete. The case of application of the improved concrete mixture is pointed out and the properties of the polymer concrete were investigated. A brief note is given on the use of a steel plus polymer anchor for securing mine workings, based on the use of FRA phenol-A stage resin, hardened with an acid catalyst.

A183 Raff, R. A. V., and Austin, H., "Epoxy Polymer-Modified Concretes," Polymers in Concrete, SP 40-16, pp 339-354, 1973, Detroit, Mich.

Polymer cement concretes prepared by substituting at least 30 percent of epoxy resin for cement into ordinary portland-cement concrete mixes showed increased compressive strengths. The addition of fly ash to the epoxy cement mixes increased the compressive strength further. Preliminary tests indicated that the presence of the epoxy resin does not inhibit the hydration of the portland cement.

A184 Sawyer, R. C., Boyko, L. L., Hunt, G. M., "Microwave Heating for Road Maintenance," p 133, Sep 1972-Aug 1973, Aug 1973, Syracuse University Research Corp., N. Y.

The report describes a 1-year feasibility study to determine the applicability of microwave power in conjunction with polymers concrete (polymers plus aggregate) for highway maintenance. The specific concern was relative to concrete bridge decks. Work covered in the report includes the defining of polymerization parameters and optimum materials combinations to be rapidly cured in situ with microwave power. In the portion of the program concerned with microwave equipment, a field unit was designed, built, and tested. This unit was used for field testing along with a series of microwave applicators designed and built under the program. With the materials and equipment combined, the research team is able to fill a void in a concrete section and completely cure the patch in less than 3 min.

A185 Shimura, H., "New Pre-Cast Resin Concrete Manhole," Japan Telecommunications Review, Vol 25, No. 3, Jul 1973, pp 212-215.

The construction work of underground telephone facilities has become more difficult year by year because of the manpower shortage and the increasing road traffic.

Present pre-cast resin manholes divided horizontally into two blocks have been used to solve these problems and have had a great effect on construction work.

Now for certain reasons, the capacity of manholes is to be increased. As a result of this enlargement, it has been proved necessary that new pre-cast resin manholes must be divided, not only horizontally but also vertically. The vertical bonding method was applied to this new pre-cast manhole for the first time, and the strength of this joint, using adhesive, has been confirmed to be sufficient for the purpose.

A186 Spellman, D. L., Woodstrom, J. H., and Bailey, S. N., "Evaluation of a Polymer Admixture," p 27, Jun 1973, *Materials and Research Department, California State Division of Highways, Sacramento, Calif.*

This report covers a limited investigation made to verify the claims of benefits to be gained from the use of Tufchem DP as a concrete admixture. The findings essentially substantiated the manufacturer claims; however, a note of caution is given until a service record of this admixture has been established.

A187 Steinberg, M., "Concrete-Polymer Composite Materials and Its Potential for Construction, Urban Waste Utilization and Nuclear Waste Storage," BNL-17978, p 24, May 1973, Brookhaven National Laboratory, Upton, N. Y.

A wide range of concrete-polymer composite materials are under investigation. The old technology of hydraulic cement concrete is

combined with the new technology of polymers. Polymer-impregnated-precast concrete (PIC) is the more developed of the composites and exhibits the highest degree of strength and durability. Polymer concrete (PC), an aggregate bound with polymer, is potentially a most promising material for cast-in-place applications. PC with solid-waste aggregate holds out interesting possibilities for converting urban waste into valuable construction materials of commerce. PIC and PC also show potential for immobilizing radioactive waste from the nuclear power industry for long-term engineered storage.

A188 Steinberg, M., "Concrete Polymer Materials and Its Worldwide Development," Polymers in Concrete, SP 40-1, pp 1-15, 1973, Detroit, Mich.

A wide range of concrete-polymer composite materials is under investigation in a number of laboratories around the world. For this materials development, the older technology of hydraulic cement concrete is combined with the newer technology of polymers to form new and improved materials of construction. Polymer impregnated precast concrete (PIC) is the more developed of the composites and exhibits the highest degree of strength and durability properties improvements. Polymer concrete (PC), an aggregate bound with polymer appears to be a promising material for cast-in-place applications. Numerous applications of PIC are presently under development which indicates a large potential for this material.

A189 ACI Committee 503, "Use of Epoxy Compounds with Concrete," American Concrete Institute Journal Proceedings, Vol 70, No. 9, Sep 1973, pp 614-645.

Properties, uses, preparations, mixtures, application, and handling requirements of epoxy resin systems when applied to and used with concrete and mortar are presented. The adhesiveness of epoxy and its chemical, thermal, and physical properties are given. The modification of the foregoing properties to accommodate given situations is reviewed.

Problems encountered in surface preparation are reviewed and procedures and techniques given to insure successful bonding of the epoxy to the other materials. Temperature conditioning of the base material and epoxy compound are outlined. The cleaning and maintaining of equipment is reviewed. Procedures to be followed in the application of epoxy compounds in the several use situations are given. The important factors which ensure that the epoxy compound will harden (cure) and therefore perform its function are discussed together with alterations of the hardening rate. The allergenic and toxic nature of epoxies and the chemicals used with them in the industry create a hazard and precautions are detailed throughout the report.

A190 Allen, R. T. L., "The Repair of Concrete Structures," Publication 47.021, 1974, Cement and Concrete Association.

This publication aims to give a general guide to the materials and methods that are generally used in repair work.

#### Epoxide Resins

Most of the properties of epoxide resins can be adjusted over a wide range by varying the formulation. Their most important properties for repair work are very strong adhesion to sound surfaces, strength, resistance to chemical attack and impermeability. Viscosity can be adjusted over a wide range, and resins are available that will adhere to damp surfaces and will cure under water.

Epoxide resins are often used for filling cracks, as bonding agents or, in conjunction with a fine aggregate, as mortars for patching, and with coarse aggregate to make resin-bound concrete, but they are very much more expensive than cement and they evolve more heat while they are curing. They have little resistance to fire.

#### Polyester Resins

Polyester resins are used to some extent for repairing concrete structures but not as widely as epoxides. They are cheaper than epoxides, although still considerably more costly than cement mortar. They are less sensitive than epoxides to inaccuracies in proportioning, and the rate at which they cure is less dependent upon temperature. When necessary, they can be formulated to cure very rapidly. In general, they are less toxic and are less likely to cause dermatitis. They also have some disadvantages. The quantity of heat evolved during curing is greater than with epoxides and shrinkage is also greater, with the result that undesirably high stresses may be set up. In some cases shrinkage may continue over a long period. Polyester resins tend to be moisture-sensitive, although this difficulty can be overcome by suitable formulation. Some of them may be adversely affected by alkalis in cement. They have little resistance to fire.

A material is available that is based on polyester resin and portland cement, with catalysts that are activated by the addition of a controlled quantity of water in the presence of suitable aggregates. It is used mainly for surfacing and repairs to floors, and is generally not suitable for structural repairs because it cannot be applied to vertical surfaces.

A191 Baker, C. A., "Polymer Concrete: A Chemically Inert Structural Material," Civil Engineering Transaction, Vol 16, No. 1, 1974, pp 12-16.

This paper presents a study of the physical and chemical properties of an ultra low binder content polymer concrete, particularly in relation to its usage for underground pipe. The development of the material is described, in particular the means adopted to ensure complete chemical inertness and to overcome loss of strength caused by bond failure in an aqueous environment.

A192 Cox, F. B., "Crack-Arrest Techniques in Reinforced Concrete Structural Elements, Report 1, Laboratory Tests," Technical Report C-74-7, Nov 1974, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

In this study, tests were conducted to develop improved methods of arresting or preventing undesired flexural cracking within the tensile zones of conventionally reinforced concrete beams. Specimens representing several potential crack-arrest techniques including (a) fiber-reinforced concrete, (b) concrete with wire mesh, and (c) epoxy-resin concrete were tested under either short- or long-term static loading.

A193 Fowler, D. W. and DePuy, G. W., "Concrete Polymer Materials Development in the U. S.," Australia Conference on Engineering Materials, 1st Proceedings, Sydney, Aug 1974, pp 121-136.

The three basic types of materials are polymer-impregnated concrete, polymer-concrete, and polymer-cement concrete. Most of the research has been focused on polymer-impregnated concrete. All three types of materials have considerable potential, however. The process or method for producing each material is reviewed. The properties of each are summarized, and past and current research is briefly reviewed. Potential applications are presented.

A194 Galler, S., and Steinberg, M., "Polymer Concrete Shows Promise as Patching Material," Public Works, Vol 105, No. 5, May 1974, pp 92-93.

The new product, consisting of sand, stone, and methyl methacrylate, a chemical which solidifies upon activation to bond these materials firmly together, and is called polymer concrete was developed. The product possesses the property of developing strength greater than conventional portland-cement concrete within 2 hr of application.

A195 Graham, J. R., "Polymer Shotcrete," Conference Proceedings, American Society of Civil Engineers, Report No. SP-45, pp 418-434, 1974.

The results are presented of work oriented toward the development of a polymer shotcrete type material, the development of an application technique, and the development of the necessary application equipment. The materials investigation was directed toward the development of a suitable monomer system, the determination of aggregate properties and optimum gradings, and the selection of a promoter-catalyst system for polymer shotcrete applications. Factors of particular concern were the cohesive qualities of the mix, the physical properties of the cured material, and the low temperature performance of the polymerization system. The results of laboratory tests indicated that a monomer system containing 72 weight percent MMA (methyl methacrylate), 13 weight percent TMPTMA (trimethylolpropane trimethacrylate), and 15 weight percent acryloid A-11 (a moulding powder composed primarily of polymethyl

methacrylate) had the proper viscosity and was suitable for use in polymer shotcrete. It was determined that the viscosity of polymer concrete using 0.375-in. maximum size aggregate was acceptable for shooting and that extremely high ultimate compressive strengths in the 12,000- to 14,000-psi range could easily be obtained with most of the strength gain occurring in the first 10 to 15 min at ambient temperature. Two application techniques (in one the shotcrete equipment was modified to accommodate the two-part monomer system and aggregate, and in the other the application technique was altered) are described. Application equipment and tests are also described. In "Use of Shotcrete for Underground Structural Support: Proceedings of the Engineering Foundation Conference, South Berwick, Maine, 16-20 July 1973."

A196 Jenkins, J. C., "Polymer Concrete Overlay Test Program," Interim Report, Nov 1974, Oregon State Highway Division.

This report describes work done on various combinations of monomers and polymer concrete mixes and identifies the mixes showing the greatest potential for use in bridge deck overlays. Presented are test results showing physical properties of various polymer concrete mixes, such as compressive strength, split tensile strength, modulus of elasticity, thermal coefficient of expansion, and shrinkage coefficient. The effects of polymer content, work time, and temperature on various properties are also discussed. The development of two polymer concrete systems with excellent membrane potential are described along with the details of bonding characteristics of several systems. Finally, a polymer concrete mix with suitable properties for deck and pavement patching is detailed.

A197 Knab, L. I., and Cook, J. P., "Shear and Flexural Behavior of Reinforced Polyester Concrete Beams," Proceedings, American Concrete Institute Journal, Vol 71, No. 10, Oct 1974.

The feasibility of using reinforced polyester concrete in structural beams is studied. A preliminary investigation and analysis of the shear and flexural behavior of reinforced polyester concrete for short- (1 hr) and long- (44 days) term loading is presented. To evaluate the effects of short-term, monotonic loading, 27 shear beams and 18 flexural beams with varying length to depth ratios were tested. The flexural beams exhibited relatively high strength accompanied by very large deflections. The effects of the depth and length to depth ratio on shear and moment stress parameters were statistically analyzed. The shear and moment stress parameters were shown to be meaningful in describing the behavior of the beams tested.

The relatively low stiffness, large ultimate strain, and significant creep of polyester concrete can give rise to relatively large structural deformations, including large beam deflections. The deflection due to long-term sustained loading for a typical beam was shown to be significant.

A198 Knuth, O. H., "Vibrating Trestles in Cast Stone Factories and Precasting Plants," Precast Concrete, Vol 5, No. 4, Apr 1974, pp 201-208,

Vibrating trestles can be used alone, with ancillary equipment, or as vibrating stations in cast stone and precasting plants. Given the correct layout, they effect optimum compacting efficiency and impart the required strength and facing to precast concrete members. This paper also discusses the use of vibrating trestles with synthetic resin bound concrete.

A199 Kukacka, L. E., Fontana, J., and Steinberg, M., "Polymer-Concrete for Use in the Repair of Deteriorated Bridge Decks," BNL-19161, p 30, 1974, Brookhaven National Laboratory, Upton, N. Y.

One of the most severe problems facing the highway industry is the rapid deterioration of highway-type structures. As part of a concerted effort to solve this problem, research is being performed to determine if concrete-polymer materials can be used for the repair of deteriorated and delaminated bridge decks. Process variables studied included monomer-type, aggregate size distribution, and polymerization method. Field testing of PC has been in progress for ~3 yr and to date deterioration has not been observed.

A200 Kukacka, L. E., Auskern, A., Steinberg, M., Colombo, P., and Fontana, J., Introductory Course on Concrete-Polymer Materials, Radiation Division, Brookhaven National Laboratory, Upton, N. Y., Dec 1974.

At the request of the Implementation Division of the Federal Highway Administration, an introductory course on Concrete-Polymer Materials was given by the staff of Brookhaven National Laboratory. The purpose of the course was to provide representatives of state highway departments with a working knowledge of concrete-polymer materials development and applications.

The course, which was presented in a one-week series of lectures and laboratory demonstrations, and the text of this report were designed to provide the following information: (1) a review of concrete-polymer materials development, (2) knowledge of polymer chemistry as applied to concrete-polymer materials, (3) knowledge of the technology required to produce concrete-polymer materials, (4) a description of the fundamental characteristics and properties of the composites, and (5) an in-depth study of the applications of concrete-polymer materials.

A201 Lehmann, E. J., "Concrete Polymer Composites. A Bibliography with Abstracts," Report No. NTIS/WIN-74-079, Oct 1974, National Technical Information Service, Springfield, Va.

This bibliography contains 72 selected abstracts of research reports retrieved using the NTIS on-line search system - NTISearch. The abstracts contain information on the production, uses, and properties of



concrete polymer composites. Major potential applications include piping, building panels, bridge decking, distillation vessels, and tunnel supports.

A202 Manowitz, B., et al., "Promoting the Utilization of Solid Waste Glass-Polymer Composite Technology in the Public and Private Sectors," Oct 1974, Brookhaven National Laboratory, Upton, N. Y.

This report was part of a larger effort to explore how best to transfer technology which had originated in Federal laboratories to the civilian/commercial sector. In this report, Brookhaven discusses the actions undertaken to transfer its glass-polymer composite sewer pipe technology to several local governments in the Eastern United States. Problems which were encountered and their attempted solutions are described, and recommendations for certain policy actions by the federal government are identified.

A203 Manowitz, B., et al., "Polymer-Concrete Composites for Energy Related Systems," BNL-19746, Progress Report No. 3, Oct-Dec 1974, Brookhaven National Laboratory, Upton, N. Y.

Polymer-concrete (PC) materials were exposed to a synthetic geothermal brine at 177 exp 0 C for up to 100 days; changes in compressive strength, dimensions, and composition were determined. Thermal shock tests on PC-lined steel pipe and tests on use of PC in geothermal systems were initiated. Research is continuing on the use of solid waste in glass polymer composite sewer pipe. Tests are underway on the use of polymer-impregnated concrete to prevent ice formation on canal lock walls and as railroad ties.

A204 Martino, R., "Plastics Help Concrete Bear the Load," Modern Plastics, Vol 51, No. 1, Jan 1974, pp 53-55.

The paper discusses various types cement-polymer composite materials which found uses in the construction industry in load-bearing applications. The new technology uses plastics as an additive to, or as total replacement for, one or more of these constituents. Among the most promising recipes are polymer-impregnated concrete, polymer concrete (cement entirely replaced by plastic), and polymer-cement concrete (monomer replaces some water and some cement in the wet concrete mix, forming with cement a dual binder). It is concluded that stronger and more durable than conventional concrete, polymer/concrete composites are poised for heavy-duty future in building and construction. Coming new markets for polymer-impregnated concrete are indicated as follows: tunnel support linings, pipe and draintile, desalinization facilities, housing, and underwater habitats.

A205 McLaren, K. G., and Samarin, A., "Concrete-Polymer Composite Materials Produced by Radiation Polymerization Techniques," p 40, Jul 1974, Australian Atomic Energy Commission Research Establishment, Lucas Heights.

Exploratory studies have been carried out on the production and properties of concrete-polymer composite materials, made by impregnating precast concrete with monomers and polymerizing the monomer in situ with gamma radiation. The main factor influencing the degree of enhancement of these properties is the total polymer loading in the interstices of the concrete, and the ultimate strength attainable in the composites is largely independent of the type of concrete used to make the composite.

A206 Nichols, R. W., "Initial Development of Polymer Shotcrete," p 19, Jan 1974, Bureau of Reclamation, Denver, Colo.

A limited program was conducted to investigate the potential use of polymer concrete for shotcrete application. Polymer shotcrete is similar to conventional shotcrete except that a polymeric binder is used in lieu of portland cement and water. The polymer shotcrete was successfully applied using modified conventional shotcrete equipment. Polymer shotcrete cures in 10 to 15 min after application, develops full compressive strength ranging upwards to 14,600 psi immediately upon curing, and should have potential applications in areas in which these properties would offer definite benefits over conventional shotcrete. Polymer shotcrete, being organic in nature, requires that certain safety measures be taken to assure safe use.

A207 Pike, R. G., and Baker, W. M., "Concrete Patching Materials," Report No. FHWA-RD-74-55, 1974, Federal Highway Administration, Washington, D. C.

Nine potential patching materials were evaluated by a series of different tests and compared with a Type III High Early cement to determine which tests would be most significant and which of the nine materials showed sufficient promise to warrant further evaluation by field installations. The following six tests appear to evaluate the most significant properties of a patching material: (1) Initial setting time; (2) Compressive strength; (3) Bond strength; (4) Resistance to scaling; (5) Resistance to rapid freezing in air and thawing in water; (6) Percentage of chlorides in the mortar.

A208 Podagel, R. S., and Kudzia, A., "Some Mechanical Properties of Polymer Cement Concrete Exposed to Infrared Radiation," p 13, Jun 1974, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio.

Infrared irradiation is an effective means of intensifying the hardening process of polymer cement concrete, and makes it possible to obtain a high-quality concrete of tempered strength. The rate of the temperature rise has a great effect on the strength of the concrete immediately after its irradiation and has practically no effect on its strength after aging for 28 days. The length of irradiation has an opposite effect.

A209 Pomeroy, C. D., Taylor, H. P. J., and Brown, J. H., "Concrete Products for the Replacement of Timber for Chock Construction in Coal Mining," Publication 42.491, 1974, London, Cement and Concrete Association.

Timber is used in coal mines to construct chocks or cribs that resist the loads from the convergence of the strata as coal is extracted. The chocks deform under load, frequently to less than half their initial height, without a drop in the bearing capacity of the crib structure, and the load carried by the chock may rise continuously as compaction occurs. This report describes a development programme in which a number of techniques have been used to manufacture concrete products that have a comparable load-deformation performance. It is concluded that the solution is likely to include the use of a low-density material, which can be compacted under load, reinforced with a form of ductile hoop reinforcement. A number of possible solutions are described which mining engineers can exploit for their own particular applications.

A210 Popovics, S., "Polymer-Cement Concretes for Field Construction," American Society of Civil Engineers, Journal of the Construction Division, Vol 100, No. CO3, Sep 1974, pp 469-487.

The technology of the polymer-cement concrete (PCC) is relatively simple. Therefore, it is more suitable for field constructions than the other types of polymerized concretes.

The most widely investigated PCC contains aqueous suspensions of polymers, e.g., polyvinyl thermoplastics or latexes. The use of these emulsions has beneficial effects mainly on the flexural, tensile, and bond strengths of the polymer-cement concrete, especially when the concrete is cured under dry conditions. The maximum concrete strength increase has been obtained with 0.15 to 0.20 polymer-cement ratio by weight.

Water solutions of polymers as well as polymerizable components of a monomer system or prepolymer system have also been tried out. To date, investigations concerning this type of PCC have been confined to small-scale feasibility studies of limited success.

A211 Riley, V. R., and Razl, I., "Polymer Additives for Cement Composite: A Review," Composites, Vol 5, No. 1, Jun 1974, pp 27-33.

The properties of mortars, concretes, or other composites based on inorganic cements such as fibre reinforced systems can be greatly improved by the addition of polymers. Various types of polymers which can be added to these composites in their fresh or wet state are discussed.

A212 Smoak, W. G., and Causey, F. E., "Polymer Concrete," Patent Application-504 925, Sep 1974, Department of the Interior, Washington, D. C.

The patent application concerns a polymer concrete which may be mixed and formed using equipment and techniques identical to those used with portland-cement concrete comprises a conventional concrete aggregate and a polymer binder. The polymer binder consists of methyl methacrylate reacted with a crosslinking agent in the presence of a suitable peroxide catalyst. A catalyst promoter, such as dimethyl aniline, allows ambient temperature polymerization in a relatively short time; on the order of 3 to 5 hr. Addition of particular silane-type materials increases the strength of the polymer-aggregate bond and increases the strength at the cured concrete product.

A213 Sun, P., Sauer, J. A., and Nawy, E. G., "Properties of Epoxy-Cement Mortar Systems," Journal of Materials Science and Engineering, Vol 18, No. 1, 1974, pp 85-95.

The possible benefits to be obtained by addition of an epoxy resin system to cement mortar have been explored. The epoxy resin system, consisting of a low molecular weight liquid resin, Epon 828, and either an amidoamine or a di- $\beta$ -hydroxyalkylamine as a curing agent, is first premixed and then varying percentages of the blended epoxy resin are added to a standard cement:sand:water mix. With 5 percent of added epoxy (by weight of the mortar) tensile strengths above 900 psi and compressive strengths above 8000 psi have been realized with either normal Type I or early Type III cement. Both of the hardeners used gave improved strength properties but the hydroxyalkylamine gives superior strength and workability. Additional tests were made in which the cement:water phase of the mortar was progressively replaced by the blended epoxy system. For 20 percent replacement, strength properties were improved but they diminished at 40 percent replacement as the added epoxy interfered with hydration of the cement. At still higher replacements, strength values rose again; and for 100 percent replacement, the average tensile strength exceeded 1800 psi and the water absorption was effectively zero.

A214 Tatishvili, T. I., "Polymer Concrete Creep in Air and Aqueous Environment," p 12, Jan 1974, Army Foreign Science and Technology Center, Charlottesville, Va.

Polymer concretes, using furfural-acetone (FA) monomer and modified FA monomer with and without sodium fluosilicate additive, were tested in air and aqueous environments under bending stresses. Considerable creep and some failure in the air environment were reported, as well as considerably more extensive sagging and failure in water. The latter was explained as due to water being a polymerization reaction inhibitor and by reactions promoted by the high hygroscopicity of the benzenesulfonic acid catalyst. Modified FA monomer polymer concrete with fluosilicates increases strength and reduces creep, but further research is needed.

A215 Vaitkyavichius, V. E., and Kudzys, A., "On the Cracking Resistance of Prestressed Polymer Cement Concrete Beams," p 17, Aug 1974, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio.

The purpose of this work was to investigate the crack resistance of prestressed beams made from three types of concrete mixtures with varying reinforcement prestressing and eccentricity. A mathematical scheme was used in analyzing the experimental values obtained for the moment of crack formation in beams in the least number of experimental samples and in analyzing quantitative estimates of the effect of the addition of polymers on the size of the cracks.

1975

A216 "A Future for Polymer Concretes, An International Congress Recently Reviewed the Current Situation and Potential Applications of Polymer Concretes," Precast Concrete, Vol 6, No. 8, Aug 1975, pp 421-425.

An international congress reviewed the current situation and potential applications of polymer concretes. The papers were divided into several different groups which formed the various sessions. This article reports on the various sessions.

Session A: A general introduction to polymer concretes, discussing its development and current use as well as touching on different types of polymer concrete and materials.

Session B: Surveyed the field of polymer impregnated concrete.

Session C: Dealt with the subject of concrete with polymers added.

Session D: Concretes with dispersed polymers added formed the theme of this session and the next. This former session dealt with (a) vinyl acetate and copolymers and (b) vinyl propionate.

Session E: Continued the study of concretes with dispersed polymers added, by studying (c) vinyls and acrylics and (d) rubbers. The subject matter included reference to concretes with the addition of water-soluble polymers and also to resin bound aggregates - with and without cements.

Session F: Explored the practical applications of polymer concretes.

A217 Adams, M., et al., "Using Polymer Concretes," Batim Int/Build Res Pract, Vol 3, No. 4, Jul-Aug 1975, pp 212-231.

The advantages and disadvantages of using resin concretes and polymer modified concrete are described. The practical and cost implications of using resin and polymer modified concrete are discussed.

A218 Aigrot, A., "Artificial Slates With a Resin Mortar Base," Polymers in Concrete, pp 290-295, May 1975, The Concrete Society, London.

Paper examines the problems related to a study to determine composition of the resin mortar and manufacturing process for artificial slates. Based on this work, the manufacturing process has been perfected and a manufacturing plant is now being installed in the region of RENNES, France.

For guidance, the following table gives a comparison of the

properties of reconstituted slate and those of natural slate.

	Natural Slate	Reconstituted Slate
Density (kg/dm <sup>3</sup> )	2.60 to 2.70	2.30
Compression strength (kg/cm <sup>2</sup> )	1000	800 to 900
Cross-breaking strength (kg/cm <sup>2</sup> )	600 to 900	370 to 420
Flexural modulus	7000 to 9000	2500 to 3000
Heat expansion factor/°C	$13 \times 10^{-6}$	$20 \times 10^{-6}$
Heat conductivity (W/m/°C)	≈0.55	0.55
Water absorption in % by weight	≈1	0.2 to 0.4
Resistance to abrasion (capon) mm	34	18

A219 Ashly, S., "The Use of Polymers in Concrete," Building, Vol 229, No. 43, Oct 1975, pp 88-89.

A critical review of the Concrete Society's Technical Report No. 9, "Polymer Concretes, The Report of Concrete Society Working Party," with emphasis on applications and material properties.

A220 Boyko, L. L., et al., "Rapid Runway Repair Study," Aug 1975, Syracuse University Research Corp., New York.

This report describes a series of tests to evaluate a system for rapidly repairing airfield pavement using polymer concrete (synthetic polymer plus aggregate), thermally cured by microwave power. The technique, developed by the Syracuse University Research Corporation (SURC) for highway maintenance, uses a truck-mounted 50-kilowatt microwave generator to irradiate areas patched with polymer concrete. Test results indicate that the polymer concrete can be cured in a fraction of an hour, bonds well to old pavement material, is very strong, and possesses other qualities which make it naturally suited for airfield use.

A221 Broniewski, T., et al., "Long Life Strength Polymer Concrete," Polymers in Concrete, The Concrete Society, London, May 1975, pp 179-184.

Epoxy-polymer concrete is reinforced with steel fibers in an effort to improve bending strength and brittleness. Basic properties of traditional polymer concrete are compared with those of steel fibre polymer-concretes containing 2.5, 3.0, and 3.5 percent fibres by volume, and a general approach to the evaluation of the long-life strength of any polymer-concrete is described.

A222 Browne, R. D., et al., "Experience in the Use of Polymer Concrete in the Building and Construction Industry," Polymers in Concrete, pp 433-447, May 1975, The Concrete Society, London.

The object of this paper is to highlight from the experience we have gained in the development and application of polymer concretes their

advantages and disadvantages, a number of which unfortunately were not apparent at the start of our investigations. Detailed comments on the performance of specific materials currently available in the UK are also included.

The paper concludes with a detailed listing of present limitations, the most useful properties, and those properties where more detailed information is required, for resin concretes, polymer cements, and low-dosage polymer additives to concrete.

A223 Chang, T.-Y., et al., "Polymer Concrete Prepared From An MMA-Styrene Copolymer System," Polymer Concrete, Transportation Research Record 542, pp 50-59, 1975, Washington, D. C.

Polymer concrete is a premixed material that is prepared from portland cement, aggregate, and polymer such as methyl methacrylate (MMA) or styrene or a combination of the two. A polymer is used as the main binder in the material matrix. Experiments were conducted to investigate the effect of using different copolymer ratios of MMA and styrene and the effect of polymer loading on the strength of the material. Mortar specimens with thermal curing process at 158°F (70°C) were prepared for the test program. Test results indicated that a 50:50 copolymer system of MMA and styrene gave much higher strength than the system containing MMA or styrene alone. Results also showed that the strength of the composite increased as polymer loading up to 12 percent (wt) increased; the strength decreased for higher polymer loading. Less polymer loading was required for polymer concrete containing coarse aggregate. A series of polymer concrete with 9 percent (wt) copolymer of 50:50 MMA and styrene was prepared. Tests including compression, tension, bending, double shear, water absorption, and chemical resistance (18 percent hydrochloric acid) were conducted, and results compared favorably with those for conventional concrete. Moreover, the polymer concrete appeared to have the same type of physical properties as the polymer-impregnated concrete.

A224 Chang, T.-Y., and Stephens, H. L., "Physical Properties of Premixed Polymer Concrete." American Society of Civil Engineers Journal Structural Division, Vol 101, No. 11, Nov 1975, pp 2293-2302.

Premix polymer concrete consisting of methyl methacrylate, portland cement, sand, and coarse aggregate was prepared with promoter; catalyst systems at room temperature. The materials had excellent bonding and durability with high strength in compression, tension, and flexure.

A225 Chang, T.-Y. and Stephens, H. L., "Development of Polymer Concrete as a Highway Patching Material," OHIO-DOT-01-75, Dec 1975, The University of Akron, Akron, Ohio.

A study has been conducted on the preparation and properties of polymer-concrete utilizing polystyrene and/or poly(methyl methacrylate) as the polymeric component in the concrete composites formed.

Both thermal and catalyzed polymerization methods were used to

transform monomer-polymer mixtures into the polymeric component of polymer-concrete. Catalyst promoters were used to develop room-temperature polymerization systems which developed full strength within 2 hr. The effect of aggregates (silica sand, brown sand, gravel and limestone) on the physical properties of polymer-concrete compositions was also studied.

In general, it was found that systems involving methyl methacrylate produced the best properties. Combinations containing from 9 to 15 percent of the polymer were studied; all gave higher compression, tensile, flexural and bonding strength than the corresponding control samples prepared without polymer. Abrasion resistance, water absorption, acid resistance and freeze-thaw durability were greatly improved with the use of either polymer system.

A226 "Concrete-Polymer Materials for Geothermal Applications," BNL-20571, Progress Report No. 6, Jul-Sep 1975, Brookhaven National Laboratory, Upton, N. Y.

The research program to determine if concrete-polymer composite materials can be utilized in geothermal power systems was initiated in April 1974. Five progress reports titled Polymer Concrete Composites for Energy Related Systems have been issued. Work accomplished during the period 1 July - 30 September 1975 is described in the current report. The title and format of the report have been changed to reflect the revised program plan for fiscal year 1976.

Polymer concrete (PC) systems that can be utilized as protective linings and well cementing materials at temperatures up to 300°C are being developed.

The techniques for placing PC protective linings on steel surfaces are being developed. Currently, the thickness required to produce an impermeable liner is being determined. An electrical resistivity technique developed by the State.

A227 "Concrete-Polymer Materials for Geothermal Applications," BNL-20865, Progress Report No. 7, Oct-Dec 1975, Brookhaven National Laboratory, Upton, N. Y.

Based upon the results from AEC and OSW sponsored research that indicated the long-term stability of concrete-polymer materials in seawater at 177°C and in acid solutions, a research program to determine if the composites can be utilized in geothermal systems was initiated in April 1974. Since that time laboratory and field tests have been started. The results obtained to date have been reported in six progress reports. Work accomplished during the period 1 October - 31 December 1975 is described in the current report.

A228 Davis, B., "Application of a Melamine Formaldehyde Polymer in Concrete," Polymers in Concrete, pp 375-377, May 1975, The Concrete Society, London.



Whatever water-reducing or improved workability properties are required, the melamine/formaldehyde polymer can offer advantages for all cement or gypsum based systems. The concept of flowing concrete enabling quicker placing of concrete without affecting the properties will surely play an important part in construction in the future.

A229 Davydov, S. S., and Ivanov, A. M., eds., Steel Polymer Concrete Structural Construction, 1972, Moscow; Translated from Russian by Amerind Publishing Co. Pvt. Ltd., New Delhi, 1975.

The book is concerned with one of the promising breakthroughs in the field of construction materials - polymer concrete.

Polymer concrete holds out promising possibilities because it has higher compressive and tensile strengths and is more impermeable and is considerably more resistant to attacks by most aggressive acids and alkalis and erosive forces. Structural components of reinforced and prestressed polymer concrete are particularly suitable for use in the chemical industry.

Polymerization of monomers can be effected either by radiation or by chemical means. This book is devoted to the latter technique which has been developed during the past decade in the USSR.

Starting from the ingredients that go into polymer concrete, the book deals with the production aspects and the properties, including shrinkage and creep, of this new material. The design of reinforced and prestressed structural components subjected to axial tension and flexure are presented in detail with the aid of examples.

The economics of polymer concrete in its present state of development is discussed, and situations where its use will be justified in spite of its higher cost are mentioned.

The applications of polymer concrete in construction which have already been made in the USSR are described. These include its use for the manufacture of props for mining, sewer pipes, railway sleepers laid on marshy soils and structures built for the chemical industry.

A230 DePuy, G. W., "Highway Applications of Concrete-Polymer Materials," Transportation Research Board Annual Meeting, Washington, D. C., Jan 1975.

A precast, prestressed polymer-impregnated concrete bridge deck system is being developed that incorporates the advantages of a precast, prestressed system for rapid construction and strength, and a surface-impregnation technique is being developed for field treatment of newly constructed concrete bridge decks to provide protection of reinforcing steel from deicing salts.

A231 Dikeou, J. T., "An Introduction to Polymers in Concretes," World Construction, Vol 28, No. 8, Aug 1975, pp 22-25.

The author discusses the use of plastics in construction concrete with most development in the past 5 years and reports how such concrete can be made stronger, acid-resistant, and weather- and wear-resistant.

The author emphasizes how polymer-concrete may be substituted economically for other materials such as steel masonry.

A232 Dikeou, J. T., "Review of Worldwide Development and Use of Polymers in Concrete," Polymers in Concrete, pp 2-8, May 1975, The Concrete Society, London.

The development of concretes which contain polymers has progressed rapidly in recent years. Developmental work has identified a number of applications where the high strength and excellent durability of the materials will provide definite advantages over conventional concretes. Numerous potential applications are on the horizon, pending further studies.

A233 Edmeades, R. M., and Hewlett, P. C., "Developments in Plasticised Concrete," Polymers in Concrete, pp 420-432, May 1975, The Concrete Society, London.

A study of the plasticising admixture lignosulphonate was initiated to corroborate claims made for the material and to outline general trends. The major conclusions to draw from this study are:

1. Careful consideration should be given to the detailed physical form of extracted calcium lignosulphonates before conclusions are drawn from much of the publicised adsorption data relating to this type of material.

2. Addition to concrete of a plasticiser of the type studied resulted in marked improvement in strength and indirect durability characteristics.

3. The air content, initial surface adsorption, and pore-size distribution of 'corresponding' mixes with and without admixture are similar.

4. Of the properties measured, unconfined compressive strength displayed the greatest variation to changes in concrete composition. This suggests that cube strength is a fairly sensitive indicator of concrete quality.

5. On the basis of 28-day strengths, incorporation of this admixture in 'corresponding' mixes made under laboratory conditions allowed a cement reduction of 10 percent at normal dosage levels and 15 percent by doubling the amount added.

6. Plasticised 'corresponding' mixes appeared to give an accelerated early strength. As a consequence 7- and 28-day cube strengths of plasticised concrete are liable to give an optimistic indication of ultimate strength. For this reason long-term strength properties of such concretes need to be established.

A234 Gamski, K., "Resinous Binder Concrete," Polymers in Concrete, pp 223-229, May 1975, The Concrete Society, London.

Based on a review of the types of binder in general use with resinous binder composites, the extent of crosslinking between resin and reactivity components, the kinds of charges in use for resinous binder

composite formulation, the composition of the different parts, and the methods which can be used for forecasting mechanical characteristics, this paper concludes that there is a lack of continuity in the theories used to forecast the characteristics of a composite material. It seems that the laws of mixtures and the theories of two-phase suspensions are in more general use and can be developed for the purpose of connecting the mechanical and physical characteristics.

A235 Glagoleva, L. M., and Rasulev, K. S., "The Use of Still Residues of Furfural for the Preparation of Polymer Binders of Mastics and Concretes," 1975, USSR.

Of a number of polymer binders, the greatest use in construction has been enjoyed by furfural acetone resins, which are the cheapest and permit the preparation of polymer concretes with high strength and resistance to corrosion.

High-strength furan polymer compositions, mortars, and concretes can be prepared on waste products of the production of furfural - its still residues.

Furfural-carbamide polymer compositions on still residues of furfural can be used in the preparation of dense thin-walled structures and articles for industrial, aquicultural, and other areas of construction.

A236 Goudev, N., "Plastic Concretes of Furan Polymers and Some Physical Properties and Applications," Polymers in Concrete, pp 230-235, May 1975, The Concrete Society, London.

This paper describes the production of furan polymers by condensation from furfural and furfuryl alcohol, the subsequent formulation of resin mortars, and some physical mechanical properties of the resin mortars.

In the People's Republic of Bulgaria, the FF resin concretes and mortars are employed for many kinds of applications requiring chemical resistance. Due to their excellent performance in this field, FF resins are extensively used in industrial floors (trowelling, self-levelling or tiles) constructions and production of high pressure pipes. Glass-reinforced FF resins are employed as a material for filament winding pipes and industrial pipes used for acids and alkalis.

A237 Harreus, A. "Synthetic Resin Dispersions as a Mortar and Concrete Admixture," Polymers in Concrete, pp 125-130, May 1975, The Concrete Society, London.

The properties and application possibilities of a product from the pure acrylate dispersion class are described. The acrylate based system under discussion is a finely dispersed synthetic resin dispersion with a maximum particle size of about 0.1  $\mu\text{m}$  and a white point around 0°C. It is a product which is miscible in all proportions with cement and lime, and the consistency of the mortar is stable over the necessary period of time. The selection of suitable emulsifiers and protective colloids, and the high alkali resistance of the polymer ensure good working

properties and long-term stability. The dispersion has good flow-promoting action which allows a reduction in the water-to-cement ratio and therefore improves the mechanical strength properties of the cement mortar. Thus, the flexural strength is significantly increased. The fall-off in compressive strength normally observed on addition of synthetic resin dispersions does not occur and in fact an increase takes place after sufficiently long periods of storage. Elasticity and adhesion of the cement mortar are increased and the shrinkage tendency in the setting process is reduced. In contrast to many dispersions with retardant action which are used in building, the curing characteristics, i.e., the time until the commencement or end of setting, is practically unaffected by comparison with unmodified mortar systems. The dispersion is halogen-free and shows no corrosion-promoting effect.

Some characteristic properties of mortar in the fresh and hardened states which can be modified by synthetic resin dispersions are described in detail.

A238 Ionescu, I., and Enculescu, M., "High Strength Concretes with Synthetic Resin and No Mineral Binding Matter and Their Practical Application," Polymers in Concrete, pp 360-366, May 1975, The Concrete Society, London.

Our intention is to give a brief account of the main results of research and experiments aimed at obtaining high strength concretes with furane, phenol-formaldehyde, epoxide, and polyester resins; the main fields of those concretes' application in the building material and construction industry for the next few years are also analysed.

A239 Jaber, M. M., An Investigation of the Use of Polymers for the Repair of Concrete, M.S. Thesis, University of Texas at Austin, Austin, Tex., Jan 1975.

The use of polymers for the repair of cracked or badly-damaged concrete specimens has been investigated. Methyl methacrylate has been the primary monomer studied, although other monomer systems have been investigated.

Tests were conducted to evaluate the strength and durability of the repaired concrete for a number of variables. The significant variables include: concrete moisture content, crack width, monomer viscosity, air temperature, and concrete surface temperature. The use of sand as a filler decreased the amount of monomer used, without decreasing the strength.

Tests on reinforced concrete beams that had been loaded to failure before being repaired indicated that the repaired beams had a 5 percent higher strength than the original beams. Reinforced concrete beams had essentially the same stiffness before and after repair.

In general freeze-thaw tests indicated that repaired specimens were at least as durable as uncracked, unrepaired control specimens. The freeze-thaw durability of repaired specimens with an initial polymer-impregnated surface was found to be significantly better than control specimen.

Field repairs on bridge abutments were made using several different monomer systems. The procedures and in the field repairs are presented. The performance of the repairs is reviewed.

A240 Jaber, M. M., Fowler, D. W., and Paul, D. R., "Repair of Concrete With Polymers," *Research Report 114-3, Project 3-9-71-114, Feb 1975, Center for Highway Research, The University of Texas at Austin, Austin, Tex.*

The use of polymers was investigated for repairing cracked or damaged concrete. Several monomer systems, using methyl methacrylate as the primary monomer, were studied. The variables investigated included relative moisture content, crack width, monomer viscosity, concrete temperature, and the use of sand fillers. In many cases the original flexural strength of the plain concrete could be restored by the repair.

The repair of reinforced beams that had been loaded to failure was investigated. Failure modes were flexural and diagonal tension. Sand filler was used with a monomer solution that cured at ambient temperatures. The ratio of repaired beam strength to initial strength ranged from 0.92 to 1.12, with an average of 1.05.

The freeze-thaw durability of repaired nonreinforced slabs was studied to determine the effect of crack width, monomer systems, and surface impregnation and the use of sand fillers. It was found in all cases that the repaired specimens had equal or better freeze-thaw durability than uncracked controls.

Several bridge abutments have been repaired using the techniques developed. A summary of the repairs is given.

A241 Kawakubo, S., et al., "Degradation of Polyester Resin Concrete," *Journal of the Society of Materials Science, Japan, Vol 24, No. 260, May 1975, pp 380-385.*

Recently, resin concrete, which is a kind of composite materials made of synthetic resins, sands, gravels, and so on, has become recognized as a regular structural material. But, as this material has not been in service for a long time unlike cement concrete which has been applied to structural purposes for about two centuries, it is very necessary to investigate its durability. Particularly, the durability study in water is most important for the case of resin concrete made of unsaturated polyester resin, from the point of view of the property of the resin.

From this point of view, we have carried out some accelerated experiments on its durability in water and on its chemical resistance, and tried to clarify the aging behavior of this material by deriving an experimental equation for durability in its property from these experiments. In addition, the same material was immersed in water at room temperature for about 6 years. The results showed that this resin concrete has very excellent durability in comparison with cement concrete.

A242 Kloker, W., and Dolfen, E., "Rigid Foam Lightweight Concrete Based on Unsaturated Polyester Resins: Properties and Applications in the Building Industry," Polymers in Concrete, pp 378-396, May 1975, The Concrete Society, London.

Rigid polyester (UP) foams are materials which range from tough to brittle and are based on unsaturated polyester resins which cure as a result of copolymerisation after the addition of hardeners (organic peroxides) and possibly accelerators (tertiary aromatic amines and/or heavy metal compounds like cobalt, vanadium and other salts and complex compounds). The present study deals only with rigid UP foams, which are expanded by means of organic, chemically decomposable blowing agents. The basic principles, production, properties and applications of the Legupren system <sup>(R)</sup> are described.

A243 Kobayashi, K., and Ito, T., "Several Physical Properties of Resin Concrete," Polymers in Concrete, pp 236-240, May 1975, The Concrete Society, London.

The authors, with the object of applying resin concrete using unsaturated polyester resin for structures subjected to high stresses, made experimental studies mainly of dependencies of strength on temperature and loading rate, and of fatigue properties under repetitive compression loads.

As a result of study of several of the physical properties of resin concrete using unsaturated polyester resin, the following conclusions were obtained:

(1) The effect of temperature on compressive strength is that of strength being reduced more or less linearly in accordance with temperature rise in the range of 20°C to 100°C.

(2) Regarding the influence of loading rate on compressive strength, the evaluation as a percentage of the strength at loading rate of 0.25 MN/m<sup>2</sup>/sec is that it is about the same as for the case of cement concrete.

(3) The behaviours when approximately 2 million cycles of loading are applied may be considered to be roughly the same as for cement concrete. But when silane coupling agent is added at a rate of about 1 percent, the fatigue strength is greatly improved.

A244 Koblischek, P., "Synthetic Resin-Bound Concrete," Polymers in Concrete, pp 409-419, May 1975, The Concrete Society, London.

This paper reviews the synthetic resins that can be used as binding material for synthetic resin concrete.

In the author's opinion, use of a synthetic resin system of low viscosity is essential to meet the requirement for making synthetic resin concrete using conventional technology. This can be achieved by use of methacrylate resins.

Descriptions are given of products that have been specially developed using acryl-concrete, such as: kerbstones, facades, sanitary

articles, special lining stones, staircase units and electrically heated stairs, etc.

A245 Kukacka, L. E., et al., "Polymer Concrete for Repairing Deteriorated Bridge Decks," Polymer Concrete, Transportation Research Record 542, pp 20-28, 1975, Washington, D. C.

One of the most severe problems facing the highway industry is the rapid deterioration of highway structures. As part of a concerted effort to solve this problem, research is being performed to determine if polymer-concrete materials can be used for the repair of deteriorated and delaminated bridge decks. Polymer concrete consists of an aggregate mixed with a monomer, which is subsequently polymerized in place. It is mixed and placed by using techniques similar to those used for portland-cement concrete and, after curing, produces a high-strength, durable material. Process variables studied include monomer type, aggregate size distribution, and polymerization method. Field testing of polymer concrete has been in progress for almost 3 years, and to date deterioration has not been observed. One test on a major arterial highway in New York City has been in progress for 7 months.

A246 Kukacka, L. E., Mediatore, R., Fontana, J., Steinberg, M., and Levine, A., The Use of Polymer-Concrete for Bridge Deck Repairs on the Major Deegan Expressway, FHWA-RD-75-513, Jan 1975, Federal Highway Administration, and BNL-19672, Jan 1975, Brookhaven National Laboratory.

The practicality of using polymer concrete to repair holes in bridge decks has been demonstrated by the repair of two large holes in the Third and Lincoln Avenues Viaduct of the Major Deegan Expressway in New York City. Details of the repair are given in this paper.

A247 Kukacka, L. E., et al., "Concrete Polymer Materials for Highway Applications," BNL-50417, Progress Report No. 3, Sep 1975, Brookhaven National Laboratory, Upton, N. Y.

Experimental work on the use of concrete-polymer composites for highway applications has progressed in three general areas: material properties of polymer-impregnated concrete, the repair of deteriorated and delaminated bridge decks, and the partial in-depth impregnation of new decks. The structural and durability properties of impregnated normal weight and structural lightweight concretes have been measured. The effect of temperature and cyclic loading was investigated and bond pull-out strength of reinforcement measured. Process variables studied include monomer type, method of polymerization, and air content of the concrete. The feasibility of repairing highly deteriorated and delaminated bridge decks by monomer impregnation has been demonstrated and field testing is in progress. Results to date indicate that highly deteriorated concrete can be reconstituted and bonded to the sound concrete beneath. Compressive and shear strengths of 8000 and 1100 psi,

respectively, have been obtained. No deterioration of the repaired sections has been observed after exposure to traffic for 6 months.

A248 Kukacka, L. E., Auskern, A., and Fontana, J., "Polymer-Concrete Composites for Energy Related Systems," BNL-20336, Progress Report No. 5, Apr-Jun 1975, Brookhaven National Laboratory, Upton, N. Y.

Activities in research programs are reported on polymer-concrete materials for geothermal applications and in applications for solid nonradioactive waste incorporation in useful products.

A249 Makansi, I., and Reader, C. E. L., "Epoxy Water Slurry Mortars," Polymers in Concrete, pp 174-178, May 1975, The Concrete Society, London.

In an effort to reduce the costs of trowelled floors, a new type of epoxy trowelling compound has been developed in which water is used as a temporary diluent to assist application. The system is easy and fast to apply and can be made nonporous and decorative at a filler to binder ratio of 10:1. Mechanical and chemical resistance properties are good and mechanised application techniques appear to be possible.

A250 Naus, D. J., "Resin Bound Aggregate Material Systems," Jul 1975, Army Construction Engineering Research Lab, Champaign, Ill.

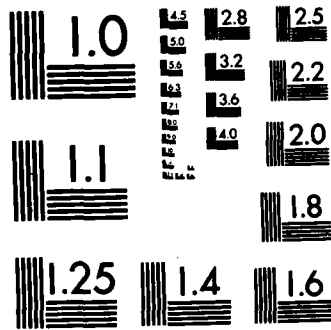
Data are presented on composition, strength, modulus of elasticity and thermal expansion for polymer concrete material systems. Resin systems included polyesters, epoxies, and vinyl esters. Fine and coarse aggregate fillers in volume fractions up to 0.85 were incorporated into the resin binders. Fiber reinforcement of various types, lengths, and contents was incorporated into several mixes. By a judicious selection of resin modifiers and filler materials a wide range of densities and strengths may be obtained. Material property data on coefficients of thermal expansion, bond strength, water absorption, and effect of elevated temperatures have been obtained.

A251 Nelson, C. A., "Application Developments of Concrete-Polymer Materials: A Summary Report," GR-3-75, Jun 1975, Division of General Research, Engineering and Research Center, Bureau of Reclamation, Denver, Colo.

This report summarizes the total application developments previously reported in detail in five referenced topical reports. It consists of five summary reports; the other four reports on the development of concrete-polymer materials, monomer and polymer studies, polymer technology, and structural properties. The program was initiated as a cooperative research and development program between the Bureau of Reclamation through Brookhaven National Laboratory and the Office of Water Research and Technology (part of the Office of Water Research and Technology) and the Office of Water Research and Technology, followed by other Government agencies.







MICROCOPY RESOLUTION TEST CHART  
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materials. Primarily three types of materials were studied: polymer-impregnated concrete (PIC), polymer concrete (PC), and polymer-cement concrete (PCC). Polymer-impregnated concrete (PIC) and polymer concrete (PC) both have improved properties which will enable them to be considered for use in many structural applications in the water resource development field. Polymer-cement concrete (PCC) may someday prove to be a good construction material; however, considerable research work on this material remains to be done. (13 ref)

A252 Ohama, Y., "Effect of Steam Cure on Strength of Polyester Resin Concrete (Polymer Concrete)," Journal of the Society of Materials Science, Japan, Vol 24, No. 260, May 1975, pp 408-410.

The objective of this study is to examine the possibility of applying steam cure to polyester resin concrete in the same manner as cement concrete.

Polyester resin concrete (polymer concrete) is mixed with variable catalyst or accelerator content for liquid resin in selected mix proportion, and the resin concrete specimens are prepared under various steam-curing conditions. The cured resin concrete specimens are tested for tensile and compressive strengths. The test results indicate that, in the catalytic system for ordinary temperature cure, the strength development of polyester resin concrete is accelerated by steam cure without noticeably harmful hydrolysis of polyester resin observed.

A253 Okada, K., et al., "Thermo-Dependent Properties of Polyester Resin Concrete," Polymers in Concrete, pp 210-215, May 1975, The Concrete Society, London.

Results of an experimental study to determine compressive and tensile strengths and static and time-dependent deformation properties of resin concrete using unsaturated polyester resin under various temperatures ranging from 5°C to 60°C are summarized as follows:

As unsaturated polyester resin is more dependent on temperature than cement, the mechanical properties of resin concrete are also largely affected by atmospheric temperature.

The factors influencing the thermo-dependent properties of resin concrete are the type of resin and resin content, as well as maximum size of aggregate.

Generally speaking, strength and modulus of elasticity decrease almost linearly when temperature rises from 5°C to 60°C. Creep deformation increases remarkably above a certain temperature. Below this temperature, creep deformation is almost proportional to the stress induced, and the apparent viscous flow observed is very small.

A254 Paturoev, V. V., and Alikulov, P. U., "Chemically Stable Polymer Concretes Based on Unified Carbamide Resin for Meliorative Construction," 1975, USSR.

The utilization of unified resin as a binder for polymer concretes made it possible to produce a material for pipes of a collection-drainage

network that is economical, nontoxic, and stable in the conditions of exploitation.

The use of polymer concrete pipes in conditions of mineralized ground waters is more economical than the use of reinforced concrete, ceramic, and polyethylene pipes of a corresponding size.

A255 Nutt, W. O., "Polymer Concretes: Report of A Concrete Society Working Party," Jan 1975, The Concrete Society, London.

In this volume, the uses of polymer in concrete are reviewed for engineers, covering polymer impregnation, additions of solid, water-soluble or dispersed polymers and resin-bonded aggregates in concrete with or without hydraulic cement. The effects of polymers on the rheology of the plastic mix, development of strength and properties of hardened concrete, including performance history, are discussed and an extensive bibliography is given.

A256 "Polymer Concretes - A Review," Precast Concrete, Vol 6, No. 4, Apr 1975, pp 189-190.

A critical appraisal of The Concrete Society report on polymer concretes (Polymer Concretes - Report of a Concrete Society Working Party, Technical Report No. 9) with particular emphasis on present and future applications of polymers.

A257 Popovics, S., "Polymer Pavement Concrete for Arizona - Study II," FHWA-AZ-RD-74-154, Mar 1975, Arizona Department of Transportation, Phoenix, Ariz.

The most important result of this investigation is the development of the addition of urea-formaldehyde combinations in the form of a monomer system to the mixing water of portland-cement mortars and concretes. Although the addition of this system to concretes produced only negligible strength increases, experimental data indicated that several combinations of the same system with mortars produced compressive strength increases of 1500 to 2500 psi.

It is not clear at this time why the urea-formaldehyde monomer system is effective in mortars and ineffective in concretes. Further investigation is needed to improve the effectiveness of this monomer system in concretes, too. The application of such a monomer system is also advantageous from economical standpoint because this is the least expensive form of the urea-formaldehyde combinations, and because the technology of such monomer systems in mortars and concretes is simple. Besides, despite the present ineffectiveness of the urea-formaldehyde monomer system in concretes, it still seems a significant breakthrough that the admixing of an unpolymerized urea-formaldehyde system increases considerably the strength of portland-cement mortars.

Several other directions were also investigated, such as the optimization of the basic urea-formaldehyde prepolymers, and several other chemical systems and commercially available polymers. Some of these systems did produce strength increases but these were not high enough.

A258 Popovics, S., "Cement-Mortar Experiments Concerning Addition of Water-Dispersible Epoxy or Furfuryl Alcohol Systems," Polymers in Concrete, pp 64-70, May 1975, The Concrete Society, London.

This paper presents the results of new laboratory tests on polymer-cement mortars containing two kinds of chemical systems, water-dispersible epoxy, and furfuryl alcohol with catalyst. Conclusions are as follows:

1. Fresh epoxy-cement mortars display a high degree of plasticity.
2. Hardened epoxy-cement mortars produce much higher strengths when they are dry-cured for a period of time.
3. The applied modification of the reaction between the two components of the epoxy seems to increase the mortar strength considerably.
4. Furfuryl alcohol-cement mortars, under the applied circumstances, do not produce as high strengths as the obtained optimum of epoxy-cement mortars.

A259 Prin, D., and Cubaud, J. C., "Polyester Polymer Concrete," Water Constr Water Struct, Vol 8, No. 46, Jul-Aug 1975, pp 291-304.

The investigation reported contributes to the development of a new material: a polyester polymer-concrete, and to its utilization in the manufacturing of a thin structure. Only polyester resins were used in the research. To develop the polyester polymer-concrete, its granular composition was considered. The mechanical properties are analyzed when the material is subjected to different boundary conditions, in terms of drying, catalysis, anti-shrinkage agents, characteristics of test-tubes, temperature, and time. In French with English abstract.

A260 Sasse, H. R., "Water-Soluble Plastics as Concrete Admixtures," Polymers in Concrete, pp 168-173, May 1975, The Concrete Society, London.

Parallel with the perfecting of classical concrete technology which has been attained appreciably within the last 20 years, a development has been seen in the use of plastics in order to improve certain undesired properties of fresh and hardened cement concretes. This paper is concerned with a part of this development, namely:

Plastics as a component material represent a constituent of the structure of the hardened cement paste, that means, they do not form a geometrically determinable "reinforcement," nor an inert "aggregate," nor a "coating."

The proportion of plastics in the concrete is low, namely less than 10 percent of the cement volume and generally less than 1 percent of the concrete volume.

The plastics are added to the fresh concrete at the mixing stage.

A261 Sommer, H., "Wear-Resistance of Resin Bound Mortar to Studded Tyres," Polymers in Concrete, pp 323-326, May 1975, The Concrete Society, London.

A traffic simulator was used as an accelerated laboratory testing method to evaluate the wear-resistance of a variety of conventional and epoxy mortars. Based on these test results, it was concluded that for repairing surface damage of concrete roads as a rule epoxy-mortars should be used, as they can be expected to give a wear-resistance equivalent to that of good road concrete after the cement mortar on the surface has been worn off. When using artificial hard aggregates instead of quartz-sand, the additional cost should be judged by the possible improvement of 20 to 30 percent at best.

A262 *Staynes, B. W., "Epoxide Resin Concrete as a Structural Material," Polymers in Concrete, pp 340-348, May 1975, The Concrete Society, London.*

The development of an optimum epoxide resin concrete mix, and the investigation of its fundamental properties and behavior, are described. Recommendations are summarized in the following:

1. Trial mixes should be used to establish all the mechanical properties of an epoxide resin concrete prior to its application.
2. Long-term creep tests on epoxide resin concrete should be instigated immediately for a range of potential epoxide resin systems likely to find structural applications.
3. A combined safety factor of not less than 2 is recommended. Therefore, a partial safety factor for material strength of 1.4 should be used where the dead load is over 50 percent of the total load.
4. Until experience has been gained in the practical application of epoxide resin concretes, the maximum stress under working load conditions should be limited to the specific creep transition stress. Relaxation of this requirement may be possible where creep is not a significant factor in the performance of the structure. In this case an adequate margin of safety should be provided against the discontinuity stress being reached.
5. Epoxide resin concrete is highly durable and it is considered that this quality will be an important factor in its adoption as a structural material.
6. Care must be taken in the selection of an epoxide resin system for a particular application, having regard to the performance of the epoxide resin concrete over the required temperature range. This requirement will limit the use of epoxide resin concretes.

A263 *Sun, P., et al., "Properties of Epoxy-Cement Concrete Systems," Proceedings, American Concrete Institute Journal, Vol 72, No. 11, Nov 1975, pp 608-613.*

Blended epoxy systems have been added to several different cement concrete mixes to improve the strength and durability of the cement concrete. In a standard mix having a water-cement ratio of 0.4, adding epoxy up to 20 percent by weight of the cement mortar gave no improvement in tensile or compressive strength values. However, when a second group of test specimens was prepared in which the amount of water was reduced as epoxy was added so as to maintain essentially constant slump, both

the tensile and compressive strengths were found to increase by over 90 percent for an added resin content of 15 percent. In a third series of tests, the cement-sand-aggregate ratio was held constant but the water was progressively replaced by the blended epoxy. For replacements over 50 percent, strength values increased noticeably and for specimens having water-cement ratio of 0.15 and epoxy-cement ratio of 0.52 the average tensile strength exceeded 1100 psi (77 kgf/cm<sup>2</sup>) and the average compressive strength exceeded 9000 psi (633 kgf/cm<sup>2</sup>).

A264 Suzuki, H., and Sugahara, S., "Fire Tests on Models Constructed of Resin Concrete," *Polymers in Concrete*, pp 306-311, May 1975, The Concrete Society, London.

In view of the fact that relatively little previous work has been conducted on the safety-evaluation of resin concrete or mortars under the action of fire, this paper, although not exhaustive, constitutes such a beginning but more work is necessary. It gives the results of fire tests of resin-concrete by using model units and reports an investigation into the combustion behaviour of resin-mortars with a view to improving fire resistance by adding Dawsonite as a fire-retardant agent.

A265 Sviklis, P. B., and Baturina, A. D., "Principle Results and Future Direction of Scientific-Research Work on the Use of Polymer Materials in Reclamation and Water Management," Translated from Russian, 1975.

The main factors determining the great technical efficiency and economical use of polymers in land reclamation are the notable reduction in labor costs both for construction and operation of water management structures and reclamation systems; reduction in construction time due to improvement in the technology and organization of the construction work, especially under unfavorable climatic and hydrogeological conditions; more efficient use of water and land resources as well as capital outlay; increase in the general level of technical knowledge; and improvement in working conditions during construction and operation of reclamation systems and water management projects.

Scientific-research work on the use of polymer materials in reclamation and water management has been conducted by a number of institutes in this field in various areas of the country. The main directions for the investigations are:

Invention of new modifications and compositions of polymer materials and improvements in and development of polymer products to meet the needs of reclamation.

Study the effectiveness and durability of products made from polymer materials under actual operating conditions of reclamation systems.

Development of machines and construction technology of reclamation systems for use of polymers.

Analysis of economics problems and prediction of the use to be made of polymers in reclamation and water management.

As a result of the creative cooperation among the scientists,

reclamation engineers, and chemists, products made from polymer materials for irrigation and drainage systems and farm water supply systems have been developed and introduced into use.

A266 *Teichmann, H., "Polymer Dispersions for Cement and Concrete," Polymers in Concrete, pp 112-124, May 1975, The Concrete Society, London.*

The requirements for satisfactory polymer dispersions are discussed and their advantages are described.

The adhesive strength can be increased most effectively by means of dispersions. The flexibility has the effect of increasing the tensile strength in flexure of cement mortars. The workability and plasticity of such mixes can also be improved. By means of a suitable auxiliaries system, e.g., a special emulsifier, the mortar can be rendered more workable, can be liquefied, thus reducing the amount of water required. This in turn results in an increase in strength and particularly in compressive strength. An amazing increase in the abrasion resistance can also be obtained using special acrylic copolymers.

In addition to their use as binders for bonding new to old concrete, polymer dispersions are also used as modifying agents in mortars for patching work, levelling courses, abrasion-resistant industrial floorings which have to be virtually resistant to oil and chemicals. Polymer dispersions are also just as important for use in jointing compounds and renderings, and for fitting of ceramic articles.

A267 *Tokumoto, M., "A Study on Drying Shrinkage of Cement Mortars with Acrylic Polymer Emulsion," Journal of the Society of Materials Science, Japan, Vol 24, No. 259, Apr 1975, pp 314-319.*

The drying shrinkage of cement mortars modified by polymer emulsions except polyvinyl acetate emulsion is generally known to be lower than that of unmodified cement mortars. The drying shrinkage depends on the polymer composition and content.

The first part of experiments were performed to determine the drying shrinkage of cement mortars modified with polyethylacrylate. The results used to discuss the relationships between the drying shrinkage and the polymer-cement ratio, water-cement ratio at a constant polymer-cement ratio and the evaporative water loss.

The second part of experiments were performed to study the drying shrinkage of mortars with acrylic polymers or copolymers having various glass transition temperatures.

The main results are as follows:

(1) The cement mortars modified with polyethylacrylate were observed to expand during the initial period of curing, the magnitude of expansion depending upon the polymer-cement ratio, cement-sand ratio, and humidity of curing.

(2) The close relationship between the drying shrinkage of cement mortars with acrylic polymer or copolymer and the glass transition temperature of polymer was noticeable.

(3) The very low drying shrinkage of cement mortar could be



obtained by the modification with acrylic polymer or copolymer having very low glass transition temperature.

A268 Valore, R. C., Jr., and Naus, D. J., "Resin Bound Aggregate Material Systems," Polymers in Concrete, pp 216-222, May 1975, The Concrete Society, London.

This study was conducted to determine the effect of constituent materials on polymer-concrete properties, and to develop data for evaluating the feasibility of "tailor-making" polymer-aggregate mixtures with a wide range of predictable strength, density, and stiffness properties.

A269 Vekey, R. C., and De Majumdar, A. J., "Durability of Cement Pastes Modified by Polymer Dispersions," Materials and Structures, Research and Testing, Paris, Vol 8, No. 46, Jul-Aug 1975, pp 315-321.

The time-dependence of some of the properties of portland cement pastes modified by several polymer dispersions has been investigated up to one year and two curing conditions: (a) in air of 65 percent relative humidity at 20°C, and (b) immersed in water at 20°C. Five different classes of polymer have been tried so far: polyvinyl acetates, polyvinyl propionates, butadiene styrenes, polyvinylidene dichlorides, and acrylics. Two or more examples of each type of polymer have been incorporated into cement to produce pastes with a polymer-to-cement ratio of 0.1 and water-to-cement ratios of 0.3 and 0.5.

The density and elastic properties of the pastes have been measured nondestructively and strength values have been determined using a universal testing machine. Attempts have been made to correlate the results of this comparative study with data on the reactivity of the polymers towards alkalis.

#### 1976

A270 Aleinikov, C. M., Moiseev, V. I., and Paniushkin, A. V., "Polymer Anti-Ice Coatings," Third All-Union Scientific and Technical Conference On the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Polymer coatings which reduce the adhesion of ice represent an outstanding means of protecting surfaces from ice formation. These coatings are anti-ice systems of the physicochemical type, whose mechanism is based on the weak interaction of water (in both the liquid and solid states) with surfaces which have a low value of specific free surface energy. The authors have developed a rational method of making solid polymer coatings with a low value of free surface energy and low ice adhesion.

The contact angle (for wetting with water) of the coatings which was developed is as high as 158°; the magnitude of ice adhesion is

reduced by a factor of 10 (as compared with the paint or varnish coatings which are usually used).

A271 *Babaev, M. G., and Akorov, V. A., "Experience in Using Asphalt Concrete Revetments in the Karakum Canal IM. V.I. LENIN," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

The extensive development of hydraulic engineering construction and water-development construction in the Turkmen SSR has strongly emphasized the necessity of installing waterproof canal revetments.

Under the conditions in our country, revetments made of monolithic cement concrete and precast reinforced concrete have not been able to provide long-term resistance to seepage for the overlays as a whole. This is due to difficulties in maintaining newly laid concrete in a hot dry climate, substandard installation of expansion joints, and the shortage (and high cost) of installation equipment.

Experience in constructing revetments made of asphalt concrete along a 28-kilometer section of the Kopetdagskii main distribution canal of the Karakum canal has allowed us to identify a number of advantages of asphalt concrete revetments over revetments made from portland-cement concrete. If properly designed and constructed, asphalt concrete revetments are waterproof, strong, long-lasting, and economical. The flexibility and plasticity of this material guarantees crack resistance even with large temperature fluctuations and dynamic seismic oscillations.

A272 *Berman, G. M., and Zabusova, E. A., "Polymer-Concrete and Polymer-Mortar Revetments for Special Coverings of Reinforced Structures of Nuclear Power Plants," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

Certain reinforced concrete structures in nuclear power plants must be resistant to corrosion. New materials, new technical designs, and new technology are needed for providing this corrosion resistance because of the shortage of stainless steel, the complexity of multilayer paint-and-varnish coatings, and the labor-intensive nature of building protective revetments from these materials.

One solution to the problem of replacing stainless steel is the use of polymer-concrete and polymer-mortar revetments of the monolithic type and of the precast type. The precast type includes polymer concrete, reinforced polymer concrete, large-scale reveting elements, as well as two-layer precast reinforced concrete structures with polymer concrete in the zone of greatest force and corrosion effects. These are used to make shielding elements impermeable (bottoms of tanks and cells, sumps, water traps, tanks for liquid waste storage).

This work treats the following: the processing of compositions,

research on their physicomechanical properties, corrosion resistance, radiation resistance, and the decontamination properties of polymer concretes and polymer mortars based on an epoxy/coal-tar binder and a furfural acetone binder.

- A273 Berman, G. M., and Taldenkova, E. N., "Protective Polymer Coatings for Reinforced Concrete Structures of Power Installations," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Our experimental work included the development of compounds for protection of concrete and prestressed high-strength wire in the reinforced concrete structures of power installations.

The following resins served as film-formers: ED-20 and ED-16 epoxy-diene, EIS-1 alkyl resorcinol, and FAED-20 epoxy-furan.

The systems were modified using various types of rubbers: NVB-2 Thiokol and the SKN-10-1, SKN-18-1, and PDI-3A nitriles.

Paint and varnish systems made with the petroleum distillate give only hard coatings; elastic coatings may be obtained with toluene and 646 solvent with the appropriate modifier.

The rheological properties of the paint and varnish systems which have been developed were investigated. The functional dependences of the creep rate on the shear stress which were observed characterize the systems as being pseudoplastic.

- A274 Borisov, G. V., and Uspenskii, V. V., "Mechanization of the Construction of Asphalt Concrete Shields for Industrial Effluent Tanks," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Research conducted at the B. E. Vedeneev VNIIG has resulted in the development of a technology which anticipates complex mechanization of the entire process of constructing asphalt concrete shields. Thus, a technology based on mass-produced highway machinery was developed for constructing asphalt concrete shields on the bottoms of industrial effluent tanks, and the use of both mass-produced and specialized machinery for reveting the sides of the tanks was foreseen. Attention was focused on execution of the key industrial operations involved in shield installation: emplacement and compaction of the asphalt concrete on the sides of the basins.

- A276 Butakov, A. A., Orlov, B. N., and Bukatova, "Restoration of the Concrete of Hydraulic Engineering Structures Using Epoxy Compounds", Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification 1976.

Under conditions in Siberia, failures in the concrete of hydraulic engineering structures are such that there is a necessity for repair and restoration work 10 to 15 years after the structure has been put into operation. This is particularly true in the zone of variable water level.

The traditional methods of concrete repair (plastering with cement-sand mortars, fixing flaws with concrete, shotcreting) do not produce reliable results.

Recently, thermosetting polymer resins, including epoxies, have come into wider use for restoration of concrete.

The fast hardening rate of epoxy compounds allows repair time to be reduced significantly. In addition, their high adhesion to concrete and their high water resistance and frost resistance permit the interval between repairs to be increased significantly.

Investigations conducted had the following goals: improvement of the physical and mechanical properties of the hardened mixtures (by modification with various materials) and development of epoxy compounds which harden at low and below-zero temperatures. The effect of accelerators on the hardening rates and properties of the compounds was studied. Surfactants were added to the epoxy compounds for more successful application to moist or wet concrete and for better adhesion to it. The effect of surfactants on the properties of the hardened compounds was studied.

A277 Causey, F. E., "Initial Study of Vinyl Ester Polymer Shotcrete," Technical Report GR-1-77, Dec 1976, Bureau of Reclamation, Denver, Colo.

A limited study of vinyl ester polymer concrete was conducted to investigate its potential for shotcrete application. Polymer shotcrete is applied using modified conventional shotcrete equipment, but differs from conventional shotcrete in that a polymeric binder is used in lieu of portland cement and water. The polymer-shotcrete application was partly successful, but further work is needed to improve mixing of materials at the nozzle of the gun. Vinyl ester shotcrete cures in 5 to 10 min for a rapid cure system after application, develops full compressive strength ranging upwards to 92 MPa (13,400 lb/in.<sup>2</sup>) upon curing, and could have potential applications in areas in which these properties would offer definite benefits over conventional shotcrete. Polymer shotcrete requires that certain safety precautions be taken to assure safe use.

A278 Deanin, R. D., "Plastics in Building: Present Status and Future Prospects," 1976, Plastics in Buildings Division, Stamford, Conn.

This volume contains proceedings of 17 papers delivered at the meeting. Among others the following topics are covered: precast polymer concrete; cumylphenol derivatives and titanium coupling agents improved construction materials; large-scale fire tests and plastics products; fire hazard of plastics foams in buildings; thermal barrier tests for urethane foam insulation; creep of plastics used in buildings;

elastomeric roofing; plastics shelter for slum clearance in poor countries; use of extruded rigid PVC profiles in low-cost housing; new design concepts for plastics in housing. Building codes and regulatory trends. Some contributions are accompanied by bibliographic data. Each paper is abstracted and indexed separately.

- A279 Dymant, A. N., Romanov, V. I., et al., "Polymer Coatings for Increasing the Waterproofness of Concrete in High Arch Dams," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Waterproofing of the upstream faces was required in order to increase the waterproofness of the 230-meter concrete dam of the Chirkeiskaia hydroelectric power plant and the 300-meter concrete dam of the Inguri hydroelectric power plant. It has been established that the greatest technical and economic effectiveness can be achieved by using epoxy-rubber systems as the coatings. Depending on the construction zone and time interval, the amount of rubber in the system can vary from 25 to 100 parts (by mass) per 100 parts (by mass) of epoxy resin.

The sealing of the upstream face of the Chirkeiskaia HEP concrete dam is almost complete at this time; the 32,000 m<sup>2</sup> of sealing required before flooding the reservoir was accomplished within two months. Application of the epoxy coatings was a mechanized operation: spraying was carried out using self-propelled buckets and single-deck and multideck scaffolding.

- A280 Elshin, I. M., Abduzhubarov, Kh. S., and Mamatov, Iu. M., "Polymer Concrete Based on FAED-20 Resin," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

New materials for contemporary hydroeconomic construction must meet certain requirements (strength, abrasion resistance, cavitation resistance, etc.). An example is the construction of hydraulic works on alpine rivers, where the indicated requirements must be met by the reveting materials (chill-cast iron, wood, granite slabs, and steel). In the last decade, polymer concretes based on epoxy and furan resins have come into wider use in these applications.

We have formulated compositions with a 10 to 90 percent epoxy resin content. The surfactant additives for these binders were quaternary ammonium salts of alkyl benzyl dimethyl ammonium chloride (ABDM). The effectiveness of adding a surfactant during resin synthesis was demonstrated. The optimum composition was established to be 20 percent epoxy and 80 percent furan resin. We developed polymer concrete mixes based on the resins synthesized. A composition with 20 percent ED-5 is the most favorable component ratio for the furan-epoxy resins.

A281 Elshin, I. M., Reznik, V. B., and Koretskii, V. P., "Precast Polymer Concrete Revetments for Protection of Hydraulic Structures from Abrasion By Detritus," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

The usual materials for protection of hydraulic structures from impact abrasion by bottom detritus are cast iron, steel, natural rock, and wood. In addition to these, polymer concretes based on FA monomer have been used for the last 10 to 12 years.

The advantages of this material for hydraulic construction have been demonstrated by experience in the installation of monolithic revetments in a number of structures and by observation of the in-use condition of the coatings. Its disadvantages have also been revealed: Slide-off of the mix reduces coating quality on the sloped portions of spillways; the technology of operations is significantly complicated by unfavorable weather conditions, and labor costs increase.

The first applications of precast polymer concrete revetments in hydraulic construction practice were made by the UkrNIIGiM on the Gavasai hydraulic development in 1973 in the Uzbek SSR (650 m<sup>2</sup>) and on the Bashariu water supply in 1975 in the Azerbaidzhan SSR (220 m<sup>2</sup>). Cast iron revetments would have cost 2 to 2.5 times as much.

A282 Elshin, I. M., et al., "The Role of Fillers in the Structure and Strength of Polymer Concrete Based of Furfural Aceton Monomer," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Other things being equal, the mineralogical and petrographic properties of finely dispersed fillers play a special role in determining the structure and strength of polymer concrete. The addition of these materials to the polymer concrete composition can have favorable or unfavorable effects on the structure and the strength properties of the concrete.

Electron micrographs of polymer with various mineral fillers have revealed a globular supermolecular structure; the size of the globules depends on the nature of the filler.

In the case of a filler made from obsidian, amphibole, andesite, or granite, there is poor contact at the interface; the polymer structure at the interface is the same as it is in the bulk of the polymer.

In the case of a filler made of quartz or feldspar, there is good contact at the interface; the fact that there are no globules is explained by increased adsorption, which leads to an increase in the rigidity of the macromolecules and a more brittle packing structure.

The internal stresses of these systems were measured using the optical polarization method; stresses were decreased in the case of the granite filler and increased in the cases of the other fillers, particularly quartz and feldspar.

The structures which have the greatest strength are those in which the internal stresses are minimal but the adhesion strength is high. For the systems under consideration, this optimum is obtained when quartz or feldspar is used with small amounts of graphite.

A large effect is observed even in systems in which polymer concretes are prepared with quartz sand and a graphite powder additive. Polymer concretes of this type have higher strength and higher resistance to water, frost, abrasion, etc.

A283 Gokhman, L. M., and Davydov, K. I., "The Use of Heavy Solvents in Making Asphalt Polymer Concrete with Divinylstyrene Thermosetting Elastoplastic," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

It is possible to make highway bitumens elastic at low temperatures and heat-resistant at high temperatures by mixing them with polymer substances such as thermosetting elastoplastics, particularly divinylstyrene thermosetting elastoplastic (DVSE).

The polymer-bitumen binder (PBB) is made by adding small amounts (2 to 2.5 percent) of DVSE (dissolved in hydrocarbon solvent) to the bitumen.

The aromatic solvents which were tested under production conditions (Solvent, xylene and benzine), and which were recommended earlier by us for preparation of PBB can be used under production conditions. However, they are characterized by a sharp odor (xylene, Solvent) or they present a fire hazard (benzine) with the existing equipment in an asphalt-bitumen plant (ABZ).

When large volumes of PBB are used, the indicated disadvantages may seriously inhibit use of this material in highway construction.

Therefore, it was necessary to select solvents and the conditions for dissolving the DVSE which would insure fire safety during preparation of the PBB and PBB-based asphalt-concrete mixtures, and to reduce the toxicity of the PBB.

The investigations (and a production test) allowed us to select heavier solvents which satisfy the above requirements: winter diesel fuel, summer diesel fuel, kerosene, and TS-1.

A284 Gegeliia, D. I., "Ways to Increase the Long-Term Water and Frost Resistance of Asphalt Concrete," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

One of the main causes of premature failure of asphalt concrete overlays is inadequate resistance of the asphalt concrete to water and frost. These properties are especially important for the asphalt concrete mixtures used in hydraulic engineering construction. In addition to the destructive effects caused by penetration of polar water molecules through the bitumen films and exfoliation of bitumen from the

mineral component of the material, intensive destruction of asphalt concrete is also caused by the freezing and expansion of water in the pores, which creates significant pressures. The diffusion of water molecules through the bitumen film to the bitumen-mineral interface is a secondary process; it is preceded by the primary process of water penetration into the pore spaces of the asphalt concrete.

Therefore, the most effective means of increasing the long-term water and frost resistance of asphalt concrete are to control the structural formation of the pore space and to strengthen the structural bonds. Research done at the Soiuzdornii has shown that these means, which mutually augment each other, permit the production of a material with adequate water and frost resistance. A very great improvement was achieved by using a surfactant and activated mineral materials in the asphalt concrete.

A large body of experimental research on the seepage properties and the pore space of asphalt concrete was done at the Soiuzdornii. This research yielded a new classification principle for asphalt concrete based on all its porosimetric properties. This approach allowed us to select asphalts with an abundance of fine, compacted pores and with high water and frost resistance from a wide spectrum of asphalt concrete mixes without having to use special methods. The basic results of our research on improving the long-term water and frost resistance of asphalt concretes are reflected in the new standard for asphalt concrete (GOST 9128-76: "Highway and Airport Asphalt Concrete Mixes and Asphalt Concrete") which will be put into effect on January 1, 1977.

A285 Hartwig, G., and Weiss, W., "Die Thermische Ausdehnung von Pulvergefuellten Epoxidharzen" (in German), Materials Science and Engineering, Vol 22, 1976, pp 261-264.

The thermal expansion of powder filled epoxy resins - mainly determined by the thermomechanical parameters of the components - is influenced by thermal stress arising between filler and epoxy matrix. Also, the shape of the filler may play a part. On the basis of models the coefficient of thermal expansion is calculated as a function of the filling factor taking into account the thermal stress distribution. A comparison with experimental results is given in Part 2 of this paper.

A286 Hoge, J. H., Discussion of paper "Properties of Epoxy-Cement Concrete Systems," Sun, et al., Proceedings, American Concrete Institute Journal, Vol 73, No. 5, May 1976.

From the description of the epoxy concretes tested, it appears that the epoxy used was a conventional polymer rather than one of the recently developed latex-types which are compatible with water either by predilution or when dispersed in concrete mixes or cement pastes. In view of the present prices of epoxy resins, the quantities required to produce significant improvement in the mechanical properties of concrete are prohibitive compared to the cost-effectiveness of other approaches. Using the mix proportions of the A and C series, for example,  $f'_c$  of 10,000 to 11,000 psi and  $f'_t$  of 1100 psi can be obtained



using about \$5 worth of water-reducing agent to attain 4- to 5-in. slump at a water-cement ratio of 0.29, compared to the cost of around \$300 for the epoxy loading indicated in the report.

By another approach, using alkali resistant glass fibers, equal or better results can be obtained for about \$35 extra cost per cubic yard.

A287 Igonin, L. A., "The Use of Polymer Mortars in Construction - Research and Practical Experience," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Research has indicated that epoxy compounds can be used effectively for various construction tasks; in particular, it can be used for bonding the following materials: concrete, steel reinforcement, and reinforced concrete.

High-filling epoxy compositions were developed which are suitable for preparing so-called redistributing and adhesive spacers, and their technical properties were investigated. The purpose of this was to simplify the technology of making monolithic concrete in reinforced concrete designs. This new technology has been used in the construction of thermal electric power stations.

The technology for injecting epoxy compounds is being used successfully for filling cracks in concrete at a number of heat and electric power stations, and at other installations. It is also being successfully used for making narrow monolithic seams in the joints of precast reinforced concrete designs in the construction of heat and electric power stations.

Comprehensive research was done on the use of epoxy compounds for improving the strength of adhesion of rod-type reinforcement to concrete and for weld-free butt-joining of reinforcement rods and of precast reinforced concrete. Epoxy compounds suitable for these applications were developed and investigated, and the technical features of the designs which use these compounds were determined.

The research suggests that the strength of adhesion of new concrete to reinforcement can be improved by preliminary application of a layer of epoxy compound to the surface of the reinforcement (a so-called adhesion coating). There is also the possibility of full-strength adhesive bonding of steel reinforcement in old concrete. It has been shown experimentally that, in order to realize full-strength (based on the yield point of the reinforcement) adhesive anchoring in concrete, it is necessary to guarantee the following:  $l_a \geq 3.5 d_a$  for Class A-II reinforcement, and  $l_a \geq 4.45d_a$  for Class A-III reinforcement (where  $l_a$  is the calculated length of the adhesive anchoring of the reinforcement in the concrete, and  $d_a$  is the calculated diameter of the reinforcement which is being anchored).

The technology which has been developed for adhesive anchoring of reinforcement in concrete was successfully applied at the Plyabin'skii GES: 160 anchors (diameter 40 mm) were installed for mounting steel

plates for 20 additional turbine servomotors. This technology was also used successfully for repairing damaged concrete of a spillway at the Bratsk GES.

We investigated the fundamental properties of adhesive bonding of rod-type reinforcement and the fundamental properties of adhesive joints of precast reinforced concrete elements; the designs inspired by this research were also investigated.

Experimental work which estimates the effects of short-term, repetitive, and continuous loads indicates that full-strength joints of the above types can be realized.

**A288 Igonin, L. A., et al., "Increasing the In-Use Efficiency of Reinforced Concrete Structures with the Aid of Epoxy Polymer Mortars," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.**

The performance of nonprestressed girder slabs with sheet reinforcement was investigated. The purpose was to study the possibility of using reinforced concrete structures with bondable sheet reinforcement.

Of the various methods of reinforcement bonding which involve adhesives, the two which are most efficient technologically, and which satisfy the imposed requirements, are the method of adhesive anchoring in a metal box coupling (the adhesive-coupling reinforcement joint) and the method of adhesive anchoring in the tothing of a reinforced concrete element (the adhesive-tothing reinforcement joint).

A high-filling epoxy polymer mortar was used to make monolithic joints. The composite slabs and the control slabs were subjected to bending tests 7 to 9 days after making the monolithic joints. A load was applied in the form of two forces localized at the quarter spans.

Our research was used as the basis of design developments and the erection of an experimental fully-prefabricated reinforced-concrete reservoir (volume = 100 m<sup>3</sup>) with adhesive joints for the wall panels.

The results of our tests showed that designs of this type have significant advantages; this is true for a whole class of structures which must simultaneously have high construction qualities and insulation from corrosive factors (tunnels, special underwater and floating structures, etc.). An investigation of similar structures in the USSR (Leningrad, L/vov) and abroad (France, East Germany) shows that this is a promising line of development.

**A289 Ironman, R., "Resin Concrete Enjoys Rapid Growth," Concrete Products, Vol 79, No. 10, Oct 1976, pp 36-38.**

While the European precasting industry continues to suffer under serious recession conditions, one field is noting record growth. This is in the use of resin concrete.

There are several reasons for this present general acceptance: improved equipment has led to much faster production (between 2- and 30-min curing times are now normal, with most products taking less than

10 min), and finishes have reached an amazingly beautiful standard (many products are now indistinguishable, for example, from natural marbles).

The boom is also very noticeable in equipment exports, particularly to the Middle East and developing countries where start-from-scratch conditions prevail, and yet high quality products can find a ready market. This paper looks at some of the developments of this product.

A290 Kasatkin, I. N., "Some Properties of Poured Asphalt Concretes and Mortars Which are Important During Construction and In Service," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Until recently, the use of poured asphalt concretes and mortars in domestic industry and hydraulic engineering has been limited to a low-volume application: the installation of poured waterproofing. Its specifications are essentially based on specifications worked out in the 1940's for poured asphalt concretes for highways. Now, there is increased interest in poured asphalts for hydraulic engineering applications. The main areas of application of these materials are as follows: asphalt dam cores, shields, and reinforcements made by pouring asphalt over rocks (also under water).

Thus, we are compelled to reinvestigate these materials and to raise the level of mechanization involved in executing designs made from them. We have now studied the following things in adequate detail: the preparation and transportation of poured asphalt concretes and mortars, their behavior in structures during the construction period and the use period, and the conditions under which they retain their properties when poured under water. We have also drawn up preliminary specifications for standardized indices of their properties.

A291 Khasin, B. F., Segal, M. S., and Sigaliva, L. S., "The Service Life of Polymer Materials Used for Seepage Control in Hydraulic Engineering Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

It is essential to predict the service life of polymers used for seepage control in hydraulic engineering structures. Type 15303-003 polyethylene (PVD) and EKT-02 (a modified epoxy-rubber compound) were used in this investigation. Creep testing under static load ( $\sigma = \text{constant}$ ) was conducted over the course of 100, 300, 600, 1,000, and 10,000 hr to determine the stresses permissible during the given service life; subsequent final destruction occurred after being held under load. The stresses ( $\epsilon = \text{constant}$ ) at relaxation were determined. Dynamic thermal gravimetric analysis (TGA) in air and in a vacuum was used to determine the initial activation energy of the failure process. The safe (allowable) stress  $[\sigma]$  was determined by the maximum deformation

criterion  $\epsilon_{\max}$ . This was done using a linear model of viscoelasticity and a nonlinear model.

The calculation yielded the values of the creep deformation at various stresses over a 10-yr range. This allowed the values of  $[\sigma]$  (2.05 MPa and 2.25 Mpa for  $\epsilon_{\max} = 20$  percent and 50 percent, respectively) to be determined. These figures are also confirmed by the results of final destructive testing.

A292 *Koretskii, V. P., "The Service Life of the Protective Polymer-Concrete Revetments of Hydraulic Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

As a result of on-site inspection of a number of hydraulic structures with furan polymer-concrete revetments, it was established that the service life of the overlay is a function of a number of factors. These factors may be divided into two classes: controllable and uncontrollable.

The controllable factors are the strength and porosity of the polymer concrete, the hardness and degree of polymerization of the polymer binder, the strength of the aggregates, and the percentage of acid-resistant rock in the aggregates.

The uncontrollable factors are the rate of water flow, the volume of the bed load and its average fineness, the time (per year) during which the revetments are dried (by solar irradiation), and the time (per year) during which therevetments are exposed to water. This paper describes both practical and theoretical parameters studied.

A293 *Korolev, I. V., "Controlling the Structural and Mechanical Properties of Asphalt Concrete," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

The properties of asphalt concrete can be controlled by adjustment of the following interrelated factors: the gravel, sand, and mineral contents of the mixture, and the viscosity of the bitumen which is used. The presence of the binder in the contact zones of the mineral grains causes adhesion forces whose magnitude depends on the surface properties of the granular material and the properties of the binder. Maximum strength is obtained at the smallest film thickness which can preserve uniformity during the high-temperature production process and uniformity during use at below-zero temperatures. This paper describes tests taken to optimize the properties of asphalt concrete by the above procedures.

A294 *Kudoiarov, L. I., and Popchenko, S. N., "Investigations of Polymer Materials for Hydraulic Engineering Construction and Outlook for Their Development in the Tenth Five-Year Period," Third All-Union*

Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

The decisions of the 25th Congress of the Communist Party of the Soviet Union anticipate an increase in the industrial output of new polymer materials by a factor of 1.7 to 2.2; this raises new prospects for their widespread use in hydraulic engineering.

New materials for waterproofing and heat insulation have been created for hydraulic structures made of concrete. These materials are based on modified epoxy resins and bitumen-polymer systems; for regions with inclement climatic conditions a heat-insulation/waterproofing complex has been developed on the basis of asphalt-lightweight concrete and foamed epoxides. There is a need for widespread adoption of these waterproofing systems, along with development of procedures for comprehensive mechanization and industrialization of operations - in particular, the creation of industrial designs for protective enclosures providing heat insulation and waterproofing. The outlook for the use of concrete elements impregnated with organic binders and polymers (polymer-impregnated concretes, PIC) should be emphasized. Seepage control in concrete dams is of special significance.

This research has established that cavitation and abrasion-control coatings based on polymer materials can be widely used in hydraulic engineering construction. The most effective coatings are based on modified epoxy resins, furan polymer concretes, and polymer-impregnated concrete. More work is needed to perfect these materials and to effect wider assimilation of them by hydraulic engineering practice. The investigations have also demonstrated the effectiveness of colloidal cement mortars (CCM) and colloidal polymer-cement mortars (CPCM) in protecting concrete structures exposed to intensive mechanical action. Also, these materials can be used successfully to repair the concrete in hydraulic structures, just as can polymer concretes.

A295 Kukacka, L. E., "Use of Concrete Polymer Materials for Bridge Deck Applications," BNL-21340, Apr 1976, Brookhaven National Laboratory, Upton, N. Y.

The rapid deterioration of concrete bridge decks as a result of the increased use of deicing salts is one of the most severe problems facing the highway industry today. One possible solution to the problem is the use of concrete polymer materials. The materials of prime interest are polymer-impregnated concrete (PIC) and polymer concrete (PC), both of which have excellent durability and strength properties. Three potential applications: repair of deteriorated bridge decks, polymer impregnation of new bridge deck surfaces, and full impregnation of precast deck panels have been studied in laboratory and field tests and the results have been encouraging. These results and economic considerations are described in the paper. The work in each of the areas is currently being implemented by the Federal Highway Administration.

A296 Kukacka, L. E., Zeldin, A., Fontana, J., and Carciello, N., "Cementing of Geothermal Wells," BNL-50621, Progress Report No. 3, Oct-Dec 1976, Brookhaven National Laboratory, Upton, N. Y.

A coordinated program for the development of improved cements specifically designed for geothermal well applications was started in April 1976. Since that time an assessment of the state of the art of well cementing has been made, a management plan prepared, and research on polymer cementing materials started. Plans to initiate research to develop inorganic cementing materials are being implemented. Work accomplished during the period 1 October-31 December 1976 is described in the current report.

A297 Kukacka, L. E., "Alternate Materials of Construction for Geothermal Applications," BNL-50594, Progress Report No. 10, Jul-Sep 1976, Brookhaven National Laboratory, Upton, N. Y.

A program to determine if concrete polymer materials can be utilized as materials of construction in geothermal processes has been in progress since April 1974. Since that time high temperature polymer concrete formulations have been developed, laboratory tests performed in simulated geothermal environments, field testing initiated at four geothermal sites, and economic studies started. Laboratory data for exposure times greater than 1 year are available and field test results have been obtained for 180-day exposures to dry steam, flashing brine, and hot water. Good durability is indicated. Work accomplished during the period 1 July to 30 September 1976 is described. (ERA citation 02:045321)

A298 Kukacka, L. E., et al., "Alternate Materials of Construction for Geothermal Applications," BNL-50627, Progress Report No. 11, Oct-Dec 1976.

A program to determine if concrete polymer materials can be utilized as materials of construction in geothermal processes is in progress. Work accomplished during the period 1 October-31 December 1976 is described in the current report.

Significant improvements in the thermal stability of polymer cement lining materials have been made by the use of chemical additives and by increasing the amount of portland cement in the aggregate. An optimum aggregate composition of 50 percent sand-50 percent cement has been determined.

A299 Maisuradze, L. A., "Polymer Sealants for the Expansion Joints of Hydraulic Engineering Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Expansion joints are critical elements of structures. They are installed to avoid significant internal thermal stresses and stresses

due to environmental temperature changes. The problem of creating a waterproof joint has always required a search for materials which effectively provide reliability and longevity of the structures in which they are used. Experience in the construction and use of hydraulic engineering structures shows that such traditional materials as bitumen, oakum, tar, etc., do not always answer modern construction requirements. Thus, new problems are posed in the development, installation, and use of polymer materials.

The GruzNIEGS has investigated the usefulness of polysulfide, organosilicon, and other polymer materials for sealing the expansion joints of hydraulic engineering structures.

As a result of this work, the following facts were established:

1. The strength and deformation parameters of the sealant which is based on KM-0.5 Thiokol mastic exceed the requirements. Moreover, the adhesion properties improve when a primer (epoxy glue) is used, and remain stable after exposure to water, temperature, and freezing and thawing.
2. Sealants based on SKT-N rubber have high strength parameters and low specific elongation.
3. Porous rubber based on SKT-N has a high water-resistance coefficient, low strength parameters, and a low elastic recovery value.
4. Single-component sealants of the type VGO-1 and 11-6 are not suited for hydraulic engineering construction because of their low water resistance and weak adhesion to concrete.
5. The thermosetting elastoplastics 14 TEP-1 and 14 TEP-4 are characterized by high water resistance and weatherproofness, and they have good adhesion to concrete independently of surface conditions (dry or humid) and storage conditions.

An economic analysis comparing traditional and polymer materials as joint sealants has demonstrated the expedience of using the latter. This is especially true because polymer materials tend to increase the longevity of structures, and are highly developed construction materials.

A300 Manson, J. A., "Modifications of Concretes with Polymers," Materials Science and Engineering, Vol 25, 1976, pp 41-52.

Within the past few years, many investigators have developed new composites based on various combinations of polymers with concrete, from polymer-impregnated materials to concretes in which polymers are used to bind an aggregate together. While many developments have occurred, technology has tended to outstrip basic scientific and engineering understanding. For sophisticated design much knowledge about these composites, which have seldom been treated as such, is required. Areas of uncertainty are therefore reviewed and discussed.

A301 Manson, J. A., and Sperling, J. H., Polymer Blends and Composites, Plenum Press, N. Y., 1976.

For convenience, the monograph is divided into four parts. The first, Chapter 1, relates to homopolymers, and gives the reader a brief glimpse at the basic structures and properties of polymers. The second

part, Chapters 2-9, is concerned with polymer blends, including mechanical blends, graft copolymers, block copolymers, ionomers, and interpenetrating polymer networks. The third part, Chapters 10-12, examines the properties of composites, where one component is usually nonpolymeric. Two broad classes of composites are treated: polymer-impregnated materials, such as wood or concrete, and fiber- and particle-reinforced plastics and elastomers. Chapter 13, comprising part four, gives a brief view of very recent developments, together with some unsolved problems.

A302 *Matkov, N. G., "Experimental and Theoretical Research on the Load-Carrying Capacity and the Deformability of Compressed Column Joints Based on Epoxy Polymer Mortars," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

When erecting precast concrete frames of multistory buildings, it is frequently necessary to place significant loads on their structures after the joints have been made monolithic; these loads can be 60 to 70 percent of the in-use load for extended periods of time, and sometimes even 100 percent for a brief period. In this situation, advantages can be realized by the use of improved techniques. The advantages are significantly shorter erection times, increased crack resistance, and improvement in joint quality; the improved techniques are the use of new joint designs with anchored reinforcement protrusions, and the installation of fine, high-strength seams using polymer-sand mortars based on epoxy resins (compositions 1:3 and 1:6) with PEPA (polyethylene polyamine) and AF-2 hardeners.

Epoxy polymer mortars have high strength properties and good adhesion to concrete and reinforcement. This permits a new approach to the design of column joints. In the new design, centering spacers are omitted and field welding of the reinforcement does not take place. The latter is replaced by anchoring the protrusions in steel housings which are filled with polymer mortar in the field. In this type of joint, as well as in hinged joints, transfer of the forces is accomplished without covering the seam with reinforcement; but by means of a fine seam of polymer mortar injected along the entire section of the precast component of the column - without any subsequent measures for making the joint monolithic.

Tests have revealed significant joint creep; however, it tends to decrease with time. We note that the deformability of polymer mortar (which is higher than that of concrete) is undesirable when it is used as a construction material. However, when it is used for joints (applied as a fine seam between abutting concrete ends), it has a favorable effect: it facilitates reduction of concentrated stress and redistribution of force in the joint zone.

A303 *McChesney, N., "Modern Materials for Underground Support," South African Institute of Mining and Metall Journal, Vol 77, No. 5, Dec 1976, pp 114-118.*



The properties required of a support material for underground tunnels are discussed and, because concrete is both economical and easy to apply, a number of new reinforcing materials for concrete are examined with particular reference to these properties. From about 30 tests on different types of reinforced concrete, it is concluded that the addition of polymer to a concrete does not seem to influence the concrete's post-failure behavior, and the only benefit to be achieved by this addition is to increase its flexibility (or to decrease it, depending on the polymer). Steel fibers tend to increase both the strength and stiffness of the concrete, but polypropylene fibers, although having definite load-carrying capacities, provide nonstable failure, also known as brittle failure. The best result is obtained for concrete reinforced with steel wire: the post-cracking strength is very good and is maintained for a considerable deformation.

A304 *Mosiak, V. I., "Epoxy Polymer Mortars for the Joints of Hydraulic Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

A study of the cohesion and adhesion strengths of adhesive spacers has shown that full-strength monolithic joining of concrete can be accomplished using spacers made from adhesive compounds based on epoxy resins. In general, the following composition is optimal: 100 parts (by weight) of ED-16 resin, 20 parts (by weight) of plasticizer (dibutyl phthalate, MGF-9 polyether, Thiokol, etc.), 10 to 15 parts (by weight) of hardening agent (polyethylene polyamine, hexamethylene diamine, pyridine, triethanol amine, or mixtures of these compounds in calculated amounts), and 400 to 1000 parts (by weight) of quartz sand filler.

It has been established that the adhesives with the greatest advantages are adhesives in the form of industrially produced high-filling adhesive spacers based on liquid epoxy resins. Spacers of this type redistribute the stress in the contact zone of the elements being joined together; this creates joints from which one of the main inadequacies of traditional methods has been eliminated.

Experiments showed that the deformability (pliability) of the adhesive spacers (up to 80 to 87 percent) is much greater than the deformability of the elements being joined. Therefore, when the installation load is applied, complete "immersion" of the surfaces being abutted takes place; this includes the concave regions of these surfaces as well as the convex regions. Thus, there is a significant increase in the contact area which reduces the stresses in the plane of the joint.

A305 *Paturoev, V. V., Volgushev, A. N., and Sviridov, V. G., "Experience in Using Polymer Concrete Slabs Based on FAM Monomer in Construction of the Kursk AES (Nuclear Power Plant)," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.*

In the construction of the Kursk AES (Nuclear Power Plant) there was the problem of protecting the floors of chambers in which various corrosive liquids might be spilled when the plant was in use; the main solution to this problem was the use of stainless sheet-steel sumps mounted on cement supports.

Chemical-resistant polymer concrete slabs based on furan resins (FA, FAM) have been successfully adopted by many of the enterprises in this country; the compositions of these slabs and the techniques for manufacturing them were developed at the NIIZhB.

In cooperation with the Hidroproekt NIS (Scientific Research Station), a variant type of slab was developed as the covering for an experimental section of the floor of a room of the main building of the AES; 50- by 50- by 4-cm polymer concrete slabs were involved.

Investigation of the physical and mechanical properties of the compositions has shown that the material meets the given specifications for the use properties as far as the primary indices are concerned. Additional specifications were drawn up for the slab face, which must be hard, glossy, and without open pores; these specifications can be met by modification of the composition and the casting methods.

A306 Patureov, V. V., Putlyayev, I. Ye., et al., "Mastics, Polymer-Concretes and Polymersilicates," AD B018827L, Nov 1976, Defense Documentation Center, Alexandria, Va.

In the book are given the results of investigations of materials utilized as effective protective systems and for the preparation of chemically stable structures - mastic, polymer-concretes and polymer-silicates. During the preparation of material the authors strove as far as possible fully to encompass the demands of organizations, to give the information about the latest achievements in the region of structural materials.

A307 "Polyester Concrete," Precast Concrete, Vol 7, No. 2, Feb 1976, p 101.

BASF, who claim to be the leading international chemical group based in West Germany, have carried out research into the application of polyester resins in the construction field, especially concrete. With more than 10 years experience of this work, the company now offers advice on this particular application of its unsaturated polyester resin grades of "Palatal."

A308 Pomeroy, C. D., "Commercial Prospects for Fiber and Polymer-Modified Concretes," Precast Concrete, Vol 7, No. 10, Oct 1976, pp 522-523.

An appraisal was made of the benefits that accrue from fibers and polymers in concrete in an attempt to establish areas in which their incorporation is likely to be commercially worthwhile. This paper is based on the appraisal. The two classes of material are introduced separately, and their individual characteristics are discussed. A

general discussion of their commercial application follows.

- A309 Prusinski, R. C., "Precast Polymer Concrete: A Twenty Year History," pp 1-21, 1976, *Plastics in Building Division, Stamford, Conn.*

A brief history of polymer concrete precasting industry is followed by a description of concrete in which cement has been replaced partly or totally by polymer matrix. Examples of polymer-based precast concrete panels are given.

- A310 Romano, P., "Evaluation of Bridge Patching Materials (Polymer Concrete) - Second and Third Field Sites - Operation," Interim Report No. III-R-2-76, Nov 1976, *Research and Materials Division, Massachusetts Department of Public Works, Wellesley Hills.*

This report relates the procedure followed in the Second and Third field installations of a polymer concrete repair to a bridge deck in Massachusetts. An evaluation of the results of these field site installations will be used as a guide in future experimental installations.

- A311 Rozhkov, L. P., Gol'Fam, I. B., and Aksel'rod, T. V., "Experimental Evaluation of the Reliability of Protective Polymer Coatings," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

The problem of protecting hydraulic engineering structures from the effects of cavitation and hydraulic abrasion is extremely pressing. Therefore, it is necessary to investigate new materials which combine high structural strength and high erosion resistance and which provide high resistance to abrasion by sand and ice particles, water vapor, spray, and precipitation.

The large number of operational factors which affect surface wear makes it difficult to evaluate coatings using the results of tests at a single test site. To make a comparative evaluation of coating properties, it is necessary to conduct concurrent tests at several test sites, simulating the on-site work conditions.

An experimental evaluation of the properties and reliability of protective coatings was conducted at various test sites: the hydraulic abrasion site, the impact erosion site, the site with an air stream containing free abrasive.

The following materials were investigated: SKU-PFLM polyurethane, two-ply polyethylene, epoxy fluoroplastic films, IRP-1175 and 51-2064 rubbers, kerovynyl, and others.

The greatest resistance to hydraulic abrasion was exhibited by polyurethane coatings based on SKU-PFLM polyurethane which were applied using a spray coating method, and type 51-2061 resin coatings obtained by joint pressing with fiber glass.

1. Of the available test sites, the impact erosion site (with high intensity at a speed of 54 m/sec, n = 2000 rpm) allowed us to confirm the reliability of the adhesion between the coating and the base material.

2. An accelerated method of evaluating the service life of protective coatings of on-site components was proposed. It is based on the results of test-site examinations.

3. The nature of polymer-coating wear depends on the coating's environment and thickness. Under hydraulic abrasion, the SKU-PFLM polyurethane and the type 51-2064 rubber turned out to be the most wear-resistant. The 3/39 kerovinyl was the most wear-resistant at the impact erosion site.

A312 Sauer, J. A., et al., "Strength Improvements in Mortar and Concrete By Addition of Epoxies," *Transportation Research Record N613*, 1976, pp 30-36, Washington, D. C.

To raise the tensile strength of cement mortar and concrete, we conducted a series of experiments in which suitably formulated epoxy resins were added to standard cement mortar and to selected concrete mixes. Tensile and compressive strength measurements were made on various formulations, and strengths were determined as a function of epoxy-added content. Both tensile and compressive strengths are appreciably increased by additions of epoxy to cement mortar and concrete. These additions are 5 and 10 percent by weight of mortar for the cement mortar and concrete, respectively. The effects of polymer additions on aggregate-paste bond have been studied by use of a scanning electron microscope. The influence of the epoxy on workability, stiffness, and water absorption is also discussed.

A313 Shvidko, Ia. I., "Polymer Concretes with Disperse Reinforcement," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

The construction properties of dispersely reinforced polymer concretes were investigated, taking the above-mentioned facts into consideration. This investigation was based on mathematical statistical methods of planning experiments and processing data; specifically, multifactor analysis was used for determining the compositions.

In the case of epoxy/coal-tar polymer concrete dispersely reinforced with rigid discrete fibers, we obtained mathematical models (adequate according to Fisher's criterion) for axial compression, flexural strength, and elastic modulus.

An analysis of each of the factors and their interactions has shown the following:

1. All paired interactions promote an increase in the flexural strength of dispersely reinforced polymer concrete.

2. The flexural strength decreases only with an increase in the percentage of filling of the polymer concrete matrix with the reinforcement fibers.

A314 Shtepa, B. G., "Use of Polymer Materials in Reclamation," Translated from Russian, 1976.

The main direction of the scientific-technical progress of reclamation is geared toward the creation of technically perfect irrigation and drainage systems that will guarantee plentiful and stable harvests, an increase in labor production, a decrease in production costs, and an economic use of water resources.

The development of closed (pipe) systems is the main trend in the perfection of reclamation techniques. Technical-scientific advancement to create modern reclamation systems is impossible without using the achievements of a number of other branches of industry, particularly the wide use of polymer materials and their by-products.

Use of polymer materials will, in the first place, considerably lower the demand for such scarce materials as metal, asbestos cement, and others. Secondly, the use of polymers will contribute to better quality construction, to an increase in labor production, to decrease labor costs, and a decrease in the construction time of reclamation systems.

Industrial experience in the use of polymer materials in reclamation confirms the expediency and the high effectiveness of their use, especially in forms of pipes, coatings, and sealants.

A315 Solomatov, V. I., "New Polymer Concretes for Construction Work," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian: USSR Ministry of Power Engineering and Electrification, 1976.

A new technology has been developed for producing high-strength polymer concretes directly from the starting materials usually used to prepare synthetic thermosetting resins, omitting the step of in-plant preparation of the resins. The resin formation reaction and the polycondensation reaction take place simultaneously in an environment of disperse fillers.

This technology has been used to make polymer concretes from furfural, urea, formalin, and other materials. Carbamide polymer concrete can have a compressive strength of 900 kgf/cm<sup>2</sup> (90 MPa), a tensile strength of 100 kgf/cm<sup>2</sup> (10 MPa), and an elastic modulus of 300,000 to 350,000 kg.

A316 Stabnikov, N. V., and Kocherova, V. I., "Asphalt Concrete Based on a Bitumen-Polymer Binder," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction; Translated from Russian by USSR Ministry of Power Engineering and Electrification, 1976.

Effective, abundant, and economical waterproofing materials are needed for the development of power-related construction in remote northern and eastern regions with harsh climates.

One of the ways to obtain materials of this type is to prepare

asphalt-polymer concretes by adding bitumen-polymer binder to traditional asphalt concretes.

The recommended polymer additives are DST-30 divinyl styrene thermosetting elastoplastics and SKEP-30 ethylene propylene rubbers. When these additives are mixed with bitumen, a binder with an embrittlement temperature as low as  $-50^{\circ}\text{C}$  can be obtained.

An analysis of the physicomechanical properties of asphalt-polymer concretes has shown that, as a rule, they are better than the standards set for improving the compositions of dense asphalt concretes for hydraulic engineering.

Investigation of the rheological properties of impermeable fine-grained asphalt-polymer concretes has shown that the deformability of these materials at  $-20^{\circ}\text{C}$  is the same as that of the usual asphalt concretes; a difference becomes noticeable only at  $-40^{\circ}\text{C}$ , but this difference is small compared to the absolute magnitude of the deformability. Therefore, our attention is directed to plastic and pourable compounds of asphalt-polymer concretes with up to 20 percent binder with up to 10 percent polymer.

The rheological research data indicate that it may be possible to estimate the service life of asphalt-polymer concrete with the aid of the well-known function of Academician S. N. Zhurkov.

A317 Tolbert, R. N., Hackett, R. M., and Baluch, M. H., "Parameter Testing of Epoxy Polymer Concrete," Polymer Engineering and Science, Vol 18, No. 8, Aug 1976, pp 575-578.

The ultimate strength of polymer concrete was investigated utilizing epichlorohydrin bisphenol A-type epoxy resin. Parameters were tested in an effort to conclude how variation of a specific parameter would affect the compressive strength of the polymer concrete. The parameter testing included studies to determine the effect of the polymer loading; the catalyst; the exothermic reaction; aggregate type, gradation, and moisture content; curing age; and aggregate additives of portland cement and limestone powder.

A318 USSR Ministry of Land Reclamation and Water Resources, Ukrainian Scientific Research Institute of Water Engineering and Land Reclamation, Precast Polymeric Concrete in Water Facilities Construction, Reklama Press, Kiev, USSR, Oct 1976.

Concrete structural elements of montane and piedmont intake structures - spillways, pump-transporting chutes, dividing walls, barrages, and bridge abutments - are susceptible to collapse during highwater periods owing to bottom-bed sand-and-pebble silt or cavitation erosion.

Studies conducted for a number of years at the Ukrniigim [Ukrainian Scientific Research Institute of Water Facilities and Land Reclamation] have demonstrated the expediency of cladding such structures with furan-type polymeric concrete.

Such concrete is produced from high-strength rock and sands. The binder for such concrete is a furfural-acetone monomer.

The durability and reliability of protective facings of furan-type polymeric concrete is due to its high strength (800 to 1100 kg/cm<sup>2</sup>) and wear resistance.

The estimated durability of these wear-resistant precast polymeric-concrete facings is at least 25 to 30 years.

1977

A319 *ACI Committee 548, "Polymers in Concrete," 1977, American Concrete Institute, Detroit, Mich.*

This state-of-the-art report reviews the present state of development and use of concrete composites which contain polymers. Concrete containing polymers includes composites prepared by either (1) monomer impregnation of normal hardened concrete followed by in situ polymerization (PIC), (2) addition of monomers or polymers during mixing of ordinary fresh concrete with subsequent curing or in situ polymerization if needed after the concrete has hardened (PPCC), and (3) polymerization of a monomer and aggregate mixture with the resulting polymer acting as a binder for the composite (PC). The report describes monomers and polymers used in the three types of composites, the technology for composite production, and the properties of the composite materials. The state of knowledge of engineering design of PIC and PC is summarized, and applications under studor in use for the various concrete-polymer composites, both in the United States and in other countires around the world, are reviewed.

A320 *Aleksandrina, V. P., et al., "Research on Polymer Concretes;" Translated from Russian by Bureau of Reclamation, Denver, Colo., 1977.*

Polymer concrete on resin NPS-609-22m is low in toxicity, barely flammable and at the same time retains the high physicomechanical properties inherent to organo-mineral concretes. The possibilities of its use in construction, therefore, are broadened considerably in comparison with the other types of polymer concrete. For instance, it can be used in unventilated areas as well as in areas ventilated with a low volume of air exchange or with the use of outside air in small quantities.

A321 *Baluch, M. H., et al., "Long-Term Chemical Stability of Epichlorohydrin/Bisphenol Resin Polymer Concrete," Cement and Concrete Research, Vol 7, No. 6, Nov 1977, pp 637-642.*

The chemical stability of an epichlorohydrin/bisphenol resin polymer concrete under corrosive environment is investigated over a long period extending to 625 days. The The results indicate a levelling off at a loss of approximately 50 percent of the compressive strength at room temperature under the action of the most critical corrosive environment. The combined characterstics of high strength and resistance

to corrosive environment render the developed polymer concrete an attractive alternative construction material for bridge decks, pavements, tunnels, underwater structures and long-term storage of radioactive nuclear waste material, contingent on a carefully designed cost effective analysis.

A322 Causey, F. E., "Laboratory Investigation and Experimental Field Application of Vinyl Ester Polymer Shotcrete," May 1977, Concrete and Structural Branch, Division of General Research, Engineering and Research Center, Bureau of Reclamation, Denver, Colo.

A vinyl ester polymer shotcrete was developed in the laboratory and later used to repair eroded baffle blocks in a Bureau tunnel outlet structure to demonstrate the technical feasibility of field application. Polymer shotcrete was applied using modified conventional shotcrete equipment but differs from conventional shotcrete in that a polymeric binder is used instead of portland cement and water. Vinyl ester shotcrete cures in 5 to 10 min after application and develops compressive strengths of 92 MPa (13,400 lb/in.<sup>2</sup>) upon curing. Polymer shotcrete has potential for applications similar to those of conventional portland-cement shotcrete as a lining or overlay; however, polymer shotcrete is expensive and is not intended as a general replacement for conventional shotcrete. Polymer shotcrete should be used where rapid cure, high strength, and greater durability are important. The organic chemicals used to produce polymer shotcrete require that certain precautions be taken to assure safe use.

A323 Causey, F. E., "Vinyl Ester Polymer Concrete and Experimental Repair of Madera Canal Drop Structure," GR-7-77, Jul 1977, U. S. Bureau of Reclamation, Washington, D. C.

A program was initiated to develop a vinyl ester polymer concrete and to investigate the suitability of this material for the repair of concrete hydraulic structures. Vinyl ester polymer concrete has high strength, good durability, and abrasion resistance. Vinyl ester polymer concrete may be prepared with conventional concrete equipment and cured in unsealed molds. A promoter-catalyst system was developed which produced polymerization of vinyl ester monomer in 1 to 3 hours. Test on vinyl ester polymer concrete show compressive strengths up to 110 MPa (16,000 lb/in.<sup>2</sup>) and excellent resistance to freeze-thaw and acid tests. Abrasion tests showed greater abrasion resistance than conventional concrete. Application of an abrasion-resistant vinyl ester polymer overlay was made on a Madera Canal drop structure. Certain precautions must be taken to assure safe use of the organic chemicals needed to produce polymer concrete.

A324 North Pacific Division Materials Laboratory, "Cavitation-Erosion Test of Polymer-Dry Sand Repair of Concrete, Libby Dam Sluiceways and Stilling Basin," Feb 1977, Corps of Engineers, U. S. Army, Troutdale, Oreg.



The repair procedure consisted of (1) drying the eroded area of the concrete test slab, (2) filling the erosion depression with dry sand, (3) applying the monomer to the sand-filled depression, and (4) polymerizing or curing the monomer by the application of heat.

Following test in the Detroit Dam erosion facility, the polymerized dry sand repair specimen was compared to concrete previously tested. It was concluded that the cavitation-erosion resistance exhibited in this test by the polymer-dry sand repair is in the order of 10 to 20 times greater than that of the original conventional concrete, and in the order of 3 times greater than that of polymerized conventional concrete. Also, that the polymer-dry sand system used in this investigation is an effective method of repair of horizontal concrete surfaces.

A325 *Cunningham, J. D., "An Experimental Investigation of the Effect of ASTM Fire Exposure on Six-Inch-Thick Epoxy Repaired Concrete Prisms," A Thesis Presented to the Department of Civil Engineering, California State University, Long Beach, Dec 1977.*

The effect of ASTM fire exposure on the high temperature and residual strengths of concrete repaired with epoxy is investigated. In addition, the effect of the standard ASTM hose test on strength of epoxy-repaired concrete is determined.

The presence of epoxy in 6-in.-thick concrete structural elements does not alter the strength reduction due to ASTM fire exposure at elevated temperatures, after cooling, or following rapid cooling, as experienced in hose spray, providing crack width is 0.1 in. or less. For wide cracks of 0.25 in. or more, repaired with epoxy, strength reduction due to fire is increased due to epoxy deterioration, seriously impairing the load capacity of repaired 6-in. concrete elements.

A326 *Davydov, S. S., et al., "Method of Making Polymer-Concrete Articles," Report No. FTD-ID(RS)T-1145-77, Jul 1977, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio.*

This invention is a method of making polymer-concrete articles by preparing the raw mixture, molding and heat treatment. It differs in that in order to speed up hardening and reduce the internal stress in the polymer-concrete, the heat treatment process is carried out in an electromagnetic field at a frequency of 2,500 to 30,000 MHz and voltage of 0.1 to 0.025 kV/cm for 5 to 10 min.

Under the action of the electromagnetic field, uniform cooling of the polymer-concrete mass occurs over its entire depth and it hardens in 5 to 10 min, thus eliminating the origination of nonuniform temperature fields and the internal stress connected with them.

A327 *Brookhaven National Laboratory, "Economic Assessment of Polymer Concrete Usage in Geothermal Power Plants," BNL-50777, Nov 1977, Upton, N. Y.*

The objective of this report was to review the Heber and Niland, California, 50-MWe conceptual geothermal power plants designs and to

identify areas where nonmetallic materials, such as polymer concrete, can be technically and economically employed. Emphasis was directed toward determining potential economic advantages and resulting improvements in plant availability. It is estimated that use of polymer concrete in the Heber plant will effect a savings of 6.18 mills per KWH in the cost of power delivered to the network, a savings of 9.7 percent. A similar savings should be effected in the Niland plant.

A328 *Elshin, I. M., "Experience in the Use of Plastic Concrete in Water Intake Structures;" Translated from Russian by Bureau of Reclamation, Denver, Colo., 1977.*

Laboratory and subsequent production tests of plastic concrete based on "FA" furfural acetone monomer, conducted in 1959-61 at a number of water intake complexes in Central Asia, made it possible to switch to the use of this material in place of those previously used for durable linings. Plastic concrete linings, constructed in 1961-62 under the supervision of the author at the Iangi-Sai and Sary-Kurgan dams (Uzbek SSR), were the first in the practice of hydraulic engineering.

Experience gained in the use of plastic concrete on the Iangi-Sai and Sary-Kurgan dams makes it possible to recommend this material for widespread use to protect water engineering structures against wear by sediments. In the construction of new hydrocomplexes it is expedient to use prefabricated plastic concrete or reinforced plastic concrete slabs which can be cast in situ.

A329 *Fontana, J., "Polymer Concrete Patching Materials," Report No. 23369, 1977, Brookhaven National Laboratory, Upton, N. Y.*

The increased use of deicing salts is causing rapid deterioration of portland-cement concrete bridge decks. Soluble chlorides cause corrosion of the steel reinforcing rods with a corresponding increase in volume of the rods. This expansion causes stresses in the concrete which result in delaminations and surface spalling. The repair of surface spalls with portland-cement concrete can only be made if traffic can be avoided for several days. A patching material which would allow traffic to resume over the repaired area in a few hours was needed. Polymer concrete (PC) was developed to repair deteriorated portland-cement concrete.

A330 *Fraint, T. M., et al., "Application of Polymeric Materials in Hydrotechnical Constructions," 1977, Ministry of Energy and Electricity, USSR.*

The perfection of a filler with an epoxy substance serves significantly in the increase of the resistance of the cavitation with a cement-sand composition. In that the major effect is reached when in the event that the expenditure of the epoxy substance, for the perfection of the filler, consists of 4.6 percent of the subsequent weight.

The perfection of epoxy filler compositions containing up to

70 ch.m. of diethylene glycol on 100 ch.m. ED-20, decreases erosion in cavitation in the actual concrete by 8 times.

A331 *Graham, J. R., et al., "Repair of Cavitation Damaged Concrete," International Conference on Wear of Materials, pp 439-445, 1977, Bureau of Reclamation, Denver, Colo.*

The Bureau of Reclamation has been working for several years to develop concrete-polymer systems for use in water conveyance and storage structures. One of the systems presently under development uses vinyl ester patching materials. These polymer-concrete systems have the potential for quick, straight-forward placement, short-term curing and long-term life. It is expected that someday these repair systems will compete with epoxy for repair of cavitation damaged concrete.

A334 *Kukacka, L. E., "Production Methods and Applications for Concrete Polymer," BNL-22640, Mar 1977, Brookhaven National Laboratory, Upton, N. Y.*

Concrete polymer materials are being used worldwide in applications where high strength and durability are required. Methods for producing two materials, polymer-impregnated concrete and polymer concrete, are discussed and their structural and durability properties summarized. Existing and potential applications for these materials such as for chemical storage tanks, pilings, pipe, curbstones, and bridge decks are reviewed.

A335 *Kukacka, L. E., "Applications of Concrete Polymer Materials for Rehabilitation of Bridge Decks," Symposium on Polymers in Concrete, Phoenix, Ariz., Report No. CONF-780102-2, Oct 1977, Brookhaven National Laboratory, Upton, N. Y.*

The rapid deterioration of concrete bridge decks as a result of the increased use of deicing salts is one of the most severe problems facing the highway industry today. One possible solution to the problems is the use of concrete polymer materials. The materials of prime interest are polymer-impregnated concrete (PIC) and polymer concrete (PC), both of which have excellent durability and strength properties. Three potential applications: repair of deteriorated bridge decks, polymer impregnation of new bridge deck surfaces, and full impregnation of precast deck panels have been studied in laboratory and field tests and the results have been encouraging. These results and economic considerations are described.

A336 *Kukacka, L. E., and Fontana, J., Polymer Concrete Patching Materials Users Manual, FHWA Implementation Package 77-11, Vol 1, Apr 1977.*

This manual outlines the procedures for using polymer concrete as a rapid patching material to repair deteriorated concrete.

The process technology, materials, equipment, and safety provisions used in the technique are discussed. The objective of the report is to

inform potential users of the various steps necessary to insure successful field application of the material.

A337 Kukacka, L. E., et al., "Polymer Concrete Workshop," Special Report EPRI EL-492-SR, Mar 1977, Electric Power Research Institute, Calif.

The purpose of the workshop described was to exchange information on experiences and knowledge of polymer concretes, their application as an electrical insulating material, identify requirements of electric utilities, and attempt to outline a program for future development of this material. Formulations, manufacturing methods, testing procedures and designs of insulators were discussed. A new material, which has the EPRI trade name of POLYSIL, was described as a replacement for electrical porcelain.

Porcelain is presently used for indoor and outdoor applications. POLYSIL was revealed as a low energy of porcelain, with less than half the finished product cost. It has twice the dielectric strength and one-half the dielectric constant of electrical porcelain. Also, it exceeds the mechanical strength of presently produced electrical porcelain, is castable in simple molds, and can be produced in large cross sections, as it has a very low exotherm during its curing stage. It was agreed that testing of POLYSIL as an insulating material should address the concerns involving impact strength, weathering degradation, attack by environmental elements (algae growth), and cracking. An external coating to improve surface properties was discussed. Utilities should help decide what types of tests they prefer and aid in field testing the polymer concrete on their systems. Participants also agreed that every effort should be made to keep the basic material development going, as it appears that knowledge has only been developed on a few formulations and their applications. The possibilities for application look much broader for the future.

A338 Kukacka, L. E., "The Use of Concrete Polymer Materials for Bridge Deck Applications," Chloride Corrosion of Steel in Concrete, D. E. Tonini and S. W. Dean, Jr., eds., American Society for Testing and Materials STP 629, pp 100-109, 1977, American Society for Testing and Materials.

One possible solution to the problem of rapid deterioration of concrete bridge decks as a result of the increased use of deicing salts is the use of polymer materials. The materials of prime importance are polymer-impregnated concrete (PIC) and polymer concrete (PC), both of which have excellent durability and strength properties. PIC consists of a precast or cast-in-place portland-cement concrete impregnated with a monomer system that is subsequently polymerized in situ. PC consists of an aggregate mixed with a monomer or resin that is used to prevent chloride intrusion into cast-in-place bridge decks. This is a precast concrete that has been partially impregnated to a finite depth with a monomer that is subsequently polymerized. Examples of application are described.

A339 Kukacka, L. E., Sugama, T., Fontana, J., and Horn, W., "Alternate Materials for Geothermal Applications," BNL-50665, Progress Report No. 12, Jan-Mar 1977, Brookhaven National Laboratory, Upton, N. Y.

A program to determine if concrete polymer materials can be utilized as materials of construction in geothermal processes is in progress. To date, several high temperature polymer concrete systems have been formulated, laboratory and field tests performed in brine, flashing brine, and steam at temperatures up to 260°C (500°F), and economic studies started. Laboratory data for exposure times up to 2 years are available. Results are also available from field exposures of up to 12 months in four geothermal environments. Good durability is indicated. Work at two of these sites is continuing and tests have recently been initiated at two locations in the Imperial Valley. Work accomplished during the period 1 January-31 March 1977 is described in the current report.

A340 Kukacka, L. E., et al., "Alternate Materials of Construction for Geothermal Applications," BNL-50699, Progress Report No. 13, Apr-Jun 1977, Brookhaven National Laboratory, Upton, N. Y.

A program to determine if nonmetallic materials such as polymers, concrete polymer composites, and refractory cements can be utilized as materials of construction in geothermal processes is in progress. Work accomplished during the period 1 April-30 June 1977 is described in the current report.

Preliminary results indicate that the significant improvements obtained in the durability of polymer concrete materials to hot brine and steam when aggregate containing portland cement is used, may be due to chemical bonding between the vinyl groups in the monomer and CaO.

Field testing of a 6-in.-diam section of lined pipe has been started at Raft River and sections of 2- and 3-in. pipe are being prepared for testing at East Mesa.

Laboratory testing of specimens in simulated geothermal environments was continued. Samples exposed to 25 percent brine solutions at 177°C (350°F) for 760 days have not deteriorated. Similar results have been obtained with pipe specimens exposed to a 400-ppm solution at 150°C (302°F) for 252 days.

Samples exposed to a pH 1 hydrochloric acid solution at 90°C (194°F) for 322 days have not deteriorated. Samples containing silica sand-portland cement aggregate have yielded similar results after 94 days in pH 1 hydrochloric acid at 200°C (392°F).

Polymer concrete pipe sections exposed for 18 months to high sulfate containing soils show no visible signs of deterioration.

Field testing of specimens at Raft River, The Geysers, and Niland is continuing. During the report period samples were removed from The Geysers and East Mesa. Visual examination of the former after 18-months exposure to dry steam at 238°C (460°F) indicated no apparent deterioration. Evaluation is in progress. Samples exposed at East Mesa to flowing brine at 160°C (320°F) for 60 days are reportedly in good condition. These samples have not yet been returned to BNL.

A341 Kukacka, L. E., and Fontana, J., et al., "Alternate Materials of Construction for Geothermal Applications," BNL-50751, Progress Report No. 14, Jul-Sep 1977, Brookhaven National Laboratory, Upton, N. Y.

Experiments to determine the effect of aggregate composition on the durability of PC to high temperature brine indicates that the presence of portland cement in the aggregate greatly enhances the durability. The evidence indicates that CaO reacts chemically with  $-CH_2$  groups in the vinyl monomers. However, there is no evidence whether the reaction is caused by free CaO or the calcium ion.

Field testing of a 6-in.-diam section of lined pipe is in progress at Raft River and sections of pipe are being prepared for installation at East Mesa, Niland, and the U. S. Naval Weapons Center.

Samples exposed to a pH 1 hydrochloric acid solution at 90°C (194°F) for 441 days have not deteriorated. Samples containing silica sand-portland cement aggregate have yielded similar results after 170 days in pH 1 hydrochloric acid at 200°C (392°F).

Field testing of specimens at Raft River and The Geysers is continuing. During the report period samples removed from The Geysers and East Mesa were evaluated. Good durability is indicated after exposure to 238°C (460°F) steam at The Geysers, for 18 months. Similar observations were noted for samples exposed for 60 days to 160°C (320°F) flowing brine at East Mesa.

A study to determine the potential benefits of using PC as a material of construction in geothermal power plants has been completed. Conceptual designs for 50 MWe power plants at Heber and Niland were used as the basis for the study. The results indicate that savings can be accrued in the capital cost of both plants. These savings result in reductions in the cost of electric power of 2.7 mills per kilowatt hour. Additionally, the use of PC should markedly reduce corrosion problems in the plant. It was estimated that on-stream availability will increase by 4 percent and that electric power cost will be reduced by an additional 3.4 mills per kilowatt hour.

A342 Kukacka, L. E., "Alternate Materials of Construction for Geothermal Applications," BNL-50834, Progress Report No. 15, Oct 1977-Mar 1978, Brookhaven National Laboratory, Upton, N. Y.

A program to determine if nonmetallic materials such as polymers, concrete polymer composites, and refractory cements can be utilized as materials of construction in geothermal processes. Work accomplished during the period October 1977-March 1978 is described in the current report.

Test results indicate that polymer concrete (PC) containing mixtures of styrene-acrylonitrile-acrylamide or methacrylamide produce composites with the best high temperature and chemical resistance obtained to date. The results show that the use of a 12 wt percent concentration of a 55 wt percent styrene-35 wt percent acrylonitrile-5 wt percent acrylamide-5 wt percent TMPTMA monomer mixture in conjunction with 88 wt percent of a 70 wt percent silica sand-30 wt percent portland

cement aggregate produced a composite with a compressive strength at 20°C (68°F) in the range of 25,000 to 30,000 psi. The PC is thermally stable to ~240°C (464°F).

Work to determine the effect of calcium oxide compounds of anhydrous cement on the durability of PC is continuing. The results indicate that the  $3 \text{ CaO} \cdot \text{SiO}_2$  component of cement has the greatest effect on the thermal stability of vinyl-type polymers.

Work to determine the descaling characteristics of PC has been started. Scale has been used successfully as aggregate in PC. Specimens with compressive strengths up to 8000 psi were produced. Durability tests are in progress. If successful, the technique may yield an environmentally and economically acceptable method for the disposal of scale.

A343 Lau, D. H.-K., Thermal Properties of Epoxy for Structural Repair, M.S. Thesis, Dec 1977, Department of Civil Engineering, California State University, Long Beach, Calif.

The purpose of this paper is to determine the thermal properties of epoxy adhesives which are widely used for repair of damaged structures. The properties investigated include compressive strength, hardness, impact energy, and the dynamic strength at various temperatures. Three different specimen configurations are discussed: 1/2 in. diameter and 1 in. long, 1 in. diameter and 2 in. long, and 1/2 in. square and 2-1/2 in. long.

Five unique experiments including the hardness test, the residual compressive strength test, the hot compressive strength test, the dynamic test, and the impact test are herein discussed. Experimental data are totally included in tabular form. The results are subsequently summarized in graphical form showing the effects of temperature on various mechanical properties.

A344 Mangat, P. S., and Swamy, R. N., "Some Properties of Fibre-Polymer Concrete Systems," Mater Constr Mater Struct, Vol 10, No. 60, Nov-Dec 1977, pp 339-349.

This paper investigates the possibilities of using polymer dispersions to overcome the difficulties of low elongation at break and possibly of the high stiffness of the cement matrix. Five different types of polymer dispersions have been studied and their influence on the strength, stiffness and shrinkage characteristics of polymer modified plain and fiber concrete has been investigated. The effects of dry, wet and dry-wet curing on these properties have been studied.

A345 Murray, M. A., and Schultheis, V. F., "Polymerization of Concrete Fights Cavitation," Civil Engineering, Vol 47, No. 4, Apr 1977, pp 67-70.

At Dworshak Dam on the north fork of the Clearwater River in Idaho, cavitation gutted the concrete of the spillway outlets and stilling basin. The owner, the Corps of Engineers, has pioneered a solution to

this maintenance problem: Replace the missing concrete, then when it's dry, soak a liquid plastic into the concrete's pores and harden by applying heat. This article presents the polymerization procedure.

A346 Ohama, Y., "Hot Water Resistance of Polyester Resin Concrete," Proceedings, Japan Congr. Mater. Res., 1977, pp 176-177.

In this paper, polyester resin concrete using various unsaturated polyester resins as binding materials is prepared with a silane coupling agent and its durability in boiling water is examined.

A347 O'Neil, D. J., "Polymer-Concrete Composites," International Journal of Polymer Materials, Vol 6, No. 1-2, 1977, pp 73-84.

The need for cost-effective, high-strength, corrosion-resistant materials of construction has led to the development of a new class of materials, polymer-concrete composites. Production of such composites may be effected in four ways. This report focuses on polymer-impregnated concrete composites and looks at the technical, processing, and economic merits of these materials. A case for increased research is made. It is shown that this new class of structural materials which have strong technical, design, and economic potential for applications in numerous fields, particularly in highway applications.

A348 Patureov, V. V., Technology of Polymer Concretes, Stroyizdat Press, USSR, 1977.

The Principal Areas of Development of the National Economy of the USSR in 1976-1980 provides for advancing rates of development of the chemical industry, including an approximately twofold increase in polymer output. An active field of use of polymers is the production of high strength and chemically stable concretes based on them. The most widespread special concretes properly include polymer cement and polymer silicate concretes, concrete polymers, and polymer concretes.

The characteristics of the raw materials (synthetic resins, hardeners, and additives) of polymer concretes are presented, and their rheological and technological properties and the thermal and shrinkage stresses during their formation and consolidation are discussed. Data are presented for the design and calculation of optimum polymer concrete compositions, and a technical and economic analysis of the use of chemically stable reinforced polymer concrete structures is given.

Part of the questions touched on in the monograph, including methods of electrical heating of polymer concretes with industrial frequency, high frequency, and ultra high frequency current, have not been completely covered and some conclusions are controversial.

A349 Patureov, V. V., et al., "Precast Foundations Made of Polymer Concrete and Polymeric Silicate Materials for Pumps in Hydrometallurgical Foundries;" Translated from Russian, 1977.



The use of polymerized concretes and polymerized silicates, which have high durability, density, and chemical resistance, permits the complete rejection of additional multi-purpose waterproofing of the foundations and increases the time period of their service without dislocating the hermetically sealed floors. The foundations can be prefabricated in the form of a slab, by installing them immediately on a continuous chemical resistant floor, like a monolith.

Considering the dynamic effects of the equipment, the foundations have been reinforced with steel nets and frames made from class steel.

Depending on the available materials, the foundations are constructed from polymerized concrete (made from heavy cement on a furan resin), from light concrete on a furan and polyester resins, and also from polymerized silicates.

The use of polymerized concrete foundations under pumps:

- decreases the labor costs of their construction by 15 times.
- increases durability by 5 times.
- decreases material costs by 1.5 to 2 times.

A350 *Paturoev, V. V., et al., "Polymer Concrete Structural Elements for Cell Support Platforms and Shelves for Copper Electrolysis Shops;" Translated from Russian, 1977.*

Hydrometallurgy factories for electrolysis copper production and construction of submerged piers and built-in stories are now in progress, being aggressively exploited under intensive conditions of high tension currents and elevated temperatures.

Current multi-purpose protective coats do not, in most instances, secure reinforced concrete constructions sufficiently for dependability and long-range standing.

The proposed material, which consists of polymerized concrete on the basis of tar FAM (Furfurolacetonized Tar), is defined as being of high durability and almost stable in universal chemistry, to include high dielectric characteristics.

Application of polymerized concrete for the construction of submerged platforms and built-in stories allows:

- To decrease leakage of the floating blocks by 5 to 10 times.
- To decrease the cost for material in the construction by 1.5 to 2 times.
- To decrease labor by 10 times.
- To increase the existence/duration time of the construction by 3 times.
- To completely disregard protection of the construction, which is expensive, deficit, multi-hydro insulation, and consists of ceramic material.

A351 *Paturoev, V. V., et al., "Reinforced Polymeric Concrete Cells for Electrolysis of Copper and Zinc;" Translated from Russian, 1977.*

The institute for the planning of establishments of nonferrous metallurgy, in conjunction with the NII ZHB, MIIT, VISI, Kazakh Nonferrous metallurgy Repair Combine, and the Kazakh Copper Construction Combine,

have developed working models of standard construction baths, designed for the electrolysis of copper and zinc, which are made from reinforced polymerized concrete with nonpressurized and pressurized armatures.

Electrolytic baths are used in conditions of strong chemical and electro-chemical reactions. At the present time, the basic material for the construction of baths is ferroconcrete with an expensive and multi-purpose chemical protective coat on both the outer and inner surfaces of the bath.

Due to the destruction of the protective inserts, which are generally made from lead or vinyl sheeting, from 5 to 10 percent of the baths are in for monthly repairs; after 4 to 5 years, used baths are no longer operable.

The solution to the problem of increasing the durability of the electrolytic baths is in the utilization of chemically stable materials, i.e., polymerized concretes, which possess high durability, density, overall chemical stability, and have high nonconducting properties, during the construction phase.

A352 *Paturoev, V. V., et al., "Precast Foundations Made of Polymer Concrete and Polymeric Silicate Materials for Pumps in Hydrometallurgical Foundries," USSR Gosstroy, Scientific Research Institute of Concrete and Reinforced Concrete, NIIZhB, Moscow, 1977.*

The GUPROTSVETMET and NIIZHB with the assistance of the Moscow branch of the Planning department for Technical, Energy, and Chemical Industry have developed working models of standard construction foundations made from polymerized concrete and polymerized silicate materials for use under the pulping pumps in the hydrometallurgy workshops during the production of zinc and copper.

The use of polymerized concretes and polymerized silicates, which have high durability, density, and chemical resistance, permits the complete rejection of additional multi-purpose waterproofing of the foundations and increases the time period of their service without dislocating the hermetically sealed floors.

A continuous slab of ferrous concrete serves as a base under the foundations. Depending on the available materials, the foundations are constructed from polymerized concrete (made from heavy cement on a furan resin), from light concrete on a furan and polyester resins, and also from polymerized silicates.

A353 *Westinghouse Research and Development Center, "Polymer-Bonded Silica for Electrical Applications," Report No. EPRI EL-488, 1977, Pittsburgh, Penn.*

This report deals with the development of high voltage electrical insulation applications of a new family of composite materials systems which can effectively replace electrical porcelain with significant technical and cost advantages, coupled with considerable savings in total energy consumption. These materials systems, trademarked under the name Polysil, are essentially polymer concrete and polymer-impregnated

concrete reinforced with randomly dispersed, chopped alkali-resistant glass or organic (aramid) fibers. Both cross-linked low viscosity acrylic and polyester resins were used as the organic phase of the composites. Coatings such as plasma-sprayed fluorocarbon and inorganic glass-resins were examined to enhance the surface characteristics and performance of the composite insulation, especially in polluted environments. Data on the dielectric, mechanical, and physical properties of Polysil are presented and discussed in detail, together with examples of insulator prototypes made with these material systems.

A354 Putliaev, I. E., et al., "Low-Shrinkage, Nonshrinkage, and Expansive Polymer Concretes Made with Monomer FA;" Translated from Russian by Bureau of Reclamation, Denver, Colo., 1977.

The methods of minimizing shrinkage by incorporation of kerogen into polymer concrete compositions are described, and the possible mechanism of kerogen interaction with components of a polymer concrete is discussed. The physical and mechanical characteristics as well as the chemical resistance of nonshrinkage, FA monomer-based polymer concretes are also given.

A355 Transportation Research Board, "Rapid-Setting Materials for Patching of Concrete," NCHRP Synthesis of Highway Practice 45, 1977, Washington, D. C.

The use of rapid-setting materials for patching portland-cement concrete pavements and bridge decks has increased greatly during the past several years. This report reviews information presently available on the performance of such materials. Patch materials evaluated fall into eight groups: 1. portland cement, 2. other chemical-setting cements, 3. thermosetting materials, 4. thermoplastics, 5. calcium sulfate, 6. bituminous materials, 7. composites, and 8. additives used to alter mix characteristics. Recommendations for further study are also included.

A356 Smith, A., "Resin Concrete for Bomb Damage Repair of Airfield Pavements," Report No. CEEDO-TR-77-53, Nov 1977, U. S. Army Construction Engineering Research Laboratory, CE, Champaign, Ill.

This study was Phase I of a two-phase study and was conducted to determine whether commercial liquid resins can be used successfully as binders or matrix materials with aggregates to form a resin concrete for rapidly repairing small damaged areas in airfield runway pavements.

One type of liquid resin system, a highly reactive polyester, was shown to have the necessary properties. It came nearest to meeting all of the design objectives, including aggregate penetration, polymerization rate, early strength development, ease of application, and cost.

A357 Stanely, A. F., "Field Performance of Shallow Epoxy Mortar Bridge Deck Patches," Special Report No. ML-10-77-L, Aug 1977, Idaho Transportation Department.

Under the exposure conditions in Boise, the life of thin epoxy mortar bridge deck patches is relatively short compared to the expected service life of the structure. Such patches will likely develop serious distress within about three years.

The high wear rate of epoxy-sand mixtures might be overcome by placing a wearing course over the deck after patching. This would not necessarily solve the problem of debonding, however.

On the basis of limited evaluation, using aggregate sizes up to 3/8 in. does not appear to increase field durability compared to using only sand as the mineral filler in shallow epoxy mortar patches.

A358 Stanely, A. F., "Field Test of Sinmast Deep Conservation," Research Project 82, Aug 1977, Idaho Transportation Department.

Sinmast Deep Conservation, a solvent cutback epoxy product sold as a penetrating sealer for portland-cement concrete and other construction materials, was applied to a 7-year-old traffic structure in Boise. After approximately 2-years exposure, minor delaminated spots existing at the time of treatment have grown and have begun to break through the deck surface, resulting in surface spalling. Under the condition of shallow penetration attained in the test, this type of sealer is essentially ineffective in retarding deck deterioration when applied to a deck which has begun to show even minor distress.

A359 Steinberg, M., and Kukacka, L. E., "Cementing of Geothermal Wells," Progress Report No. 4, Jan-Mar 1977, Brookhaven National Laboratory, Upton, N. Y.

A coordinated program for the development of improved cements specifically designed for geothermal well applications was continued. Polymer cements (PC) have been identified as promising well cementing materials. Tests indicate that at temperatures above 218 exp 0 C (425 exp 0 C) only PC materials containing mixtures of silica and portland cement are durable to brine and steam. Differential thermal analysis (DIA) studies are underway to determine the reason. Tests are also being conducted on two monomer systems that may further extend the operating temperature range.

A360 Tamura, M., and Miyake, H., "Degradation of Polyester Resin Mortar in Boiling Water," Journal of the Society of Materials Science, Japan, Vol 26, No. 286, Jul 1977, pp 683-686.

Degradation of polyester resin mortar has been studied by using unsaturated polyester resins having different resistances against boiling water, and by measuring the change in flexural strength during the course of soaking in boiling water, in order to clarify the relation between the resistances of the polyester resin mortar and the unsaturated polyester resin used against boiling water.

The results showed that the resistance of the resin mortar against boiling water depends mainly on that of the unsaturated polyester resin used, although some effects of adhesion of the unsaturated polyester resins to natural silica sand and calcium carbonate are also present.

- A361 Aleksandrian, E. P., Muradian, E. S., and Sarkisov, K. A., "Use of Polymer Mortars in the Joints of Precast Hydraulic Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 70, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The achievement of impermeability and water resistance of joints, as well as equality of strength with the main structural elements, are among the most important tasks in hydraulic construction using precast reinforced concrete.

Studies of the permeability of epoxy compounds have been performed on pipes 1.5 m in length and 0.6 m in diameter, with wall thickness 6 cm and seam width up to 10 mm, made of two semicircular reinforced-concrete troughs bonded together, then subjected to water pressure of up to 2.6 atm. gauge. The testing caused the formation of longitudinal and inclined cracks in the pipes, but the seams were impermeable.

The studies established that the bonding of precast elements of the aqueduct is most effectively done element by element, with subsequent tensioning of the reinforcement in the spans and the supports.

- A362 Aleksandrovskii, S. V., and Karanfilov, T. S., "Endurance of Polymer-Treated Concrete under Dynamic, Repeated Loading," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 107, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer-treated concrete was endurance tested using specimens of four series: S-1, S-2, S-3, and S-4, differing in the prism strength of the concrete matrix (CM), equal to 37.7, 44.4, 42, and 54.7 MPa, respectively. The polymer-treated concrete (PTC), produced by saturation of the concrete matrix with MMA monomer and thermocatalytic curing at 75 C, had prism strengths of 105, 100, 77 and 90 MPa, respectively. The experiments were performed with a pulsating load device with a load repetition frequency  $\omega = 5.83$  Hz and a loading cycle asymmetry factor  $\rho = 0.1$ .

The experiment showed that the polymer-treated concrete, depending on its prism strength, has variable relative endurance limit. Given the

same relative level of endurance, the stronger polymer-treated concretes are more durable and, as the strength of these concretes increases, their durability increases.

A363 Aleksandrovskii, S. V., and Serykh, R. L., "Study of the Properties of Polymer-Treated Concrete in Long-Term Compression," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 113, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The properties of polymer-treated concrete in long-term axial compression were studied using specimens of three series: A-1, A-2, and A-3, which differed in the prism strength of the concrete matrix (CM), which was 14.9, 26.3, and 84.8 MPa, respectively, for the three series. The polymer-treated concrete (PTC), obtained by saturation of the concrete matrix with MMA monomer and thermocatalytic curing at +75 C, had a prism strength of 101.3, 119.7, and 132.5 MPa, respectively, for the three series.

The specimens were loaded to a stress level of  $\eta = 0.5$  and  $0.7$  for the concrete matrix and  $\eta = 0.4$  for the PTC, 60 days after the day of manufacture.

Analysis of the specific creep deformation curves indicated that there are significant differences both in terms of magnitude and in terms of the rate of development of creep in PTC and CM.

The measure of creep of the concrete matrix was 15 to 20 times higher than the measure of creep of the PTC. The results of the experiments showed that the measure of creep of the PTC can be predicted by determining the transfer factor  $K_c$  from values of the measure of creep of the CM to values of the measure of creep of the PTC.

The nature of the aftereffect deformation curves of the CM and PTC indicates that the creep deformations in the CM are only partially reversible, being much more reversible in the PTC. Thus, in terms of their properties, PTC can be practically considered hereditary elastic media and the theory of heredity can be successfully used to evaluate the stress-strain state of structures made of these materials.

A364 Alikulov, P. U., Makhmudov, Sh. M., Bober, A. M., and Petrov, E. G., "Centrifuged, Carbamide-Resin-Based Polymer-Concrete Pipe," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 51, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Laboratory of New Construction Materials of the Central Asian Scientific Research Institute for Irrigation has developed polymer concretes based on comparatively inexpensive and nontoxic carbamide resins types MF-17, M-1962, M-1963, and UKS, the most efficient, cheapest, and easiest to work of which is the polymer concrete based on UKS resin (technical specifications MRTU 6-06, 1066-66).

In 1977, pipe sections 600 mm in diameter, 1000 mm in length, wall thickness 55 mm, were made of this composition at the Leninabad construction materials plant.

Testing showed that the strength of centrifuged pipe based on UKS resin is sufficient to allow the pipes to be used to construct drains buried 5 m deep. The pipe can withstand a hydrostatic pressure of 0.3 to 0.35 MPa.

- A365 Alimov, L. A., and Voronin, V. V., "Failure of Concrete and Polymer-Treated Concrete from the Standpoint of Fracture Theory, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 103, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The process of failure of a material is involved with the development and accumulation of microdefects, as a result of which the physical behavior of the concrete and polymer concrete must be looked upon from the standpoint of the formation and development of cracks. One measure of the sharp change in behavior of a material is the critical value of the stress intensity factor  $K_c$  or the specific failure energy  $C_c$ , corresponding to rapid acceleration of crack growth and defining the fracture toughness of the material.

In order to study the fracture toughness of concretes, we selected compounds with identical volumetric content of aggregate, but different cement paste qualities.

The addition of polymers to concrete results in an increase in the fracture toughness, in comparison to the initial concrete, by more than a factor of 2. The polymer, while decreasing the porosity of the concrete, imparts some preliminary stress to it, due to polymerization shrinkage. Furthermore, the polymer prevents the development of microscopic cracks and, due to its high adhesion to the concrete, facilitates a sharp increase in the strength of the relatively weak bonds between the components.

A366 Andreev, E. I., and Khrulev, V. M., "Improvement of the Technology of Production of Polymer-Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 97, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

One effective means of increasing the strength and crack resistance of polymer-treated concrete is saturation of concrete which is in the stressed state with monomers. Microscopic cracks and structural defects in the concrete are thus opened and more easily filled with the monomer. Preliminary loading of the concrete to 30 to 40 percent of the ultimate strength (in bending and extension) is possible in the stage of drying of the products. After the products are saturated to the desired depth and the load is removed, the monomer is polymerized by one of the known methods. This causes the monomer to penetrate more deeply into the hairline cracks and strengthens the structure of the concrete.

Tests were performed on specimens of fine-grained concrete measuring 4 by 4 by 16 cm, saturated in a solution of alkylresorcinol oligomer at normal atmospheric pressure for 1 hr under a load of 40 percent of the bending strength.

The tests showed an increase in the strength of the specimens by 50 to 60 percent, with comparatively slight depth of penetration of the oligomer, as a result of filling of the largest defects, which influence the strength of the entire specimen.

A367 Andreev, L. V., and Khasanov, R. M., "Experience in Construction of Large Containers of Polymer Concrete Based of FAM Monomer," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 50, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer concrete based on FAM monomer, like ordinary concrete, is subject to shrinkage deformations, resulting in the appearance of cracks and, consequently, decreasing the durability of elements and structures. Studies have shown that the shrinkage deformations can be decreased by the addition of fluorine-containing fillers. This is explained by the fact that the particles of fluorine-containing filler serve as centers of structure formation of the polymer, around which fibrillar structures are formed, which have lower rigidity and internal stresses, while simultaneously retaining good physical and mechanical properties due to



increased adhesion between the binder and the filler.

The increase in strength and decrease in internal stresses have been confirmed by studies performed by the method of differential thermal analysis.

It has been established that the use of fluorine-containing fillers increases the degree of curing of the polymer binder, and also decreases the curing rate constant in the layer between phases.

The results of the experiment were confirmed by construction of a container measuring 12 by 2.5 by 1.5 m of monolithic reinforced polymer concrete based on FAM monomer. It was built using a polymer-concrete mixture which contained a microscopic filler, the product of milling of quartz sand plus 9 percent by mass of a fluorine-containing mineral (cryolite).

The container thus constructed has been in use since 1974. It is exposed to a 20 percent solution of sulfuric acid at a temperature of +60 C. No defects in the container resulting in leakage of the acid have been observed during this period of operation.

A368 Atsagortsian, Z. A., "Decorative-Lining Materials of Polymer Concrete and Polymer-Stone Composites," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 15, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Decorative powders of stone (marble, granite, colored tuff, etc.) are used as fillers for polymer concretes, with binders made of transparent curing resins such as epoxy, polyester, polymethacrylate, and other resins.

At the Institute of Stone and Silicates of the Construction Materials Ministry, Armenian SSR, new types of decorative facing materials have been developed, consisting of the wastes from quarrying and working of natural stone, in polymer binders. These products are intended for interior use in buildings and other structures.

A369 Belikov, V. A., Rusanova, L. P., "Strength and Deformation Properties of Polymer-Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 105, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In connection with the planned use of structures of polymer-treated concrete in construction, the Laboratory of Reinforced Concrete Structures of the Scientific Research Institute for Reinforced Concrete Products has studied their strength and deformation properties, using specimens made under production conditions on an installation at Reinforced Concrete Products Plant No. 7 of Glavmospromstroimaterialov. Three series of specimens were made in all: two of grade M300 concrete, and one of grade M400 concrete. After manufacture, the form and specimens were steam cured at 2 + 3 + 6 + 2 hr (holding, temperature rise to 80 C, isothermal holding, lowering of temperature).

Specimens 9 months old were treated with a monomer as follows: drying at  $t = +150$  C, evacuation - 2 hr, saturation - 6 hr, and polymerization in water at  $t = +80$  C - 8 hr. The tests were performed according to All-Union State Standard 10180-74, as well as the methods used at the Scientific Research Institute for Reinforced Concrete Products. The deformations were measured by 5-cm strain gauges.

Crack testing of prisms and cubes indicated that the specimens were not completely saturated (depth of saturation 2 to 4 cm).

A370 Bares, R., "Furane Resin Concrete and Its Application to Large Diameter Sewer Pipes," Polymers In Concrete - International Symposium, SP-58, pp 41-74, 1978, American Concrete Institute, Detroit, Mich.

Some research results of the investigations of the properties of the various types of resin concrete were described. Particular attention was afforded to furane resin concrete which is cheap, based on continuously available raw materials, of equivalent mechanical properties and superior chemical resistance to all other types of resin concrete used.

Experimental research results were used as a basis of a generalization of some relations generally valid for composite materials of granular type.

Several examples of practical application of furane resin concrete to the construction of underground works in Czechoslovakia were described.

A371 Bares, R., "Causes of Polyester Resin-Filler Surfacing Systems Failures," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 311-330.

For surfacings the unsaturated polyester-filler systems are used in a considerable extent. In some cases failures occur even after a considerable period (blisters, cracks, etc.). These failures are due to physical, chemical, and microbiological effects, a detailed analysis of various causes of these failures being given. Physical failures are due to the shrinkage of the binder, thermal effects, composite behavior of the surfacing, exceeding of mechanical properties, unsuitable structural composition, effects of unsuitable base, environment and raw materials, aging of binder and inadequate treatment of the base. Chemical failures are due primarily to the moisture content of the base or of raw materials

which inhibits polymerization and enhances oxidation and hydrolysis of the resin; polymerization is influenced heavily also by various shortcomings of raw materials and technology.

Thorough knowledge of all circumstances influencing the properties of UP systems is the necessary prerequisite of a successful application of surfacings (in the form of cast systems, screeds, glass-reinforced plastics, polymer concretes). Analysis of the causes of various failures of polyester systems which have occurred in construction practice is a valuable source of information in this respect.

A372 Bartz, J. A., et al., "Some Experimental Investigations on Polymer-Cementitious Composite Materials in Poland," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 271-282.

Laboratory tests to determine the feasibility of using polymer emulsion based on Polymethyl Methacrylate mixed with a fresh concrete have been performed. Selected polymer must neither affect the setting properties of the hydraulic binder not be attacked by the alkalinity. Three series of PCC standard specimens to be composed of zero, 4, and 6 percent of polymer emulsion have been produced for compression, tension, abrasion, and absorption tests. Some PCC specimens of 4 percent PMM content were subject to ultrasonic tests. Investigations on an effective initiator added to the polymerization medium, for PIC specimens, have been performed. Addition of amine or persulphate results in characteristic distribution of the polymer in specimens. Considerations concerning the chemical affinity of polymer concrete components and inhibiting processes of polymerization in polymer-impregnated concrete are discussed.

A373 Barzikova, T. V., Gruz, A. I., Lorettova, R. N., and Maloshitskii, A. S., "Predicting the Strength of Concrete Products Reinforced with Glass Fiber," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 96, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

As we know, the use of various types of glass fibers is very promising for reinforcement of concrete. Unfortunately, the low chemical stability of ordinary glass fiber in an alkaline medium such as concrete prevents its extensive utilization.

The results of a number of studies have shown that type RBR aluminoborosilicate fiber is subject to corrosion, resulting in a decrease in the strength of glass-reinforced concrete by 50 to 60 percent after 12-months exposure to corrosive media.

We performed a comparative study of the influence of corrosion of

glass fiber on the strength properties of concrete treated with a monomer and its matrix.

The glass fiber content was varied from 4 to 8 percent by volume of the specimens with fiber lengths of 10 and 5 mm, respectively. Some of the specimens were treated with a monomer, with subsequent polymerization.

The results of physical-mechanical testing of dispersely reinforced concrete and polymer-treated concrete specimens are presented in the paper.

In all cases, the strength of the dispersely reinforced concretes after treatment with monomer increased significantly. The highest tensile strength in bending was that of specimens in which the reinforcing fibers were oriented in the concrete matrix.

A374 Bazhenov, Iu. M., "Prospects for the Application of Polymer-Treated Concrete in Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 4, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer-treated concretes (PTC) are one variety of polymer concrete. They usually consist of materials in which the mineral and polymer matrices are combined. PTC are usually produced by filling the pore space of various types of concrete with special compositions, usually based on polymers. As an exception, at the present time, concrete, the pore space of which has been filled with certain inorganic substances, e.g., sulfur, are also included in the class of polymer-treated concretes.

PTC are composite materials and have a number of attractive properties: higher strength than ordinary concrete, particularly tensile strength; high resistance to the effects of alternate freezing and thawing, particularly when simultaneously exposed to salts; high stability in corrosive media; cavitation and wear resistance several times higher than that of ordinary concretes; practically complete imperviousness to water. By altering compositions and technologies, it is possible to produce PTC with widely varied combinations of properties, including: provision of special properties (e.g., production of electric insulating PTC or, conversely, current-conducting materials); production of PTC which have identical strength, but differ by several times in modulus of deformation; preplanning of the permeability of materials, etc.

A375 Beaumont, P. W. R., et al., "Cracking and Toughening of Concrete and Polymer-Concrete Dispersed with Short Steel Wires," Journal of Materials Science, Vol 13, No. 8, Aug 1978, pp 1749-1760.

A fiber-strengthened brittle solid can crack and fracture in a number of ways and simple models can be used to describe quantitatively the fracture processes. This paper discusses some of these models and compares experimental measurements of cracking stress and toughness for two brittle fibrous composites with the theoretical predictions. The two brittle matrices are concrete and concrete impregnated polymethylmethacrylate reinforced by discontinuous (short) high strength steel wires. It involved extracting a single steel wire from each brittle matrix to evaluate the debonding stress and pull-out stress as a function of fiber embedded length. These key material parameters and the energetics of cracking determined in three-point flexural experiments, together with the cracking and toughening equations are then used to characterize the fracture behavior of fiber-strengthened concrete and polymer-concrete composites.

A376 Beliaev, V. E., and Bogdanovskii, L. N., "Thermodynamic Analysis of the Results of Testing of Polymer Concrete Under Short-Term and Long-Term Loading," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 53, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Short-term compressive, tensile, and shear strength testing of polymer concretes at various temperatures revealed certain regularities.

In the area of below-freezing temperatures, the variation of deformation with stress is linear, right up to the point of failure. With a load application rate of 60 MPa/min, the linear dependence is also retained at 293 K. Further increases in temperature result in the appearance of a nonlinear variation of strain with stress: The higher the temperature, the more clearly the nonlinearity is expressed.

Analysis of curves of the strain of polymer concrete as a function of stress at various temperatures led to the development of several empirical equations.

Thus, the studies performed allow us, based on the results of short-term testing at any given temperature, to predict the properties of the polymer concrete.

A377 Beliaev, V. E., and Iakovlev, V. M., "Strength and Deformation Properties of Reinforced and Nonreinforced Polymer Concretes Based on FAM, NTS-609-ZIM, PN-1, and EN-5 at Elevated and Below-Freezing Temperatures, With Short-Term and Long-Term Loading," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220

(C-92), Paper No. 64, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

As we know, construction structures are used over a broad range of temperatures, which influence the strength and deformation characteristics of the materials.

Tests were performed of the most widely used polymer concretes, based on FAM, NPS-609-21M, PN-1, and ED-5 resins, in various stress states (compression, extension, shear, bending) and at temperatures from 20 C to 300 C.

The specimens were tested under short-term and long-term loading in each stress state. During short-term loading, the rate of application of the load was 6 MPa/min.

Rapid loading of the specimens results in linear variation of strain with stress at normal and below-freezing temperatures. At elevated temperatures, the variation becomes nonlinear, the nonlinearity being greater, the higher the temperature.

For each polymer concrete, there is a temperature of maximum deformation. When this temperature is exceeded, the strength of the specimens drops rapidly, with a simultaneous decrease in the maximum deformation.

During long-term testing, certain regularities of creep as a function of temperature and stress were determined. Creep and the process of attenuation of deformations are more clearly seen in heated specimens than in nonheated specimens. The creep deformation, with identical levels of stress, is less in heated specimens than in unheated specimens.

However, this regularity appears only for heating up to certain temperatures: Beyond these temperatures, a further rapid increase in deformations occurs, although at certain stress levels they tend to decrease. Based on the studies performed, it has been established that under certain conditions, the temperature coefficients and coefficients of duration are quite similar in value (0.4 to 0.5) for certain temperatures. Consequently, in practical calculations, it is possible to use stress-strain diagrams for various temperatures rather than stress-strain diagrams for short-term and long-term loading.

A378 Berman, G. M., "Optimization of Compositions and Prediction of Durability of Structures of Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 32, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In order to estimate the time interval over which polymer concrete can withstand the application of mechanical loadings without failure, its

long-term deformation under the influence of tensile and bending loads and corrosive media (water and sulfuric acid solutions of 10, 30, and 50 percent concentration at normal and elevated temperatures) was studied.

The tests were performed for furan (FAM)- and epoxy (ED-20)-based polymer concretes, the optimal compositions of which were determined by rotatable experimental planning.

This paper presents optimization equations for determining the mechanical load below which polymer concrete will not fail as a result of static fatigue for a given period of time.

A379 Bhargava, J., and Rehnstrom, A., "Dynamic Behavior of Polymer-Cement Concrete," Polymers in Concrete - International Symposium, SP-58, pp 313-328, 1978, American Concrete Institute, Detroit.

For evaluating the performance of concrete constructions such as foundation piles, a knowledge of the dynamic properties of concrete is also required. The results of a study of concrete under dynamic impact loading are given in this paper. Cylinders, 100 by 200 mm, were cast from plain and polymer-cement concrete; some of the specimens were reinforced by polypropylene fibers also. The experimental details of the Hopkinson split-bar method used are given. The dynamic strength of concrete obtained was 40 to 45 percent higher than the static strength. Compared to plain concrete, polymer-cement concrete showed 30 to 35 percent higher dynamic strength, and significantly higher energy transmission capacity.

A380 Biriukov, K. S., "Influence of Repeated Long-Term Axial Compression on the Load-Bearing Capacity of Steel-Reinforced Polymer-Concrete Elements," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 55, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

This paper presents theoretical calculations that describe the effects of axial compressive loading on steel-reinforced FAM-based polymer concrete. The calculations given suggest that high strength steels should not be used to reinforce this type of polymer concrete since the elasticity of the steel rods will damage the polymer concrete on the unloading cycle leading to gradual or even rapid failure of the polymer concrete.

A381 Blinov, G. A. and Bakirov, V. M., "Conditions of Processing of Initial Materials in the Production of Polymer-Treated Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia

Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),  
Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 131, Jan  
1979; Translated from the Russian by Engineering Services Branch,  
U. S. Bureau of Reclamation Translation Group, Denver, Colo.

This report analyzes two stages in the production of a polymer-treated concrete: evacuation and impregnation.

Evacuation has an important influence on the properties of the PTC. Since oxygen, in most cases, acts to inhibit radiation polymerization, the extent to which it is removed from the material influences the radiation dose of the duration of thermocatalytic polymerization. The depth and duration of evacuation influence the rate of saturation and the distribution of the monomer in the body of the material.

The impregnation stage is the most important and definitive stage in the entire technological cycle. A number of factors must be considered: the composition and structure of the initial material, the shape and size of the product being impregnated, the duration of impregnation, the moisture content of the specimen, the viscosity of the impregnating material, etc.

A knowledge of these basic factors allows rather precise determination of the impregnation parameters.

A382 Borisevich, V. A., Veiner, B. B., Kirkovskii, D. A., and Rushii, M. P., "Radiation Polymerization of Styrene in the Production of Polymer Treated Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 86, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In order to evaluate the capabilities of gamma-polymerization treatment of styrene and determine the economically justified total dose of radiation, we calculated the cost of radiation treatment using fast electrons and gamma rays. The paper discussed calculations made to justify this treatment and the resulting savings achieved.

A383 Bozov, B. A., "Experience in Planning Shops for the Manufacture of Polymer-Based Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 37, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.



The technology of manufacturing polymer concrete products includes three factors: preparation of the components, preparation of the polymer-concrete mixture (mixing of the components) and forming.

Various institutes have developed versions of a technology for the manufacture of products of polymer concretes, allowing a successful combination of all factors, which have been in use for several years in shops manufacturing polymer-concrete products at Ust-Kamenogorsk and Svetlogorsk.

This paper discusses the technology developed and the procedures adopted to produce these polymer concrete products.

A384 *Bul'khina, Sh. A., "Study of the Viability of Polymer Cement Compositions Used to Finish the Outer Surfaces of Buildings," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 157, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Practice has shown that compositions for decorative coatings containing a complex binder consisting of a polyvinyl-acetate emulsion and cement rapidly lose their viability when used in hot, dry climates, rapidly taking on a viscosity such that they are unsuitable for application to the surface of the buildings.

In order to regulate the rheologic properties, a study was made of the influence of whey on the viscosity of the cement-polymer-water system. As the study showed, the addition of whey at 0.15 to 0.25 percent of the mass of the cement decreases the viscosity of the optimal composition from 80 to 30 P. It was found that the addition of whey increases the period of viability of the compositions by 1 to 1.5 hr and improves the physical and mechanical properties of the decorative coatings produced.

Based on the results of the studies, we can conclude that the addition of whey at 0.15 to 0.25 percent of the mass of the cement to polymer-cement compositions significantly expands the range of their application in hot, dry climates.

A385 *Burd, V. A., "Reinforced Polymer Concrete Structures for Industrial Buildings," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 48, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The development of commercial precast reinforced polymer-concrete structures, to be used in industrial buildings where the environment is highly corrosive, is very significant.

Giprotsvetmet Institute has undertaken an engineering and economic analysis of the expediency of using reinforced, polymer-concrete structures in areas exposed to highly corrosive substances due to spilling of solutions containing sulfuric acid, formation of powder containing salts of sulfur, and the presence of sulfuric acid aerosols in the air, with relative humidities of over 75 percent. As a part of these studies, working drawings have been prepared for the production of pilot-scale structures (foundations, columns, crane-support beams, trusses, and flooring slabs). Type 700 polymer concrete, based on FAM-furan resin, was used for the structures.

A386 *Burleson, J. D., et al., "An Investigation of the Properties of Polymer Concrete," SP 58-1, pp 1-19, 1978, American Concrete Institute, Detroit, Mich.*

An investigation of various formulations of polymer and aggregate composites was undertaken in order to determine possible applications of these new materials in building construction. A number of polyester-styrene-methyl methacrylate resin systems were mixed with combinations of sand, gypsum, gravel, clay, and chopped glass fibers, cast and cured, and the resulting materials were then tested. No portland cement was used. Maximum compressive strength obtained was 21,100 psi (145.6 N/mm<sup>2</sup>) and maximum splitting tensile strength was 2,210 psi (15.2 N/mm<sup>2</sup>); unit weights ranged from 122 to 145 pcf (1,970 to 2,350 kg/m<sup>3</sup>) and modulus of elasticity ranged from 1,460,000 to 3,300,000 psi (10.1 to 22.8 kN/mm<sup>2</sup>). Rapid curing at ambient temperatures was possible. The addition of a chlorendic anhydride improved polymerization at both ambient and elevated temperatures.

Detailed formulations are presented for the most promising systems investigated. These polymer composites cost more than portland-cement concretes for equal volumes of material but compare well on a strength-to-cost basis. Specific applications of these new materials will require additional development and testing. However, in many instances, they offer an attractive alternative to conventional concretes with regard to physical properties and architectural aesthetics.

A387 *Causey, F. E., "Concrete Polymer Materials Systems, Progress Report," Mar 1978, Concrete and Structural Branch, Division of Research, Engineering and Research Center, U. S. Bureau of Reclamation, Denver, Colo.*

Investigations of concrete-polymer materials for January 1974 to June 1976, under DR-256 - Engineering Materials Systems Research, are covered in this report. The two types of materials investigated were: (1) PCC (polymer-cement concrete) or PPCC (polymer-portland cement concrete). - These are modified portland cement concretes prepared by adding a monomer or polymeric material to the concrete during the mixing operation. This generally requires a final curing or a postplacing

treatment to impart improved properties to the hardened concrete. (2) PC (polymer concrete). - This is a composite material prepared by mixing a concrete aggregate with a liquid monomer or resin system, and subsequently polymerizing the monomer to form the binder for the concrete. Presently, PCC materials studied show little advantage over conventional concrete, whereas PC has shown promise. Tests of PC have shown excellent durability, and strengths of four to five times that of conventional concrete. One PC system has shown promise for high-temperature (100 to 143°C) application. Several experimental field applications of PC for concrete repair are discussed. Polymer shotcrete has also been developed using conventional portland cement shotcrete equipment.

- A388 Chebanenko, A. I., and Ivanov, A. M., "Improvement of the Design and Planning of Reinforced Polymer-Concrete Structures, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 10, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The industrial use of reinforced polymer concrete is being delayed by the lack of national standards documentation. The time has come for a comprehensive discussion of this problem, to determine the most important tasks and goals for research and areas of coordination. This paper is an overview of the directions in which research on polymer concrete structures is progressing along with the author's recommendations as to areas where future improvement in design and planning should go. Topics include: shape of structural diagram, the influence of corrosive factors, the use of statistical interpretation, loss of prestressing, stability in compression, and more.

- A389 Chebanenko, A. I., "Resistance of Reinforced Polymer Concrete to Static and Dynamic Loads, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 52, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Structural polymer concretes and reinforced polymer concretes have, as we know, a number of distinguishing properties and peculiarities, which significantly reflect on their operation and which must be considered for proper estimation of the resistance of the material and structures made of it to external effects.

Polymer concrete, in contrast to mineral concretes, is quite

sensitive to variations in external factors, e.g., loads. This paper presents equations for calculating the strength characteristic  $R_c$  and deformation characteristic  $\epsilon_c$  of the polymer concrete as well as coefficients to the equations to adjust the formulas for inclusion of steel reinforcement.

The new equations suggested for calculation of the characteristics  $R_c$  and  $\epsilon_c$  were obtained in their nonlinear statement and mathematically rigorously interpreted. Their use allows additional and, in many cases, quite significant reserves of strength of the reinforced polymer concrete to be revealed.

The question of the optimal content of reinforcement (unstressed and prestressed) was also studied, based on utilization of the entire capacity of reinforced polymer concrete for deformation within the limits of the calculated shape of the structural diagram of the material.

A390 Chekhov, A. P., and Danileiko, A. V., "Properties of Polymer Concrete Based on FA Monomer Mixed with Coke-Chemical, Production Wastes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 22, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Dnepropetrovsk Construction Engineering Institute has studied the possibility of using still residues from fractional distillation of crude benzene [KORB], a coke-chemistry production waste, as a component in a binder based on type FA furfural-acetone monomer.

KORB contains 25 to 30 percent styrene-indene copolymers, as well as ternary copolymers with methylstyrene, dimethylindene, and coumarone. They are dark brown in color, density  $1.067 \text{ g/cm}^3$ , viscosity 20 s, as measured by the VZ-4 viscosimeter at  $20 \pm 2$ .

Tests have shown that introduction of KORB to FA monomer increase the relative elongation at rupture of specimens of this binder without changing the tensile strength. The optimal quantity of the additive amounts to 50 percent of the mass of the FA monomer.

The high content of cross-linked polymer (94.98 percent) in cured FAKO binder indicates that the KORB added during curing of the monomer is chemically bonded in the system. This is confirmed by chemical and IR spectroscopic studies.

The optimal composition of polymer concrete based on FAKO combined binder has been established (mass percent); FA monomer - 6; KORB - 3; BSK - 1.38; crushed acid-resistant ceramic aggregate - 42; sand produced by crushing acid-resistant ceramic - 31; finely milled crushed acid-resistant ceramic - 16.62. This polymer concrete has the following physical and mechanical properties: density  $1800 \text{ kg/m}^3$ ; compressive strength 68.2 MPa; tensile strength 7 MPa; bending strength 19.2 MPa;

modulus of elasticity 19,300 MPa; coefficient of heat conductivity - 0.732 W/m·K; specific heat capacity - 0.607 kJ/kg·K.

Polymer concrete of this composition was studied for corrosion resistance in solutions of sulfuric and hydrochloric acids of various concentrations, and also in hot sulfuric acid etching solution at 95 C, H<sub>2</sub>SO<sub>4</sub> content 20 to 22 percent.

Polymer concrete based on FA monomer, combined with still residues, after 1 year of exposure to these corrosive media, showed a decrease in bending strength of 4.3 to 7.1 percent, depending on the type of corrosive medium, indicating the high corrosion resistance of the product. As the concentration of the acid solutions increases, the resistance of the polymer concrete increases. Two years' production testing of containers made of these polymer concretes have confirmed this statement.

The use of binders based on FA monomer containing still residue allows efficient utilization of the wastes of coke-chemical production, a decrease in the consumption of FA monomer and in the cost of polymer concrete based on modern binder with an improvement of the basic usage characteristics, toughness and elasticity, while retaining high strength.

A391 Chentemirov, M. G., "Basic Trends in Scientific Research Work Intended to Increase the Durability of Commercial Buildings and Structures by the Application of Polymer Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 1, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer concrete is widely used in reclamation and hydraulic construction, as well as agricultural construction.

The most important task for further development of polymer concrete is the development of the most effective possible new binders and improvement of those used earlier. In this respect, there is particular interest in vinyl-series monomers, especially methylmethacrylate, polyisocyanate compounds, etc. Particular attention should also be given to the technology of polymer concrete, since there are great potential reserves for increasing the quality and effectiveness of application of polymer concretes. New developments in design and planning are required to realize the full effectiveness of polymer concrete. Obviously, one great shortcoming preventing the extensive development of polymer concrete is the lack of basic standards and the insufficient level of coordination of research work.

The reliability and durability of industrial buildings and structures can be significantly increased by saturation of the pore structure of concrete or reinforced concrete with liquid materials which form structures after curing. Three basic trends can be noted in development of this problem: (1) Saturation of the pore structure of

the concrete with monomers, subsequently force-cured; (2) saturation of the pore structure of the concrete with compounds which cure along with the concrete; (3) saturation of the pore structure with melted sulfur.

Concretes saturated by monomers or oligomers with subsequent curing are called polymer-treated concretes [PTC]. Work in this area is moving forward, using both liquid and gaseous monomers.

PTC characteristically have high compressive strength (up to 90 to 160 MPa), good cold resistance are practically impervious to liquids and highly resistant to corrosive media. Unfortunately, these materials are still in the stage of experimental development.

The main tasks in the area of extensive development of PTC include the development of more effective and less expensive saturating compounds, the creation of effective technological systems, the development of effective structures and areas for their application.

A significant improvement in the properties of concrete and reinforced concrete, resulting in an increase in the reliability and durability of industrial buildings and structures, could also be achieved by effective modification of the composition of the concretes themselves (polymer-cement concrete). The works of both Soviet and foreign specialists have proven that the introduction of various polymer additives to concrete can be effective as a concrete modifier. The introduction of polymer additives can significantly increase the strength, density, cold resistance, resistance to corrosive media and other properties, allowing significant increases in the reliability and durability of commercial structures without great expenditures. This is a particularly promising area for further work.

A392 *Cherkinskii, Iu. S., "Prospects for the Development and Application of Polymer Cements," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 137, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Polymer cements based on aqueous dispersions of polymers are widely used today as finishing, adhesive, and insulating compositions. It is quite obvious that this established practice will expand in the next few years. Polymer additives of the second type (aqueous solutions of polymers) are also applicable for the design of structural and impermeable concretes. The range of water-soluble natural, artificial and synthetic polymer additives suggested by the technical and patent literature is so broad that they, like combined additives containing polymers, have a very bright future.

In practice, the problem of the deserved broad application of polymer additives can be solved if these additives are delivered to reinforced-concrete plants and construction areas in a form fully ready for use. Unfortunately, apparently the chemical industry cannot accept

the responsibility for this completely. For example, our own experience, extending over a number of years, with the production of the well-known additive latex SKS-65 GP, grade "B", at synthetic rubber plants, has revealed certain organizational difficulties. It, therefore, seems promising to follow the example of the construction materials industry of Moscow, and create special production facilities for the manufacture of both pure-polymer and combined additives to satisfy the needs of each region.

The use of polymer cements, particularly polymer-cement finishing materials, based on aqueous dispersions of polymers has been attempted essentially independently, by many plants, construction trusts and administrations. This generally favorable phenomenon has proven the right of these new structural materials to continued existence. However, this has sometimes led to a "cottage-industry" approach, and the manufacture of clearly unsuitable formulations, which factories produce because they are "their own." The latest results of scientific research are not introduced on the broad scale. All of this indicates the need for clearer coordination of the efforts of industrial enterprises, scientific research and planning-design organizations in the area of development and introduction of polymer cements for various purposes.

A393 *Cherkinskii, Iu. S., "Status and Prospects for Development of Work in the Area of Polymer Cements," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 143, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The polymer cements we are studying are materials based on a composite binder, containing an organic polymer and an inorganic binder. The organic component of the polymer cement usually consists of aqueous dispersions of the products of polymerization and copolymerization of vinyl acetate and acrylates, natural or synthetic (butadiene-styrene, chloroprene, vinylidene chloride) latexes, water-soluble epoxy, polyester, organosilicon, furan and carbamide resins, polysaccharides, cellulose esters, sulfurated products of the polycondensation of melamine, naphthaline with formaldehyde, etc. The inorganic binders used are portland cement, alumina, and magnesia cements, liquid glass, gypsum, gypsum-cement-pozzuolana binder and lime. Thus, the collective term "polymer cement" refers to polymer cement per se, polymer gypsum, gypsum-polymer cement, etc.

In recent years, the number of publications dedicated to the creation and use of polymer-cement additives for mortars and concretes has risen sharply. This is particularly true of the patent literature.

An analysis is presented of these works, as well as monographs dedicated to polymer cements based on aqueous dispersions of polymers; considerable attention is given to the problem of stabilization, and the

main areas of application are discussed. The most promising area of application of water-soluble polymers (polyelectrolytes) is that of improvement of the quality of concrete by plugging of pores and defects in the cement paste, and also by plasticizing (with "superplasticizers"). A special discussion is presented of the possibilities of chemical interaction of organic polymers and cements.

A394 Choshchshiev, K. Ch., "Study of Polymer Concrete Utilizing Raw Materials of the Turkmenian SSR, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 16, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In order to develop new, effective construction materials, studies have been performed on the expansion of the possibility of application of local-raw materials, such as the sand in dunes in various areas, expanded argillite, rock sand and cotton stems, as well as synthetic corundum. In these studies, polymers are usually the binders of choice, since they allow the production of new structural materials with highly effective properties (adhesion, strength, wear resistance, resistance to the atmosphere, stability in chemically corrosive media), and also have the best decorative-esthetic qualities, improved production technology, etc., practically impossible to achieve in materials based on traditional inorganic binders.

Polymer compositions based on alkyl-resorcinal epoxy resin type EIS-1B and furfural-acetone monomer type FA have been developed, using dune sand and synthetic corundum with various ratios of the components, depending on the purpose and usage conditions of the products.

The use of compositions which have been developed to cover the operating parts of dredges working on the Kara-Kum canal has resulted in an increase in wear life by a factor of 3 to 3.5. Furan-epoxy polymer mortar containing dune sand has also been used to cover the surfaces of highway bridges and containers for processing of petroleum products. Porous polymer concrete based on the carbamide resin MF-17 and UKS resin with organic fillers, dune sand and expanded argillite, has been developed for lightweight partition structures and heated flooring for rural-area construction in the republic.

This report presents tabular and graphic data illustrating the primary physical and mechanical properties and chemical stability of the polymer compositions which have been developed.

Studies are now under way for the development of polymer-concrete compositions based on an unsaturated polyester resin using local rock and dune sands to produce artificial finishing materials which meet the requirements of esthetics and modern architecture.



A395 Cook, D. J., and Crookham, G. D., "Fracture Toughness Measurements of Polymer Concrete," Magazine of Concrete Research, London, Vol 30, No. 105, Dec 1978, pp 205-214.

This paper describes the use of linear elastic fracture mechanics to examine the behavior of premixed and impregnated polymer concretes. Results are given for three monomers, styrene, methyl methacrylate and butyl methacrylate, and two strengths of concrete, as well as for appropriate control series. The notched-beam technique is used to determine fracture parameters, together with compliance measurements to determine slow crack growth. Experimental results indicate that terminal treatment to polymerize the monomer in the premixed concrete has a marked influence upon fracture toughness. Irradiation, however, has little influence. Polymer impregnation increases the stress-intensity factor and the strain at failure, the latter increase being influenced by the extensibility of the polymer. The results also show that the plain and the premixed polymer concretes are partially notch-sensitive, whereas the impregnated polymer concrete is a notch-sensitive material.

A396 Davydov, S. S., "Reinforced Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 2, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Reinforced polymer concrete is a cementless concrete based on a polymer binder, containing metallic or nonmetallic reinforcement, either concentrated or dispersed. If the reinforcement is made of steel (wire or rod), it is called steel-polymer concrete.

This paper describes the different types of steel polymer concretes available showing the advantages and disadvantages of each type. Uses of the materials described are given, and results of research conducted are presented. The paper covers reinforced polymer concretes containing steel, wire, rods, fibers, and screens, both metallic and nonmetallic. Associated topics covered include binders, aggregates, and prestressing.

A397 DePuy, G. W., and Selander, C. E., "Polymer Concrete - Trials and Tribulations," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 461-482.

Polymer concrete has been under investigation by the Bureau of Reclamation primarily for applications in water resources engineering structures. Methyl methacrylate and vinyl ester polymer concretes have been investigated. Laboratory studies have been directed toward developing fabrication or application procedures and the determination of the properties of the materials. Field studies have been concluded to investigate potential applications and have revealed some problems in

scaling up from laboratory procedures to field applications. The field applications include abrasion resistant patches and overlays, and polymer shotcrete. Polymer concrete appears to be a high strength, durable engineering material with good potential for applications in construction projects. Several problems have been identified in the practical applications; however, further development should solve these problems.

A398 Diabov, V. D., Sakanskii, Iu. N., and Voznesenskii, V. A., "Multi-criterion Optimization of the Quality of Low-Temperature Curing Polymer Solutions," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. N. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 34, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

An attempt was made to adjust an epoxy-resin composition, capable of curing at the temperature of the ambient air down to -20 C. The following tasks were set as a part of this study:

to optimize the adhesive composition to achieve essentially complete curing in the temperature interval from 0 C to -20 C in the shortest possible time; to achieve a viable, technologically convenient composition; to produce an adhesive seam which does not lose its strength upon thawing.

The solution of such a multiple-criterion problem is impossible without the use of methods of the mathematical theory of experiments. With this purpose in mind, the problem relating to the strength of the adhesive seam was attacked first. An  $N_5$  plan, near D-optimal, was used for this purpose. The adhesive composition used was an alkyl-resorcinol resin, EIS-1. The studies were conducted at ambient temperatures from -10 C to -20 C.

As a result, adequate models of viscosity were produced for three temperatures, and isolines of the surfaces were constructed in space.

A399 Dikeou, J. T., "Polymers in Concrete: New Construction Achievements on the Horizon," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 1-8.

The paper discusses the history of the development of the various types of concrete-polymer materials, including polymer-impregnated concrete, polymer concrete, and polymer-portland cement concrete. Early applications under consideration for these new composites are discussed, and the progression of events that led to present development and uses is reviewed. Typical properties of the various composites are presented. As compared to ordinary concretes, these materials can be tailored to give much better structural and durability properties.

ACI activities are reviewed; included are conduct of two symposia and publication of proceedings, publication of a state-of-the-art report,

participation in the First International Congress on Polymers in Concrete, and conduct of this Second International Congress. These and other exchanges of technical information have, and will continue to accelerate the rate of development and uses of polymers in concrete.

A400 Dolgoplov, N. N., and Kozlovskii, A. I., "Optimization of the Technology of Polymer Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 81, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The time required to manufacture polymer-treated concrete products, including all stages - drying, evacuation, saturation, and polymerization - as applicable to concrete slabs and pipes with wall thickness 4 cm is

$$\tau_{\text{tot}} = 1.3 \cdot \left( \frac{0.103}{W_o^{1.07}} \cdot t_c - \frac{10.7}{W_o^{1.15}} \right)^{-1} + (0.035\mu - 2.5t_n - 0.55p_B - 22p_B^2 - 0.112) + \frac{1}{2} [0.83 + 0.5(0.69 + 4K)^{0.5}], \quad (1)$$

where  $W_o$  is the initial moisture content of the concrete products, %;

$t_c$  is the temperature in the drying chamber, C;

$p_B$  is the applied vacuum, MPa;

$K = 0.00655 R_{\text{ptc}} - 0.395 C - 0.425 t_{\text{pol}} + 5.05$ ;

$C$  is the concentration of the initiator, %;

$t_n$  is the polymerization temperature, C.

This equation was derived by applying mathematical methods of planning and can be used to optimize the process as a whole.

However, the application of the equation is limited, permissible only within the range of parameters studied: Radiation-convective drying;  $t_c = 105$  to  $200$  C;  $W_o = 3$  to  $11$  percent; saturation with methylmethacrylate;  $\phi = 90$  to  $98$  percent;  $\tau_B = 0.083$  to  $0.25$  hr;  $p_B = 0.014$  to  $0.096$  MPa; thermocatalytic polymerization, with benzoyl peroxide initiator;  $C = 1.5$  percent;  $t_n = 70$  to  $90$  C;  $R_{\text{ptc}} = 50$  to  $100$  MPa; total porosity of concrete products  $22$  to  $25$  percent.

A401 Doliuk, V. P., "Study of Technology and Properties of Polymer-Treated Concrete Pipe," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie

Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet  
Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr'  
1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 123,  
Jan 1979; Translated from the Russian by Engineering Services  
Branch, U. S. Bureau of Reclamation Translation Group, Denver,  
Colo.

The present study was performed on pipe fragments (rings) made from a concrete mixture with W/C = 0.4, cone slump 3 cm, by the method of vibration forming. Pipes 300 mm in diameter with wall thicknesses of 30 and 40 mm were saturated (24 hr at +150 C) with and without vacuum treatment. The saturating monomers used were methylmethacrylate, styrene, and mixtures of the two. The polymerization initiator used was benzoyl peroxide. Polymerization of the monomer in the body of the concrete was performed at +80 C, with water used as the sealing medium.

A402 Dorofeev, K. S., and Shumilova, I. V., "Strength and Deformation Properties of Cement-Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 155, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A study was made of the structural properties of cement-polymer concrete based on shell limestone from the Siniavskii deposit in Rostov oblast. The fine aggregate used was sand, obtained by crushing Coquina. The polymer component was water-soluble resin No. 89, at 2 percent of the mass of the cement. The cement was cured at +13 to 15 C, relative humidity 60 to 95 percent. The strength of the cement-polymer concrete was 20 percent higher than that of concrete without resin No. 89.

The tensile strength of the cement-polymer concrete, based on the results of splitting of cubes, varied from 1.53 to 4.39 MPa, with compressive strengths of 14.5 to 37.4 MPa; the figures for concrete without resin No. 89 were 1.35 and 2.85 MPa and 18.3 to 28.5 MPa, respectively.

Compression testing of prisms revealed an increase in longitudinal deformations in the cement-polymer specimens. The longitudinal compressive deformations, when loaded close to the point of rupture, varied from  $82 \cdot 10^{-5}$  to  $272 \cdot 10^{-5}$  for the cement-polymer concrete, from  $85 \cdot 10^{-5}$  to  $204 \cdot 10^{-5}$  for the concrete without resin No. 89.

A403 Egorov, Iu. V., and Kaleev, I. P., "Peculiarities of the Deformation of Polymer-Treated Concretes Under Load," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov,

*Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 104, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The stress field at the end of a crack is of great significance for prediction and explanation of the development of brittle fracture in polymer-treated concrete. Simple criteria of failure in the elastic-plastic or viscous-plastic cases are of particular interest. For a linearly elastic body, the stress field which arises near the tip of a crack can be expressed through the external loads or stresses, considering the geometry of the body, and can be characterized by the stress intensity factor  $K$ , the force of advance of the crack or the rate of liberation of elastic energy  $G$  and the crack propagation speed  $a$ . Characteristics  $K$  and  $G$  reach their critical values  $K_c$  and  $G_c$  at the point of loss of crack stability. This quantity is accepted as a measure of the strength of the material. The difficulty of studying the elastic-deformation characteristics of polymer-treated concrete results from the fact that the basic parametric points are in the local zone of the area of fracture, while the process itself, from the formation of a microscopic crack to actual fracture, occurs very rapidly at relatively high loads. Therefore, a test method must have a high degree of accuracy, with automatic recording of all of the characteristics studied. We have developed an installation allowing tensometric and acoustic measurements in the process of axial loading of a specimen, as well as recording of the moment of formation and rate of propagation of cracks during bend testing. One advantage of the installation is the possibility of automatic recording of changes occurring in the structure of a polymer-treated concrete as it is loaded. The data from studies of polymer-treated concretes with various initial compositions indicate high effectiveness of operation of the installation.

A404 *Egorov, Iu. V., "Polymer-Treated Concrete with Surface Saturation," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 80, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Studies of polymer-treated concrete materials, their technology, properties and structural peculiarities, new saturating compounds and initiating systems, as well as areas of the most efficient utilization, have formed the subject of large numbers of published works in recent years, both in the USSR and abroad. The greater effectiveness of these materials is particularly clearly seen in the manufacture of products in which the high strength of the polymer-treated concrete is utilized, resulting in a change in the cross section of the elements, a decrease

in the quantity of materials required and in the weight of the structure as a whole. However, the high cost and scarcity of monomers, which must be used to saturate the concrete products in order to improve their characteristics, limit extensive application of polymer-treated concrete to construction. In those cases in which high strength is not the most important operating property of a product, but the product must meet high requirements in terms of frost resistance, resistance to water and corrosion, durability, abrasive wear, and must have high gas and water impermeability, it is more desirable to surface-treat the products. This allows us to reduce the consumption of the saturating compound to 1 to 2 percent of the mass of the product, without significantly decreasing the characteristics just listed. The range of saturating compounds is significantly expanded when surface modification is used. It has become possible to use liquid compounds, such as methylmethacrylate (MMA) and styrene, plus more viscous compositions based on polyester, epoxy, and other resins. Good results have been achieved by saturation of the surface of concrete products with melted sulfur.

This treatment of products allows many construction objects to be protected, particularly road and airfield pavement, hydraulic construction projects, particularly in areas where the water table rises and falls and where there is alternate freezing and thawing. Pipelines and other water management and reclamation structures can also be protected.

A405 Elshin, I. M., "Polymer Concretes in Water-Management Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 38, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Furan binders type FA and FAM, which are less expensive and more plentiful than epoxy binders, have been successfully used for polymer concretes in the construction of wear-resistant linings for water-intake structures, where they have replaced expensive, labor-intensive linings made of metal and stone. The experience gained in the manufacture of pressurized and sewer pipe of furan-polymer concrete has also been positive.

However, furan-polymer concrete does have certain inherent negative properties: low adhesion with cement concrete, high deformability, difficult manufacturing technology, difficulties in pouring, etc.

Epoxy-coal-tar resins are quite effective for water-management construction, but furan-epoxy resins are of particular interest, particularly type FAED-20, which contains 20 percent epoxy resin and 80 percent monomer.

FAED-20, produced by a special process, combines the good stability in alkaline media and mineralized water, high strength and low-cost characteristics of furan resins with the good adhesion, including adhesion with cement concrete, low shrinkage, as well as high cavitation,

water, crack and wear resistance characteristics of epoxy resins.

While acknowledging the great future of FAED resins, we should note that there already is some positive experience which has been gained in their application in the production of wear-resistant concretes, adhesive compositions, and compositions for injection.

A406 Elshin, I. M., "Polymer Concretes in the Construction of Hydraulic Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 8, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Furan polymer concretes, based on furfural-acetone type FA (or FAM) resins, have high chemical stability, strength, wear and cavitation resistance, and resistance to the effects of the atmosphere. They are significantly more readily available and less expensive than epoxy concretes, but have inherently higher shrinkage, as well as poor adhesion to cement concrete (dropping practically to zero when the cement concrete is wet). All of this makes the construction of protective linings difficult, since it is necessary to install special anchors to hold the polymer concrete lining to the concrete substrate.

The solution to the situation which has developed is the use of modified epoxy and furan resins, particularly epoxy-coal and furan-epoxy (type FAED) resins.

As special studies of the structure of FA polymer, made with finely dispersed aggregates of various mineralogic composition have shown, an increase in the adhesion between the polymer and the particles of aggregate tends to increase the internal stresses in the system, which may lead to a reduction in strength. Therefore, the optimal version, when there are strong adhesion bonds, is a two-component aggregate, in which one of the components, which has low adhesion for the polymer, helps to reduce the internal stresses in the system. The optimal ratio of components can be selected experimentally. One such pair, e.g., is a quartz aggregate with a small quantity of graphite powder, which does not interact with FA polymer and therefore decreases the internal stresses.

This has been confirmed experimentally. For example, when graphite powder (5 percent) is added to a composition based on quartz sand, water resistance is increased from 0.75 to 0.88. The effectiveness of this approach has also been established in experiments determining the strength, cold resistance, and resistance of compositions to cavitation, wear, and impacts.

In hydraulic construction, compositions based on epoxy resins are used to protect structures from cavitation. Thus, according to R. Ie. Iazev (see abstract of report), the cavitation resistance of a polymer mortar based on ED-16 and ED-20 resins modified with thiokol exceeds the cavitation resistance of grade M400 cement concrete by a factor of 2500. After 5 to 11 years of operation, linings of this composition are still

in satisfactory condition at a number of hydroelectric power plants.

Since 1961, wear-resistant polymer concretes based on FA resin have been successfully used as linings, 12 to 15 cm thick, in a number of water-intake structures, where they have replaced plates made of chilled cast iron, steel, sawn stone, etc. The extensive use of furan polymer concrete, first in monolithic, then in precast form, has been successful at several dams: Besh-Alysh, Sary-Kurgan, Iakkabag, Gava-Sai (UzSSR), Karaspan (KazSSR), and the Bashariu River (AzSSR). Successful experience has also been reported in the manufacture of pressurized and drain pipe of FAM-based polymer concrete, pilings for hydraulic structures used in the Black Sea and polymer-concrete structures for oil-drilling platforms in the Caspian Sea (see abstract of report).

A407 Fantalov, A. M., Davydov, S. S., Ermakov, N. S., and Shevchenko, A. I., "Development and Introduction of Structures Based on Polymers to Industrial Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 9, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Problems of corrosion control in industrial construction are of exceptional significance, due to the large volume of such construction and the need to assure durability of buildings and structures in corrosive environments.

The processes of corrosion are particularly active for metals, concrete, reinforced concrete and other materials at plants in the chemical and nonferrous-metals industries, in coke-chemical facilities, animal-husbandry installations and in other places where the construction structures are exposed to highly corrosive solutions and gases.

Corrosion processes are intensive in cases where chemical and physical factors act on the structures simultaneously; for example, the combination of a corrosive environment and high temperature or frequent alternation of freezing and thawing, the presence of salt solutions in a dry, hot climate on surfaces of evaporation, etc. One of the main causes of early failure of construction structures due to corrosion is the use of construction materials which are not resistant to a given corrosive medium, poor performance of construction operations, equipment installation or anticorrosion protection during construction. Due to these facilities, many industrial buildings and structures are abandoned before they should be, which represents a great loss to the national economy.

The basic construction material used in modern construction is reinforced concrete; however, it has insufficient chemical stability.

Original structures made of reinforced polymer concrete have been developed and are described in many authors' certificates; these structures have high strength and crack resistance, controlled



deformation properties, and most importantly, significant stability when exposed to corrosive media.

During this time, such structures as baths for the electrolysis of zinc and copper, various tanks and containers, slabs, columns, beams, foundations, including foundations beneath equipment, supporting structures for various types of pipelines, trenches for acid runoff, various linings for containers, floors and other structures requiring no additional lining or facing have successfully completed industrial testing and have been put in use at the Dzhezkazgan and Moscow copper-smelting plants, the Ust'-Kamenogorsk lead and zinc plant, the Leninogorsk multimetals plant, the Balkhash and Almalyk combines and other enterprises. Baths for the electrolysis of zinc are in mass production and the manufacture of baths for the electrolysis of copper using prestressed FRP and steel reinforcement has been begun. At the Ust'-Kamenogorsk and Leninogorsk multimetals combines, over 1000 zinc electrolysis baths are in successful use. At the Dzhezkazgan copper-smelting plant, the construction of three-section cooling towers using polymer concretes has been begun.

The introduction of reinforced polymer concrete to the nonferrous metallurgy industry and the economic expediency of the use of this material in shops with highly corrosive environments has allowed the working drawings to be developed for typical reinforced polymer-concrete structures such as:

- Load-bearing structures for industrial buildings (foundations, columns, crane-support beams, truss beams, roofing slabs, etc.);

- Baths for the electrolysis of zinc and copper;

- Various tanks for hydrometallurgical shops (for copper, zinc, and sulfuric acid production);

- Bath support frameworks and built-in scaffolds for shops for the electrolysis of copper and zinc;

- Foundations beneath process equipment, including slurry pumps;

- Block linings for tank apparatus.

A408 *Fedorov, A. E., and Shishkanov, V. M., "Mechanism of Influence of Water-Soluble Polymer Resins on the Crack Resistance and Durability of Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 153, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The durability of concrete and reinforced-concrete structures is determined to a great extent by their crack resistance. One significant cause of decreased crack resistance in a number of modern structures is the influence of the repeated changes in relative humidity of the surrounding air, or of periodic wetting of the structure. Work performed in the Department of Construction Materials of the Moscow Institute of Railroad Transport Engineering has shown that one possible cause of the

formation of surface cracks and ultimate failure of concrete is nonvisible: capillary shrinkage under the influence of capillary forces.

The extent of nonvisible capillary shrinkage of the outer layers of the concrete is determined by the surface tension of the liquid phase in the pores of the concrete, the degree of wetting, the ratio of the area of wetted pores to the entire area of the element, the gradient of moisture content in the surface layer of the concrete, as well as the structure of the pore space of the concrete.

It can be assumed that certain types of surface-active additives will have a positive influence on the crack resistance and durability of concrete structures.

In the present work, we studied the influence of a number of surfactant additives, including polyamide resin No. 89, a combined additive consisting of polyamide resin No. 89 and epoxy resin DEG-1, and the organosilicon fluids GKZh-94 and GKZh-11. It was shown that the introduction of water-soluble resin No. 89 at 2 percent, or of organosilicon fluid GKZh-11, at 0.15 percent of the mass of the cement is an effective means of increasing the crack resistance of the concrete.

The mechanism by which the additives influence the crack resistance of the concrete was determined, and a method was suggested for analytic calculation of the measure of wetting of the concrete on the basis of the kinetics of capillary uptake, as well as a method of calculating the mean radius of capillaries, based on the results of determination of differential porosity by the method of mercury porosimetry.

A409 Feild, R. B., "Methyl Methacrylate - An Overview," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 331-336.

Methyl methacrylate is an organic chemical made by the acetone cyanohydrin process from materials derived from natural gas. Its history reaches back over 100 years, and since its first large volume use of clear sheeting for military aircraft in World War II, it has found many uses. Methyl methacrylate is produced in large quantities because it can be polymerized or copolymerized, producing a wide variety of useful products, including clear acrylic sheeting, house paints, automotive finishes, and even floor polishes. One of the newer applications is the use of methyl methacrylate as a component in polymer concrete bonding systems. While the monomer has been made and used safely for over 40 years, certain hazards such as the material's flammability must be recognized and precautions taken to insure its continued safe handling and production record. Methyl methacrylate is a skin sensitizer and direct contact should be avoided. In addition, prolonged breathing of its vapors may result in temporary respiratory related reactions. However, well established screening tests indicate the product is probably not a carcinogen.

A410 Fontana, J., et al., "Rapid Patching of Deteriorated Concrete Using Polymer Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 105-119.

The increased use of deicing salts is resulting in rapid deterioration of portland cement concrete bridge decks. Corrosion of the reinforcing steel by the chlorides results in an increase in the volume of the steel. This expansion produces stresses in the concrete which result in delaminations and surface spalling. The repair of spalls with conventional durable patching materials can be made only if traffic can be diverted from the patched areas for several days. Therefore, a durable patching material which will allow traffic to resume over the repaired area in a few hours is needed. The requirements of a quick cure time and durability can be met by the use of polymer concrete.

Polymer concrete (PC) is a composite material in which the aggregate is bound together in a dense matrix with a polymeric binder. The aggregate is mixed with a monomer mixture and subsequently cured in place. PC combines the premix characteristics of portland cement concrete with high strength, long-term durability, and short cure time. The high early strength of PC is suitable for use in the repair of highway structures where traffic conditions allow closing of the area for only a few hours.

A411 Fowler, D. W., Kukacka, L. E., Paul, D. R., Schrader, E. K., and Smoak, W. G., "Safety Aspects of Concrete-Polymer Materials," Polymers in Concrete - International Symposium, American Concrete Institute, Detroit, SP-58, 1978, pp 123-138.

The use of concrete-polymer materials in construction requires that users be knowledgeable concerning safety. This paper discusses safety aspects of chemicals and construction practices.

Monomers, from which polymers are made, are generally volatile, combustible, and toxic liquids. The required level and effectiveness of inhibitors, storage temperature, flammability, and toxicity are discussed for the most common monomers. There are several types of initiators for which storage temperatures, flammability, explosive characteristics, handling requirements, and methods of disposal are discussed. Required construction practices to insure safety are given. Training of workmen, storage and handling of chemicals including the use of electrical power and appliances, procedures to be used to avoid bulk polymerization and disposal of catalyzed monomer are discussed. Other hazards including high temperatures associated with drying and curing operations are mentioned. It is concluded that, although hazards exist, proper attention to basic safety requirements can insure safe construction.

A412 Fowler, D. W., and Paul, D. R., "Polymer-Concrete for Repair of Bridge Decks," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 337-350.

Repair of concrete bridge decks is a major problem faced by highway departments. Polymer-concrete is a composite of aggregate and liquid monomer which is subsequently polymerized to form a strong, durable material. The primary component in the present case is methyl methacrylate, a low viscosity monomer, which is used with an initiator-promoter system to produce polymerization in 30 to 90 min. Repair

procedures are given. Examples of repairs on bridge decks in Texas, which range from thin overlays to full-depth structural repairs, are presented.

- A413 Fukuchi, T., Ohama, Y., Hashimoto, H., and Sugiyama, M., "Properties of Steel Fiber Reinforced Polymer Modified Concrete," Proceedings of the Twenty-First Japan Congress on Materials Research, The Society of Materials Science, Japan, Mar 1978, pp 163-166.

In recent years a large number of papers on steel fiber-reinforced concrete have been published, and these investigations have enabled to introduce the steel fiber-reinforced concrete into the field applications. Steel fiber-reinforced concrete has some advantages such as high tensile strength, flexural strength, impact strength and toughness, in comparison with ordinary concrete. However, in general, its consistency is inferior because of addition of steel fibers. It is expected that its consistency and mechanical properties are improved by modification with polymer dispersions. The influences of steel fiber content, water-cement ratio, polymer-cement ratio, etc., on the consistency and the mechanical properties of steel fiber-reinforced polymer-modified concrete (abbreviated as SFRPCC) are tested, and on the basis of the results the possibility of its introduction into the field applications is discussed in this paper.

- A414 Galaktionov, A. I., "Two-Package Furan Mortar Compositions for Chemically Stable Flooring," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennyykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 73, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In order to expand the area of application and improve the quality of compositions based on furan resins, a technology has been developed for manufacturing and supplying them in two packages: the dry mixture of filler plus curing catalyst (package 1) and the binder plus modifying additive (package 2) (USSR Author's Certificate No. 491597). At the worksite, the contents of the two packages are mixed in any type of mixer until a homogeneous solution is produced.

The physical and mechanical indices, chemical stability, permeability, and other indices of the two-package furan compositions were studied. Laboratory floor sections were made using the compositions and their resistance to corrosive and mechanical effects was studied, allowing the area of application of such floors to be determined.

In 1974, a continuous floor covering with an area of over 50 m<sup>2</sup> was put down in the fluorine-salt shop, using the two-package product.

Periodic observation of the floor indicates that it is still in normal condition.

In 1977, a floor was put down at the Dorogobuzhskii Nitrogen Fertilizer Plant in an area where the exhaust gases from the sulfuric-acid shop were trapped. This floor was surfaced with polymer-concrete slabs with an intermediate layer of the two-package furan solution, and covered an area of over 350 m<sup>2</sup>.

- A415 Gans, Iu. Kh-A., Brikker, Ia. I., and Blank, N. B., "Increasing the Impact Resistance and Thermal Stability of Polymer-Concrete Floorings Slabs," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 14, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A production line for the manufacture of polymer-concrete flooring slabs has gone on line in Tallin.

To increase their thermal stability and resistance to organic acids, a study has been made of modification of these slabs with styrene-free polyester resins using alkyl compounds of the sulfolan series. The maximum increase in thermal stability and acid resistance is achieved by introducing 12 to 18 percent diallyloxysulfolan.

An increase in impact resistance is usually achieved by introducing liquid raw rubber to polyester resins, but this method is not suitable for the manufacture of polymer-concrete mixtures in a high-speed mixer, as is used in this plant. In cooperation with the National Scientific Research Institute for Synthetic Rubber, the polymer concrete has been modified by the addition of finely dispersed polyacetal-urethane rubber. Physical-mechanical tests and electron microscope studies indicate that the maximum specific impact toughness is achieved with the maximum specific surface of the dispersed phase in the polyester-rubber binder.

- A416 Garbar, L. D., and Gomeniuk, V. M., "Prospects for the Use of Polymer Concrete for Marine Hydraulic Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 41, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In many marine structures (e.g., in the structures used in wharves), the concrete is subjected to the effects not only of the marine environment, but also of various fertilizers, sugar, petroleum, acids,

etc. This has drawn the attention of scientists and engineers to the problem of increasing the corrosion resistance of construction structures by the use of new types of concrete, polymer concrete and polymer-treated concrete, which do not require special protection. To date, only a few attempts have been made in the USSR to use structures of reinforced polymer concrete in the construction of marine projects. For example, Gipromoneft Institute in Laku has conducted studies of the physical and mechanical properties of structures made of reinforced polymer concrete based on FAM furfural-acetone monomer. The results of these studies have been used in the construction of oil derricks. This same material has been studied under the conditions of the Black Sea. The data produced by 7 years of testing of reinforced polymer-concrete pile models under natural conditions indicate that the strength and resistance figures for this material are quite sufficient: The tensile and impact strength, as well as the crack-formation torque during bending for FAM polymer concrete is 3 to 3.5 times higher than for ordinary cement concrete, and these materials are further distinguished by their good compression and bending strength and creep attenuation. The long-term strength of these structures, considering the usage conditions, scale factor, etc., is 25 MPa, whereas for type M300 cement concrete, the compressive strength, as determined by testing, without considering usage conditions, is 13 MPa. These data indicate the advantages of FAM-based polymer concrete. The primary obstacle to its use is its high cost; however, due to its greater service life, the initial costs are rapidly amortized.

A417 Gerwick, B. C., Jr., "Application of Polymers to Concrete Sea Structures," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 37-43.

Concrete sea structures are typically subjected to a very large number of cyclic loads in an adverse environment. Environmental conditions include salt water and oxygen in combination, wave action, and ice. Durability is essential. It is measured by the properties of impermeability, abrasion resistance, cavitation-resistance, and low ice adhesion. Effective strength has a particularly high influence on the practicability and economy of concrete for sea structures. Higher compressive and tensile strengths lead to reduced thickness and, hence, less weight and less draft, which in turn reduces the hydrostatic load. The results of higher strength are cumulative. Polymer concretes, whether PIC or PC, appear to offer tremendous potential for floating structures and ships. When combined with wire fibers or mesh, the concrete can provide significantly greater toughness against impact. It is anticipated that the initial applications will be to the critical zones of concrete sea structures which are subjected to the extremes of exposure, abrasion, and strain. An economic evaluation indicates that there exists relatively little cost constraint in applications to concrete sea structures. Rather, the proper use of polymers may greatly widen the opportunity for the employment of concrete in the sea.

A418 Ghosh, R. K., Phull, Y. R., and Pant, C. S., "Special Aspects of Resins Mortars for Cement Concrete Pavement Repairs," Polymers in Concrete - International Symposium, SP-58, pp 103-122, 1978, American Concrete Institute, Detroit, Mich.

Combining the properties of rapid hardening, good adhesion, abrasion resistance, and strength as they do, synthetic resins have gained popularity for rapid repairs of cement concrete structures, including cement concrete pavements. In case of pavements, however, their constant exposure to environment - heat, cold, rains - and the fact that coefficients of thermal expansion of cement concrete and the resins are considerably different, make it imperative to study the behaviour of cement concrete-resin mix composites for deciding upon their suitability under given climatic conditions. Central Road Research Institute, New Delhi, has been actively associated with the use of synthetic resins for repair of pavement structures in India, and has already reported detailed studies on the various properties of resin-sand mortars using typical epoxy and polyester resin formulations, and their applications in the repair of cement concrete pavements. Based on the problems arising in the field, the Institute has, of late, paid special attention to the effect of climatic changes on the bond of such composites through accelerated tests. So far as is known from the published literature, this is probably the first time that such studies have been undertaken for the cement concrete-resin mix composites, and would, therefore, be of special interest to all concerned with the study and application of synthetic resins for repair of cement concrete pavements.

A419 Golikov, Iu. A., Kozlovskii, A. I., Maloshitskii, A. S., and Starkov, A. A., "Mass Transfer in Processes of Saturation of Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 87, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

An earlier paper was written to study the analytic expressions for calculation of the depth of saturation of bodies with capillary pores under conditions of one-, two-, and three-dimensional mass transfer, unfortunately, the expressions produced were usable only if the process of saturation was static, and did not reveal the kinetic regularities of the parameters included in them.

This paper presents equations to account for the kinetic regularities and provide answers to depth of saturation.

The degree of saturation is related in a definite manner with the kinetic parameters, the functional relationship of which can, in general form, be expressed by the equation

$$\phi_i = f(\tau_B, P_B, \tau_n) , \quad (1)$$

where  $\tau_B$  is the time of preliminary evacuation of the product, hr;  $P_B$  is the depth of the vacuum, MPa;  $\tau_n$  is the saturation time, hr.

In order to define the functional relationship (1) in explicit form, we performed studies on cubic specimens with an edge length of 7 cm based on a cement-sand solution manufactured by the ordinary technology (C/S = 1:3; W/C = 0.4; portland cement grade 500; sand with  $\mu = 3.29$ ). To create conditions of one-dimensional mass transfer, the corresponding faces of specimens were covered with a layer of polyepoxy. The saturating fluid used was methylmethacrylate.

A420 Golikov, Iu. A., Mirotvortsev, I. I., and Sukhanov, M. A., "Influence of Quantity of Polymer on Strength of Polymer-Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennyykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 85, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

As our preliminary data have shown, with a small content of polymer in the pores and capillaries of concrete, a graph of strength as a function of polymer content does not follow a straight line; the functional relationship can generally be represented by the equation

$$R_{PTC} = AC_n^B + D \quad (1)$$

where  $R_{PTC}$  is the prism strength of the polymer-treated concrete, MPa; A and B are coefficients which depend on the type of saturating compound and the polymerization conditions;  $C_n$  is the content of polymer, %; D is the strength of the concrete matrix, MPa.

Filling of microscopic pores in the cement paste with a solution of catalyst in monomer is difficult, due to the molecular sieve effect. Sorption and IR-spectroscopic studies have shown that the concentration of catalyst in the microscopic pores is so low that the technology of saturation of concretes using catalysts is also near the limit of its capabilities.

In the process of formation of the structure of concretes filled with polymers, the polymerization occurs in the adsorbed state. The mechanical properties of the silicate matrix and the polymer reinforcing substance are not additive when determining the properties of the composite: The experimental values of modulus of elasticity of cement paste filled with polymethylmethacrylate (PMMA) are 1.3 to 1.7 times higher than those calculated using the micromechanical equation of Khal'pin and Tsai. The reasons for this phenomenon will be studied from the standpoint of chemical and physical-chemical hypotheses.

For PMMA, the thickness of the adsorption layer of which is  $7.2 \cdot 10^{-5}$  cm, this critical concentration can be achieved if the radius of the pores of the concrete does not exceed  $10^{-4}$  cm (1  $\mu$ m). Soaking of



concretes with linear polymers with high strength and small-pore structure creates a genuine possibility of producing composites with a tensile strength of up to 30 MPa.

A421 Gorchakov, G. I., and Bazhenova, V. N., "Deformation of Polymer-Treated Concrete As It Is Manufactured, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 110, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

During special treatment of concrete, including drying, evacuation, monomer saturation and polymerization in the body of the concrete, the material is deformed by the physical and physical-chemical processes which occur. If radiation curing of the monomer is used, shrinkage of the material occurs in all stages; the total value of shrinkage for ordinary concrete is 40 to 60 · 10<sup>-5</sup>, but the actual value may fluctuate, depending on the type of concrete and the quantity of impregnated monomer, increasing with increasing monomer content.

When thermocatalytic curing is used, in addition to the shrinkage deformations which occur during polymerization, additional deformations occur as a result of heating. The total deformation is 10 to 30 percent less than that observed with radiation polymerization. The temperature deformations of polymer-treated concrete are 10 to 20 percent greater than those of ordinary concrete, depending on the polymer concrete.

The processing mode is of great significance for the value of deformation. A disruption of this mode, e.g., slight gas formation during polymerization, causes a significant change in the deformation of the material. The magnitude of deformation can be used to monitor the process.

A422 Grinberg, S. M., Kuleznev, V. N., Kandyrin, L. B., Tsyro, V. V., Shevelev, A. N., Polonetskii, Ya. M., Pukhov, G. A., and Tseitlin, S. D., "Experience in Planning a Semiautomatic Line for the Production of Small Structures and Products of Steel-Reinforced Polymer Concrete, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 36, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Two plans for semiautomatic conveyor-based production lines for the manufacture of steel-reinforced, polymer-concrete grates (based on FA

monomer) for covering of floors in barns, capable of producing up to 50,000 m<sup>2</sup> per year (in Vladimir and Gorkii) have been developed, based on scientific work at the M. V. Lomonosov Institute of Precision Chemical Technology in Moscow, the Special Design Bureau of "Stroiindustriia" and "Rosorgtekhstroii" Trust (Gorkii affiliate), with the cooperation of Giprogazoochistka Planning Institute, as well as the Scientific Research Institute for Chemical Machine Building and NIIOGAZ. The plans call for a high level of automation of production operations, complete isolation of workers from contact with toxic products which may be liberated and complete neutralization of these products by catalytic afterburners, assuring practically waste-free production. The basis for the successful implementation of the plan developments has been the conduct, at the Department of Chemistry and Polymer Physics of the Lomonosov Institute, of the following original scientific developments: studies of the rheologic properties of initial polymers and mastics based on them, which has allowed the duration and safety of processing of polymer-concrete compositions to be determined and demonstrated as a function of the formula and production conditions; and a study of the regularities involved in vibration compacting of polymer concretes and determination of the most important parameters of the process (acceleration and angle of application of vibrations, boundary parameters of thermal-fixation mode, which assure the necessary completeness of structure formation).

A423 Gromov, B. A., Ivanova, G. N., and Kazarnovskii, S. Z., "Study of the Durability of Polymer-Cement Compositions," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 139, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

According to SN 389-68, the strength of attachment of ceramic and glass-mosaic plates used for finishing of exterior wall panels must be at least 1 MPa. Construction practice and the experience gained in actual buildings has shown that this strength of attachment is not sufficient to assure that the finishing will be durable. Polymer-cement adhesive compositions based on aqueous polymer dispersions (VDP) were used to increase the bond strength of the plates. It was found that the strength of attachment, depending on the method of attachment, was 1.5 to 2 MPa and 1.2 to 1.5 MPa.

The experience showed that the bonding strength of ceramic tiles to reinforced concrete at 28 days of age, when the adhesive composition suggested is used, is 32.7 MPa, in comparison to 11. MPa for adhesive compositions normally used.

Heat and moisture testing of gypsum-concrete panels covered with ceramic slabs, lasting 365 cycles (one cycle = heat and moisture treatment at 60 C for 1 hour, followed by air drying for 1 hour) showed that the adhesion strength of the VDP-based composition was 1.5 times

higher than the strength of the composition usually used.

It was established that a VDP-based finishing composition has a compressive strength of 140 MPa, a bonding strength with the concrete surface of 0.7 MPa. The freezing stability of the composition is 35 cycles, after which the strength of the bond between the composition and the concrete surface is decreased by 10 percent.

A424 Gromov, Ie. V., and Kadeishvili, L. L., "The Properties of Polymer-Gypsum Foam, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 141, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The problem of the use of dry gypsum for the manufacture of prefabricated partitions has been solved, by creating a new type of gypsum wallboard up to 25 mm thick, with a lightweight core.

The requirements are best met by a material with a polymer-gypsum foam core. The influence of various types of surface-active agents (surfactants) was studied in the process of developing the gypsum foam core: They included nonionic surfactants (OP-7, OP-10) as well as ionic types (sulfanol, sodium and potassium alkyl sulfates, Nekal', Alkamone, albumin and alkyl sulfate).

The ability of these surfactants to reduce the weight of the gypsum mass was evaluated on the basis of the foam factor (K). It was shown that the most effective surfactant to reduce the specific mass of the gypsum is a secondary alkyl sulfate, which yielded a product with a specific mass of 800 kg/m<sup>3</sup> when used in a concentration one-tenth as great as the concentration required for the other surfactants.

Polymer additives were used to increase the strength of the gypsum foam. The greatest increase in strength of the gypsum was yielded by certain natural compounds and modified carbamide resins.

A425 Groshev, A. E., and Gomeniuk, V. M., "Design of Box-Section Beams of FAM-Based Steel-Reinforced Polymer Concrete, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 61, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Consideration of changes in the deformation properties of materials of complex three-dimensional structures with time has not yet been widely used in engineering practice. Products are designed for the elastic stage, using traditional methods of the theory of elasticity, allowing

results to be compared with experimental testing under short-term loading. Several versions were used to select a method for the design of box-section beams. For example, when such a beam is looked upon as a beam resting on two supports, it is reduced to a T-section beam with the flat surface downward, and analyzed as an undeformed cross section. As short-term tests have shown, calculations by this method yield calculated load-bearing capacities of the beam which are low approximately by a factor of 10.

Another approach is also possible: Each element of the beam is analyzed individually, elements are designed using tables with established boundary conditions and assigned loads. Primary attention in this work is given to the longitudinal wall, which is designed by solving the plane problem of the theory of elasticity. Calculation by the method of finite differences is of the greatest interest, and has been performed by Giprotsvetmet Institute. The distribution of stresses over the surface of the longitudinal wall thus produced allows us to determine the magnitude of the stresses at various points.

A new interpretation of the design of inclined cross sections of bending elements, according to SNiP II-21-75, requires that calculations be based on the main tensile stresses, which must not exceed the maximum stresses for FAM-based polymer concrete, at which cracks begin to form.

The method of finite differences solves the plane problem in each element individually, ignoring the three-dimensional nature of the structure. Representation of the resistance of a box-section beam as a shell has been used in calculations by the method of the finite element, according to the "Super" program. Using the results produced, we have written programs for the design of the main areas at various points on the surface of the longitudinal wall.

In general, the method of finite differences yield the most reliable results in the design of box-section beams as three-dimensional structures.

A426 Gruz, A. I., Loretova, R. N., Maloshitskii, A. S., and Mirotvortsev, I. I., "Optimization of the Pore Structure of a Glass-Reinforced Cement Matrix Upon Treatment with a Monomer," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 95, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

As we know, the pore structure of the initial concrete has a significant influence on the final properties of polymer-treated concrete products. Dispersed reinforcement with glass fiber helps to improve a number of structural and engineering properties of concrete. However, the pore structure of glass-reinforced concrete is more complex than that of ordinary concretes; a study of this pore structure will allow a well-founded approach to be made to the selection of the optimal

materials for subsequent monomer treatment.

We have established that an increase in the volume of reinforcing glass fiber leads to an increase in the number of large pores (Table). This phenomenon was observed with W/C ratios of 0.2 to 0.7.

A glass-reinforced cement matrix made with W/C = 0.4, containing type RBR glass fibers 10 mm in length (4 percent of concrete mass) and having good rheologic properties, was selected for further processing.

The material produced after saturation with monomer and polymerization had good strength properties when the quantity of monomer added was optimal.

Table. Porosity of cement paste manufactured with various W/C ratios and volumes of reinforcing glass fiber.

Volume of Glass Fiber, %	W/C			
	0.3	0.4	0.5	0.6
0	8.1/18.4*	5.5/19.3	3.3/32.7	2.1/33.1
1	12/19.1	6.3/25.3	5/28.5	2.7/34.5
2	12.3/17.5	6.4/26.5	5.1/28	2.9/35.9
4	12.6/17.3	6.5/22.8	5.3/29.5	4.5/34.8

\* Numerator = coarse pore structure, diameter 10  $\mu\text{m}$  or more (light microscopy); denominator = porosity with pore diameter 80 A to 10  $\mu\text{m}$  (mercury porometry).

A427 Gunasekaran, M., and Perry, E. R., "Polymer Concrete for High Voltage Electrical Insulation," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 187-191.

This paper deals with the development of polymer concrete for use as a dielectric material in high voltage electrical insulation applications. Under the auspices of a program sponsored by the Electric Power Research Institute and carried out at the Westinghouse Research and Development Center, it was shown that polymer concrete specially formulated and vacuum-processed is a high quality dielectric material which possesses significant overall cost and design advantages over electrical porcelain. Tests to date on polymer concrete specimens energized at approximately 1.5kV/in. and exposed to the weather conditions available in the Pittsburgh area have been very encouraging and have not shown any signs of failure. With a dielectric constant of about 4 and a dissipation factor of approximately 1 percent at 60 Hz, room temperature, polymer concrete possesses considerable potential for being further developed for use in conventional as well as specialized insulation applications in the electric power industry. By its ability to encapsulate metal and its ability to be reinforced with glass or organic fibers for better mechanical properties, it is believed that polymer concrete will facilitate the manufacture of vastly superior insulators, especially for futuristic power system designs.

A428 Gurbo, N. M., Nikonov, M. R., and Dibrov, S. G., "Electrical Properties of Polymer Treated Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 116, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The most important properties of electric-insulating structural materials are: the mechanical and dielectric strength, and the three-dimensional and surface resistivity. These properties were studied at the Scientific Research Institute for Reinforced Concrete Products, in cooperation with Sel'energoproekt Institute.

It was found that polymer-treated concretes are comparable in their electric-insulating properties to materials used as insulators, while their strength properties are significantly better. The best characteristics were achieved in products made with diabase fine aggregate with a water/cement ratio of 0.30 to 0.40/1.

A429 Guzeev, E. A., "Planning of Reinforced-Concrete Structures of Acid-Resistant Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 134, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In recent years, acid-resistant, fast-setting concretes of grades 100, 150, 200, and 300, containing liquid glass and modified by the inclusion of furan monomers, have been used in the laboratory and in industry. Reliable production of grade 200 and 300 concrete allows us to consider these grades as structural grades. The Central Structures Laboratory of the Scientific Research Institute for Reinforced Concrete Products has studied the deformation and strength properties of fast-setting concretes containing liquid glass, modified with furyl alcohol and sulfonal.

Research conducted during this study indicated the following:

1) Preliminary studies of long-term strength of concrete of grades M200-250 exposed to sulfuric acid and the carbon dioxide in the air have shown that the optimal level of longterm strength of acid-resistant quick-set concrete may be 0.65 to 0.7 R<sub>pr</sub>.

2) The Research Institute for Reinforced Concrete Structures and VNIPIteploproekt Institute have studied the passivation properties of acid-resistant concrete and the possibility of increasing them by the

use of anodic-action inhibitors. The studies have yielded positive results - the introduction of inhibitors (particularly those with combined effects) significantly increases the steady potential, from -650 to 350 mV, and also reduces the passivation current, with a potential of +300 mV, from 18-20 to 2.5-3  $\mu\text{A}/\text{cm}^2$ , which indicates an increase in the passivating properties of the concrete.

3) The testing of beams preliminarily held in 20 percent sulfuric acid for 100 days under long-term loading (series III) showed that at a load of 0.4 Mp, deformation stabilizes after 20 to 25 days, in both slightly reinforced and heavily reinforced specimens. With a load of 0.6 Mp for 300 to 350 days, a gradual increase was noted of the deformation of the stressed reinforcement to 6 percent in the lightly reinforced elements, and 12 percent in the heavily reinforced elements. After 350 days of testing of the beam, over an additional period of 30 days, while it was under load, sulfuric acid and water were periodically poured on the cracks on the side of the beam which was under tension. This resulted in some increase in deformation in both the compressed and stretched sections, manifested as bending by an additional 5 to 8 percent.

In addition to the advantages of traditional acid-resistant concrete, it has certain disadvantages, both technological (multiple components, toxicity of  $\text{Na}_2\text{SiF}_6$ , low thermodynamic stability of tetrahydrosilicates, etc.), and also structural (low strength, significant shrinkage, limitations on geometric cross section, etc.). These factors have set forth the task of creating nontoxic, high-strength, acid-resistant concretes with fewer components. As a result of research, a material has been produced, which is based on liquid glass and an active filler, with curing in an autoclave.

The availability of structural, acid-resistant concretes with a broad range of strength properties will allow the creation of a technology for the production of precast reinforced structures for buildings and other projects. Given the availability of these products, one task is that of determining the optimal areas of application of the products in buildings and other projects involving exposure to corrosive media, and the creation of norms for corrosiveness of steam-gas and liquid media in relationship to concrete and reinforced concrete with liquid-glass binders, when steel rod, fibra, or fiberglass is used as the reinforcement.

A430 Guzev, E. A., "Reinforced Concrete Structures of Acid-Resistant Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 158, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Scientific Research Institute for Reinforced Concrete has been studying the physical-mechanical and protective properties of

acid-resistant, quick-setting concrete, bending beams and noncentrally compressed columns for a number of years.

Studies were performed of the short-term and long-term effects of loads with various types of interaction with the medium. The basic characteristics of strength, deformation, and stability were determined. The boundaries of microscopic and macroscopic crack formation were determined, as well as the optimal levels of long-term and short-term strength of concrete.

The tests of bending elements at 40 percent of the maximum loads showed that deformation, both in the stretched and compressed portions of the cross sections of the beams, stabilized within 3 months. At high stress levels, 60 percent of the maximum stresses, the nature of the deformation changed somewhat. Deformation stabilized after several months. The nature of the deformation of lightly reinforced and heavily reinforced elements differed insignificantly over a period of 1.5 to 2.5 years.

The effect of periodically pouring acid over heavily loaded elements, followed by wetting with water for long periods of time, even with small beam dimensions, was manifested as a slight, 3 to 5 percent, increase in deformation after 25 to 30 days.

In the tests, performed by pouring acid over the beams without wetting with water, the deformation of the beams did not change. Noncentrally compressed elements with slight eccentricity were deformed slightly within the limits of the core of the cross section with loads of 40 percent and 60 percent of the maximum and periodic exposure of the maximally stressed faces of the elements to acid.

A431 Harrison, M. R., "A Case Study - Methyl Methacrylate Polymer Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 351-360.

This paper describes work done by District VI, Colorado Department of Highways to develop an acceptable polymer concrete for bridge and pavement repair and rehabilitation. It provides information on how and why Colorado Department of Highways became interested in polymer concrete. It then describes in detail the steps Colorado went through to arrive at the decision to proceed with the use of methacrylate to polymer concrete on a major bridge rehabilitation. Recommendations on the important steps to follow in the successful use of methacrylate polymer concrete are included.

A432 Iasevich, A. I., Iakovlev, V. N., Vyzhimova, A. I., and Muliukova, I. Iu., "Influence of Polymer Additives on the Electrophysical Properties of Concrete Exposed to Corrosive Media," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 149, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.



One known method of increasing the durability of reinforced-concrete structures exposed to corrosive media is the introduction of polymer additives to the concrete. The electrical characteristics of the concrete were used to evaluate the influence of the additives on the protective properties of the concrete.

This report presents the volt-ampere characteristics of concrete with additives consisting of resin No. 89, DEG-1, and TEG-1 under various conditions. The lowest conductivity is that of concrete in the air-dry state, the highest is found after holding concrete specimens in corrosive media for 5 days.

For exposure to moisture or corrosive media, the best protective properties are manifested by concretes with DEG-1 and TEG-1 resins (the volt-ampere characteristic slope tangent is least for these concretes). Concretes with these additives can be recommended for structures to be used in saline soils and where they will be exposed to corrosive groundwater.

A433 Iazev, R. E., "Cavitation-Resistant Epoxy Mastics and Polymer Mortars for Protective Lining of the Water Passages in Hydraulic Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 42, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

One effective method of protection of the water passages of hydraulic structures from cavitation damage is the use of polymer and other types of linings. It has been experimentally established that multicomponent systems containing epoxy resin, modifiers, and plasticizers, plus a specially selected combination of fillers of varying particle size and mineralogic composition, as well as additives, are the best compositions for such protective linings.

The cavitation resistance of filled epoxy compositions is 2 to 3 orders of magnitude higher than the resistance of type M400 cement concrete.

Depending on the type of water-carrying structure and the conditions under which it is used (particularly, the hydraulic mode), the Research Center of Hidroproekt Institute recommends various types of cavitation-resistant coatings based on epoxy compounds, to be applied to concrete.

The adhesion strength of the epoxy linings recommended does not decrease significantly with time, or with exposure to various corrosive factors, and is:

for paint-type coatings - at least 1 MPa;

for mastics - at least 1.5 MPa;

for polymer mortars - at least 2.5 MPa.

Polymer mastic and mortar cavitation-resistant coatings, linings and patched sections of concrete damaged earlier, in use for 5 to 11

years at the Bratsk, Murek, and Charvak Hydroelectric Powerplants, are still in satisfactory condition.

The use of protective epoxy coatings has improved the durability of concrete structures exposed to high-velocity water streams and possible cavitation by several times, and the method is 4 to 6 times less expensive than the construction of metal linings.

A434 Igonin, L. A., "Polymer Compositions in Hydropower Construction," *Translated from Russian by Bureau of Reclamation, Denver, Colo., 1978.*

The experience of many years of research on and the practical application of polymeric systems (mastics, mortars, and concretes) in hydropower construction in the USSR is examined in this report. The results of investigations into development of epoxy compounds for repairing damaged concrete in structures, in situ casting of concrete in the butt joints of precast and precast-monolithic reinforced-concrete structures, equal-strength securing of tie rods in concrete, equal-strength nonwelded butt-jointing of steel reinforcement and precast reinforced-concrete elements, as well as for installation of cavitation-resistant protective coatings on concrete in spillway structures are set forth in detail. Examples are given of the practical application of these technical developments in hydropower construction. Questions of the effectiveness and possibilities of practical application of new engineering solutions based on the use of polymer concretes are elucidated.

A435 Igonin, L. A., "Polymer Compositions In Hydraulic Engineering," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 535-553.

The paper deals with many years' experience in investigation and practical use of polymer compositions (polymer-pastes, polymer-mortars, polymer-concretes) in hydropower engineering in the USSR. Study results of the development of epoxy compositions for repair of damaged concrete in structures, concrete jointing in edge joints of precast R.C. elements and equal-strength fixing of anchor bars in concrete, equal-strength unwelded jointing of reinforcing steel and precast R.C. details; and also for protection of spillway structure surfaces against cavitation damage are discussed. Examples of practical application of these findings in hydraulic engineering are presented. Problems of efficiency and prospects of practical use of new technical trends based on applications of the polymer-compositions are given.

A436 Imamura, K., et al., "Precast Polymer Concrete For Utilities Applications," Second International Congress of Polymers in Concrete, Austin, Tex., Oct 1978, pp 173-186.

Nippon Telegraph and Telephone Public Corporation (NTT) has studied the use of polymers as a structural material since 1955. Musashino Electrical Communication Laboratory of NTT began research on polymer

concrete in 1960 (1). Various property measurements, product research, manufacturing technique development, and so on, all concerned with polymer concrete, were carried out continuously. Various products were made in the laboratory on a trial basis. Polymer concrete was first used for manhole construction in 1964. As the result of cooperation between various NTT researchers, Kyoto University, and manufacturers, a precast polymer concrete manhole was developed in 1967. Several commercial tests were made, and precast polymer concrete manholes have been in general use since April 1971. This paper describes the results of various studies carried out before precast polymer concrete manholes were in general use.

A437 Il'in, O. F., "Strength of Normal Cross Sections of Elements of Polymer-Treated Concrete With Steel Reinforcement," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 119, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Calculation of the strength of normal cross sections of reinforced-concrete elements by the method of SNiP II-21-75 is based on the condition of equilibrium of moments and longitudinal forces in the cross section being considered. Furthermore, an additional condition is introduced, relating the stress in the longitudinal reinforcement  $\sigma_a$  to the arbitrary height of the compressive zone  $x$ , assuming a rectangular stress curve in the concrete in the compressive zone, calculations are given to show the modifications to the formulas to accommodate polymer-treated concretes.

In order to test the assumptions made, the calculations were compared with experimental results on beams of polymer-treated concrete, using data supplied by G. M. Marchiukaitis and G. I. Popov. The mean value of the ratio of experimental and calculated moments was 1.05, with maximum deviations of 0.94 to 1.13. This shows that the method of SNiP II-21-75, with some additional adjustments, can be used to calculate the normal cross sections of elements made of polymer-treated concrete.

A438 Irtuganova, S. Kh., Fomicheva, T. N., and Ditsman, V. S., "Modified Furan-Epoxy Compositions in the Floors of Industrial Buildings," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 72, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

FAED furan-epoxy resin has attracted the attention of researchers, on the one hand, by its reduced content (less than 50 percent by mass) of epoxy resin, and on the other hand, by its high bond strength with concrete, ceramics and other materials, as well as its ability to be cured not only by acid, but also by alkaline curing agents. A significant improvement in the properties of compositions based on FAED resins has been achieved by the use of various modifying additives. Polymer mortars and mastics based on FAED-modified resins have been used as materials for continuous floor coverings, as well as intermediate layers and seam fillers in flooring made of acid-resistant tiles. The use of compositions based on modified FAED resins allows a significant expansion of the area of application of the floor types which have been developed, which can withstand the effects of solutions of alkalies and mineral acids. The resistance to mechanical effects, particularly impacts, is also increased.

At the Starooskol'skii motor-vehicle electric-equipment plant, a base has been constructed for a zinc-plating bath, made of slag-sitall slabs, with both intermediate layers and seam fillers of a modified polymer mortar based on FAED resin, with the addition of furfuryl alcohol. The savings achieved amounted to 16 rubles per square meter of floor area.

A439 Iusupov, R. A., Shirokov, V. S., Samigov, N. A., and Abramov, V. S., "Possibility of Producing Three-Layer Polymer-Treated Concrete Pressure-Bearing for Hydraulic Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 124, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Analysis of the operation of pressure-bearing reinforced-concrete pipe under external and internal loadings shows that the greatest bending stresses develop in the outer layer of the structure. This leads us to assume that it would be desirable to modify only the outer layer of the pipe. Modification of this sort produces a three-layer structure, the outer and inner layer consisting of polymer-treated concrete, while the middle (intermediate) layer consists of ordinary concrete.

To test this assumption, we studied the influence of the depth of saturation on the strength properties of polymer-treated concrete.

As the thickness of the middle (untreated) layer was decreased, the tensile strength in bending increased significantly, reaching a maximum value of 16 to 18 MPa.

A440 Ivanov, F. M., and Mikhal'chuk, P. A., "Saturating Compounds and Anticorrosion Coatings Based on "KN" Polymerizing Material," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers

Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),  
Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 101, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Central Corrosion Laboratory of the Scientific Research Institute for Reinforced Concrete Products has suggested product "KN" as a saturating compound; this product can be used to saturate dense concrete at its equilibrium moisture content at room temperature and atmospheric pressure. In the saturation layer, product "KN" interacts with the individual components of the concrete. Saturation of the surface of a structure to a depth of 10 to 15 mm can be achieved in 6 to 8 hr, allowing a significant increase in water and corrosion resistance of concrete which is exposed to highly mineralized ground water (containing up to 12 to 18 g/l sulfates, as  $SO_4$  ion) and acid media, as well as the strength characteristics of the concrete ( $R_u$ ,  $R_p$ ). The compressive strength and ultimate strength are increased to a lesser extent.

Very interesting data were obtained in a study of the saturation of concretes made of slag-portland cement (with electrothermal phosphorus slag 30 to 40 percent) with product "KN," which allows a significant expansion of the area of application of slag-portland cement concrete. Various single- and multiple-component compositions of anticorrosion coatings based on "KN" were studied and compositions were produced which can be used to restore concrete structures which have failed. The bonding of concrete prisms after  $R_u$  strength testing showed that during repeat testing, the tensile strength in bending is practically equal to the initial strength, and failure of the prisms occurs through the concrete, not through the bond.

A441 Ivanov, G. S., "A Plant Technology for Polymer-Treated Products," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 77, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The production of polymer-treated concrete materials (PTCM) consists of three main stages: drying of the initial products, their saturation with monomers, and thermocatalytic polymerization of the monomers in the body of the concrete (by introduction of an initiator to the monomer and heating) or radiation-chemical treatment (by exposure to gamma rays). The technology of thermocatalytic polymerization of the monomers with which structural materials are treated is preferable for the construction industry.

Equations are given for determining the drying time as a function

of the primary technological parameters of the process, the degree of saturation of the concrete products with monomers, and the strength of PTC materials as a function of the primary technological factors.

- A442 *Ivanova, I. I., "Reinforced Polymer-Concrete Tank Apparatus," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 60, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The use of process containers made of reinforced polymer concretes has demonstrated the reliability of the new material. For example, at the Balkhash Mining and Metallurgical Combine, a copper electrolysis bath has been in use for 15 years, while 50 baths for electrolysis of zinc have been used at the Ust'-Kamenogorsk zinc combine for over 5 years.

Over 100 zinc electrolysis baths with steel and glass-reinforced plastic prestressed reinforcement are now in use at the Ust-Kamenogorsk and Leninogorsk combines. The manufacture of baths for electrolysis of copper from reinforced polymer concrete has been begun.

In 1975, a group of specialists studied 115 baths for electrolysis of zinc and copper, made of reinforced polymer concrete. Analysis of the studies, performed in order to determine the reasons for crack formation, established that in the design of apparatus up to that time, the effects of elevated temperatures, which cause significantly greater stresses than all other effects, had not been properly considered.

Design and construction of the tank apparatus are based on the condition of preventing opening of cracks. Particular attention is given to prestressing, which greatly increases the crack resistance of structures and is of great significance for reducing the initial shrinkage and thermal stresses, and to the design of tank apparatus to resist elevated temperatures.

- A443 *Ivashchenko, Iu. G., Chuiko, A. V., and Kubarov, V. I., "Study of Polymer Concrete Based on Thermally Modified Quartz Fillers," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 29, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Studies are performed on the structural-mechanical properties and water resistance of FAM polymer concrete with thermally-modified quartz fillers.

IR spectroscopy, pH measurement, and calorimetry are used to show

the change in surface properties of quartz grains as a function of the method of processing. High-temperature treatment ( $T = 723-823 \text{ K}$ ) in the presence of fluorine- and carbon-containing substances facilitates lyophilization of the quartz surface, improving its wettability by the binder, increasing adsorption activity of the filler and allowing the polymer content of the compositions to be decreased by 8 to 12 percent.

An increase in the strength characteristics of compounds based on heat-modified quartz filler by from 20 to 35 percent is observed, with a simultaneous increase in the water resistance by 15 to 25 percent in comparison with control specimens. The strengthening of the structure is explained by the development of stronger adhesion bonds in bonds in the contact zone.

The variation in strength of the polymer binder is studied as a function of the quantitative relationship of mineral filler and polymer, as well as the activity of the filler.

A444 Jones, T. E. R., and Taylor, S., "Rheological Properties of Cement Pastes; Effect of Additives," Silicates Industriels, Apr-May 1978, 43(4-5), 83-3, CRI current contents Vol 10, No. 3, Paper No. 953.

Rheological properties of cement pastes with and without polymeric additives have been studied with special reference to flow curve characteristics and workability using Weissenberg Rheogoniometer based on cone and plate geometry.

Variation of shear stress with the shear rate for a range of W/C ratios (0.3 to 0.5) have been reported. Experimental results have indicated occurrence of hysteresis flow curves for cement pastes, when the shear rate is increased initially and then decreased. The up curve is generally lower than the down curve when small hydration times are considered. However, the curves tend to come closer with increase of mixing time. A reversible flow curve was obtained with mixing period of 8 min for a 0.35 W/C ratio paste. The minimum mixing time for obtaining reversible flow curves has been found to be a function of W/C ratio, however, it has not been possible to obtain reversible curves above W/C ratios of 0.5, probably due to sedimentation.

A445 Kaeding, A. O., "Structural Use of Polymers in Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 9-23.

Polymers may be used in many applications in addition to repair and protection of civil structures. Rehabilitating buildings, improving the durability and/or watertightness of industrial structures, and improving concrete's resistance to corrosive process environments are all possible. Treated as a composite material, the improved strength and stiffness of partially impregnated concrete can be accounted for in design. Additional laboratory studies are required, as indicated by an example. Rehabilitating a condemned building is reported as a case history. Properly evaluated, the use of polymers in concrete can be economically viable. In any application, careful attention to the details of safety is essential.

A446 Kashtanov, Iu. A., "Influence of Temperature on Strength and Deformation of Polymer-Concrete Beams with Rigid Reinforcement," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 63, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A study was made of steel-reinforced polymer-concrete beams based on FAM resin with rigid reinforcement in the form of I-beams and channel sections, placed in the zones of tension or tension and compression at temperatures of +20 C and -20 C.

The results of the experiments indicate that when the reinforcement was placed in the tensile zone in Type I, II, and IV beams at temperatures of -20 C, the load-bearing capacity decreases by 22 to 26 percent. In Type III beams at below-freezing temperatures, an increase in the load-bearing capacity of 20 percent is noted in the compressed zone.

The crack-resistance factor for beams with rigid reinforcement is 0.65. Cracks were detected by the indications of the strain gauges placed in the tensile zones of the beams.

A447 Kazarnovskii, S. Z., "Rheologic Properties of Polymer-Cement Compositions," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 122, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The rheologic characteristics of polymer-cement suspensions were studied using a Volarovich viscosimeter and a Reotest-2.

The kinetics of formation of the structure were studied in parallel, and the plastic strength of curing polymer-cement mixtures was determined according to GOST 310-60.

The studies were conducted using portland cement, with W/C between 0.3 and 0.6; the same material, with the addition of water-soluble polymers (polyvinyl alcohol, an organosilicon polymer, urea-formaldehyde resin type M-3); and aqueous dispersions of polymers based on stabilized divinylstyrene, butyl rubber and polyisobutylene.

The polymer-cement suspensions indicated above were studied over a broad range of speeds, stresses, and strains, allowing the results produced to be compared with earlier results, producing a more complete rheologic diagram of the behavior of the polymer-cement suspensions.

The influence of adsorption phenomena on the rheologic properties of the polymer-cement suspension was estimated.



A method has been developed for the selection of polymer additives (water-soluble polymers in aqueous dispersions) for cement suspensions by a rheologic method.

- A448 Khabakhpashev, K. G., and Sosin, V. V., "Properties of Polymer-Treated Concrete Used for Polymerization in Various Media," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 93, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The technology of thermocatalytic polymerization and the quality of the polymer-treated concrete produced depend to a significant extent on the heat-transfer medium used, which may be:

liquids (water or other highly viscous substances such as glycerin);

gases which are inert with respect to the monomer (e.g., nitrogen); steam.

Products polymerized in liquid media are contaminated with the polymerization residue and may have a surface crust consisting of drops of polymethylmethacrylate.

When gaseous media - hot air or nitrogen - are used, undesirable phenomena characteristic of liquid polymerization media are not observed. However, in this case, the conditions of transfer of heat to the saturated concrete products deteriorate and evaporation of the monomer increases.

The use of steam as a polymerization medium is quite promising; one advantage is the rapid and uniform heating achieved as a result of condensation of the steam on the surfaces of the products. Technological heating with steam is quite simple. Its shortcomings include the need to remove the condensate, which contains the monomer.

The losses of mass during drying of specimens polymerized in water, steam, and nitrogen amounted to 2.2, 0.6, and 0.04 percent. Analysis of a diagram illustrating the change in mass shows that upon polymerization in gaseous media, the losses of monomer decrease, while the weight gain of the polymer increases.

The lowest losses of monomer and the best physical and mechanical properties of the polymer-treated concrete are achieved upon polymerization in a medium of nitrogen and steam at a gauge pressure of at least 1 atm.

- A449 Kharchevnikov, V. I., "Determination of the Coefficient Defining the Conditions of Operation of Elements in Structures of Glass-Fiber-Reinforced Polymer Concrete (SVPB) When Used in Electrochemical Production Media," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978,

(Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 59, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The design of SVPB containers for use under conditions involving exposure to electrochemical corrosion, high temperatures and long-term, constant loading is a difficult task. The difficulties result both from the nonlinear stress state of the elements of such structures, and from a variety of external factors, both mechanical and electrochemical in nature. The influence of these factors must be considered using coefficients describing the operating conditions.

The final purpose of the experiments was to determine the temperature coefficient of strength,  $K_t$ , and of rigidity,  $n_t$ .

The results of the experiments allowed calculation of the coefficients describing the operating conditions of the elements of SVPB structures of various compositions for various electrochemical production facilities.

It was found that when the coefficients considering the various mechanical and physical-chemical factors are crossmultiplied, the minimum difference  $m_k = 6$  percent (with a 20 percent of sulfuric acid), while the maximum difference  $m_k = 20$  percent (in moist chlorine), values which are quite acceptable for engineering calculations.

The method of cross-multiplication of coefficients can be used to calculate the full coefficient describing the operating conditions of elements of structures made of polymer materials, used under conditions of exposure to electrochemical corrosion. Methods of determination of these coefficients must be determined for each case individually.

A450 Khrulev, V. M., and Bezverkhiaia, L. M., "Polymer-Cement Mortars with Methoxypropylcellulose, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 138, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Department of Polymers and Concrete Technology of the Novosibirsk Construction Engineering Institute has studied certain properties of mixed mortars containing methoxypropylcellulose and has developed a technology for their application.

In all, seven compositions with various ratios of cement, lime, and gypsum were tested. Some compositions contained powerplant ash as well. The studies showed that the introduction of methoxypropylcellulose

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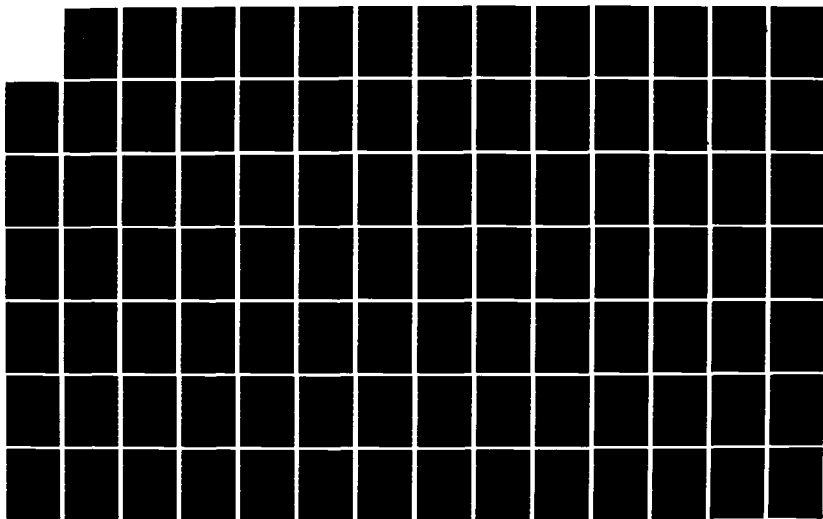
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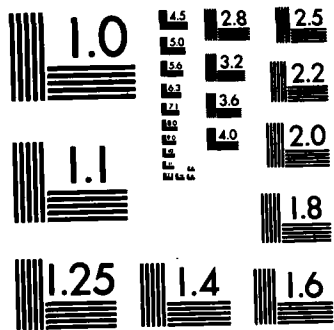
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MICROCOPY RESOLUTION TEST CHART  
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increases the viability of solutions by a factor of 2 to 4, increases the bond strength by an average of 1.5 times, and the tensile strength was found to be 1.6 to 2.7 MPa. The compositions retain the necessary plasticity for 8 to 10 hr, not separating into layers during transportation and storage. For all of the compositions, the limiting shear stress, graphed with a logarithmic ordinate, increases with time; however, the increase is much slower for compositions containing methoxypropylcellulose. This indicates that there is a delay in the formation of the crystallization structure.

Compressive testing of specimens measuring 7 by 7 by 7 cm, cured in air at room temperature, showed that the rise in strength of compositions containing methoxypropylcellulose during the first three days is slower than that of control specimens. However, at 28 days of age, the strength of the polymer-cement mortars is 15 to 20 percent greater than that of the control specimens, indicating the more compact structure of the cured paste.

- A451 Kim, I. P., and Voronkova, T. G., "Study of Polymer Silicates for the Construction of the Floors of Industrial Buildings, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 145, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Since the massive application of polymer silicates is hindered by the shortage of furyl alcohol, a search was conducted for additives similar in their effect to furyl alcohol and, therefore, capable of either completely or partially replacing it in liquid-glass composites.

The strengthening additives tested were organic products capable of combining with liquid glass and polymerizing in the structure of a curing, acid-resistant mortar. The additives were introduced to the composition of the mortar both independently and in combination with furyl alcohol. It was established that some of the organic products studied, in quantities of up to 5 percent of the mass of the liquid glass, combine with it without causing coagulation or deterioration of the ease of pouring of the polymer silicates.

Based on the results produced, some of the products studied were recommended as strengthening additives to replace furyl alcohol completely or partially in liquid-glass composites.

The study showed that the presence of Resin No. 89 intensifies the polymerization of furyl alcohol in the polymer silicate, giving it a more compact and, consequently, more alkali-resistant structure.

- A452 Kobelev, M. I., "Design of Steel-Reinforced Polymer-Concrete Prestressed Elements Considering the Influence of Highly Elastic Compressive Deformation, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes,

Summaries of Papers Presented at Tashkent, September 1978,  
(Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii,  
Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent,  
Sentiabr' 1978), Iu. N. Bazhenov, ed., Book No. 7220 (C-92), Paper  
No. 56, Jan 1979; Translated from the Russian by Engineering  
Services Branch, U. S. Bureau of Reclamation Translation Group,  
Denver, Colo.

The compression of polymer concrete caused by the prestressed reinforcement causes stresses of the opposite sign in relationship to the stresses experienced during use.

In addition to the elastic compression deformation, as time passes, irreversible plastic deformation and high elastic deformation, which is reversed over a period of time after the load is relieved, also occur.

If, after a specimen is held under compressive load, the direction of the stress is immediately changed, due to application of the usage load, then the internal stresses resulting from the highly elastic deformation, and the stresses resulting from the external load are added together, which results in crack formation at relatively low external stress values.

Analysis of this process by means of the true structural diagram of polymer concrete has allowed this decrease to be correlated with the measure of creep and a practical method of calculation to be suggested.

For the case of application of the usage load, the stresses change direction, passing through a phase in which the compressive load in the polymer concrete drops to zero. Microscopic failure frequently occurs in the tensile zone in this case.

Studies which have been performed have produced design equations which consider the highly elastic deformation of bending elements which are more complex in structure, since the degree of stresses changes through the cross section.

**A453** Koblischek, P., "Acryl-Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 413-430.

The stand held by us for years that only a low-viscosity reaction resin used as a binding agent for polymer concrete will gain economic importance and make series production of component parts possible has been confirmed in practice.

The report deals with series production of products made of polymer concrete Acryl-concrete which have been produced in pilot plants or circular production lines developed by us.

Attention is also drawn to further applications of methacrylate resins and test results for 'Tamping Mortar for Railway Bridges' and 'GFK Reinforcement of Stairs on PMMA-Basis' are included.

**A454** Koliutskii, V. N., "Influence of the Nature of the Initial Concrete on the Properties of Polymer Treated Concrete and the Consumption of Monomer in Treatment," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978,

(Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 90, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The composition of the initial sand concrete has practically no influence on the strength characteristics of a polymer-treated concrete. The consumption of monomer in saturation changes significantly, depending on the structure of the initial sand concrete, W/C ratio, and the ratio of cement to sand.

An area of composition has been distinguished which is characterized by minimum consumption of monomer in saturation. Laying out this area on a graph in the coordinates "water-cement ratio - cement-sand ratio" allows the composition of the initial sand concrete to be varied, selecting a concrete mixture with the rheologic characteristics most suitable for the technology used.

A455 Komokhov, P. G., "Fracture Inhibiting Effect of Polymer Additives in Concrete, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 156, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The addition of the water-soluble polymer additives DAS-4, S-89, DEG-1, and PDI-ZAK epoxidized rubber, up to 2 percent of the mass of the cement, which creates elastomers at the phase-division boundary, with elastic heterogeneity of the structural elements of the concrete, was studied. Significant decreases in the range of fluctuations and the degree of variability of deformation with increasing load up to the stage of failure, based on a study of the extreme deformation ( $\epsilon_{\max}$  and  $\epsilon_{\min}$ ) and average deformation ( $\epsilon_{av}$ ) were found.

It was found that the introduction of small quantities of polymer additive to the structure of high-strength concrete is a means for effectively inhibiting fracture, both during the period of early formation of the structure, and during the period of use of load-bearing concrete and reinforced-concrete structures.

A456 Kosarev, V. M. and Kagner, V. V., "Testing of the Modification of Concretes with Monomers, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper

No. 128, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The development of a single method allowing effective testing of all stages of the technological process of manufacture of polymer-treated concrete is a matter of great practical interest. In order to perform this task, we tested a method of modification of concretes with monomers. The test method was based on recording of the stresses arising in an elastic inclusion as a result of changes in the stress-strain state of the specimen (product), caused by the application of external and internal forces. The internal stresses were recorded by circular magnetoelastic transducers developed at the Central Scientific Research Institute for Construction Structures. One advantage of these transducers is that, although they have high sensitivity to changes in stress, they retain constant resolving capacity over a broad temperature range and remain absolutely passive to changes in the humidity of the surrounding environment.

In this work, we studied the processes of manufacture of polymer-treated concrete based on granite and sand aggregates and keramzit [porous clay - Tr.] gravel. The studies were performed on cubic specimens with an edge length of 7.07 cm.

A457 Kotlik, S. I., and Dzhumakhodzhaev, Z. Kh., "Polymer-Concrete Pipe Based on Furan Resins with GSK Universal Curing Agents," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. N. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 26, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A new reagent, sulfurated gas condensate or GSK, containing short-chain alkylbenzene, sulfonate-groups, produced at SANIIRI in cooperation with the Institute of Chemistry, Acad. Sci. UzSSR, greatly improves the physicochemical and chemical-mechanical properties of the polymer composites by giving the molecule a high degree of hydrophobicity, while the surface-active property of the curing agent is determined by its ability to strengthen the cross-linking of the polymer, right up to the failure of the furan ring.

These properties of the polymer concrete allow it to solve difficult technological and construction problems related to the formation of thinwall circular elements, which can be used in collector-drainage networks and water lines.

The best technology for the formation of thinwall pipe is centrifuging. For polymer-concrete, thinwall pipe, fine-grain polymer compositions are used, allowing the degree of centrifugal pressing to be increased without causing separation of the composition. The optimal pressing pressure is 0.05 MPa.



A458 Kovalenko, P. I., and Reznik, V. B., "Practice and Prospects for Polymer Concrete Utilization in Hydrotechnical Construction," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 555-565.

The report covers practice and prospects for utilizing polymer concrete and solutions in Soviet hydrotechnical construction and offers examples with regard to use of structural polymer concrete for erection of water intakes, as well as application of polymer concrete and pastes for overhaul work, anticorrosion and hydroinsulating covers, and other purposes. The basic properties of polymer concrete and other compounds in use are included.

A459 Krasil'nikova, O. M., "Dielectric Properties of Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 30, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

This article analyzes problems related to the production of new experimental data on the dielectric properties of polymer concretes and determination of possible areas of their use as electric-insulating materials.

The study of the electric characteristics of polymer concretes included measurement of dielectric permeability,  $E$ , and the dielectric-loss angle tangent,  $t_{db}$ , those characteristics were studied which allow simultaneous judgments to be made concerning the overall structure of the polymer concrete, the properties of its polymer portion and the electric-insulating properties of the materials.

In all, 10 compositions of polymer concretes based on furan, epoxy and polyester resins were studied. The aggregates used were: granite gravel, river sand, andesite, diabase, keramzit, agloporit, and slag-sitall. The selection of aggregates was determined by the nature and degree of porosity, grain size, and possibility of achieving the required properties.

At the same time, the preservation of dielectric characteristics of polymer concretes in water was determined. The processes leading to changes in the characteristics of the polymer concretes in water are complex in nature, depending on the electric nature of the binder, the packing density of its molecules and the nature of the interaction between the binder and the aggregate. The change in electric characteristics under moist conditions occurs unevenly. The dielectric-loss angle tangent  $t_{db}$  is most sensitive to variation in water content. Whereas, when specimens are placed in water, the dielectric permeability  $E$  changes slightly or remains at the same level, the order of change in

dielectric losses  $t_{db}$  increases by a factor of 10 or more, depending on the time spent in the water.

**A460 Kreis, R., "World-Wide Application and Industrial Manufacturing of Polymer Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 519-525.**

To use PC economically, applications must be found which take advantage of the unique properties of the material, such as

(1) high mechanical strength, which would allow reduction in wall thicknesses, resulting in savings in weight and reduction in shipping and handling cost;

(2) high chemical resistance and very low water absorption, which would give far longer product life than is experienced with conventional concretes;

(3) fast demolding and curing times, which would allow lower investment in molds and production space; and

(4) the ability to produce PC with decorative surfaces, which would be far superior to concrete and compare with other, far more expensive materials.

**A461 Kukacka, L. E., Fontana, J., et al., "Alternate Materials of Construction for Geothermal Applications," BNL-50925, Progress Report No. 16, Apr-Sep 1978, Brookhaven National Laboratory, Upton, N. Y.**

This is a program to determine if nonmetallic materials such as polymers, concrete polymer composites, and refractory cements can be utilized as materials of construction in geothermal processes. Work accomplished during the period Apr-Sep 1978 is described in the current report.

Polymer concrete (PC) containing organosiloxanes or cross-linked mixture of styrene, acrylonitrile and acrylamide appear to have excellent thermal and chemical resistance. Samples containing these materials have exhibited essentially no change in strength after exposure to brine at 238°C for 120 days. Earlier monomer systems have initial reductions followed by a leveling off in strength. The organosiloxane PC also has excellent high temperature strength. At 350°C, the compressive strength is ~5000 psi.

A test to determine the feasibility of using a cavitating system to remove scale from PC surfaces has been performed. The results indicated that the threshold intensity of erosion for the PC was considerably lower than that of geothermal scale. This disadvantage can be overcome by the development of a nozzle with an immediate reduction in the effective range of intensity. This would allow removal of the scale without damage to the PC liner.

**A462 Kukacka, L. E., "Alternate Materials of Construction for Geothermal Applications," BNL-50979, Progress Report No. 17, Oct-Dec 1978, Brookhaven National Laboratory, Upton, N. Y.**

A program to determine if nonmetallic materials such as polymers,

concrete polymer composites, and refractory cements can be utilized as materials of construction in geothermal processes is in progress. To date, several high temperature polymer concrete systems have been formulated, laboratory and field tests performed in brine, flashing brine, and steam at temperatures up to 260 exp 0 C (500 exp 0 F), and economic studies started. Laboratory data for exposure times > 2 years are available. Results are also available from field exposures of up to 24 months in four geothermal environments. Good durability is indicated. Work at five of these sites is continuing and plans to initiate other tests are being implemented.

A463 Kukacka, L. E., "Perlite Polymer Concrete," *SP 40-8*, pp 173-189, 1978, American Concrete Institute, Detroit, Mich.

Techniques for producing lightweight insulating-type composites with uniform polymer distributions have been developed. Three lightweight aggregates, perlite, vermiculite, and foamed glass, were evaluated and perlite was selected for continued evaluation. Two monomers, methyl methacrylate (MMA) and polyester-styrene, were used in these studies.

Structural properties equivalent to or greater than those of high quality normal weight concrete have been obtained with perlite-concrete composites containing 50 to 60 vol percent polymer.

A464 Kukacka, L. E., et al., "Cementing of Geothermal Walls," *BNL-50911, Progress Report No. 9, Apr-Jun 1978, Brookhaven National Laboratory, Upton, N. Y.*

Work on polymer concrete containing mixtures of organosiloxanes and styrene is continuing to show the potential of the system as a high temperature cementing material. Samples exposed for 360 hr to brine at 250°C have not shown evidence of hydrolysis and have maintained high strength. At 350°C, the compressive strength is > 5000 psi. Preliminary tests to determine the pumpability of the system are in progress.

A465 Kukacka, L. E., "Polymer Concrete Materials for Use in Geothermal Energy Processes," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 157-172.

The feasibility of using polymer concretes as materials of construction in geothermal processes has been demonstrated and tests to determine the practicability are in progress. High temperature polymer concrete systems have been formulated and laboratory and field tests are being performed in brine, flashing brine, and steam at temperatures up to 500°F (260°C). Results are available from field exposures of up to 18 months in four geothermal environments. Good durability at temperatures > 392°F (200°C) is obtained with samples containing portland cement-silica sand aggregate. Based upon these results, potential applications for polymer concrete in geothermal processes have been identified and the effects of its use on the cost of electric power generation have been estimated. Reductions in the cost of power delivered to the distribution system of ~10 percent were calculated. Redesign of the plants for the

optimum utilization of polymer concrete would be expected to result in greater savings.

A466 Kuntsevich, O. V., and Medynskaia, V. S., "Influence of Organic Compounds on the Freezing Resistance of Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 166, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

It has been established that organosilicon polymer additives such as GKZh-94 can produce a stable pore system, which can be considered closed, in a material, assuring high resistance to freezing, not only in laboratory-prepared concrete, but also in production concrete. For example, cores drilled from the Zeiskaia Hydroelectric Powerplant Dam, made of concrete with GKZh-94 additive, have been found to be highly resistant to freezing.

Studies of the pore-space structure of cement paste, mortars, and concretes with aliphatic epoxy resins and resin No. 89 as additives by the method of mercury porometry have shown that the maxima on the curves of differential porosity are shifted into the area of microscopic pores. However, mercury porometry and sorption methods cannot distinguish, among the total volume of pores, those which are closed, and therefore, cannot predict the freezing resistance of concretes of these compositions.

Studies of the structure of fresh fractures of specimens of cement paste on a scanning electron microscope have shown that water-soluble resins (No. 89, TEG-1, M-19-62) change not only the pore size, but also the shape of new formations on the bottom and walls of the pores. Resin No. 89 is apparently capable of forming pore-space structures in concretes and mortars which are close to a standard system of closed pores.

Tests were conducted to check this assumption and results showed that when water-soluble resins are introduced, the structure of the pore space and the products of hydration of cements change, allowing a significant increase in the freezing resistance of the concretes.

A467 Kuznetsov, V. V., Balybin, N. A., Monakov, S. S., and Kuznetsov, N. P., "Steel-Reinforced Polymer-Concrete Thinwall Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 62, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Lipetsk Polytechnical Institute has been studying the stress-strain state of thinwall reinforced polymer-concrete structures with various percentages of reinforcement under the influence of temporary and permanent loadings, both under normal conditions and under conditions of elevated temperatures.

In the detailed study of the operation of steel-reinforced polymer-concrete ribbed shells under the influence of elevated temperatures, reinforced polymer-concrete slabs, based on FAM resin with various percentages of profiled St. 5 steel reinforcement, were tested first.

To study the stress-strain state of thinwall elements, a ribbed shell with gentle compound curvature was constructed, measuring 3 by 1.5 m in plan, with radii of 5 and 1.5 m and a thickness of 12 mm.

The models were tested in the elastic stage, i.e., with short-term loading. The results of the experiments were compared with the theoretical results produced by the method of V. S. Bartenev, but considering the conditions and specific properties of polymer concretes.

The variation in relative deformation of reinforcement with various temperatures generates a graph similar to the graph of  $\epsilon$ -T for ordinary steel, but the graph is displaced due to the influence of the polymer-concrete mass.

A468 Lavrega, L. Ia., Borislavskaja, I. V., Sobolevskaja, S. G., and Morsova, L. A., "Increasing the Durability of Floor Coverings at Enterprises in the Meat and Milk Industry," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 76, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The floors in enterprises of the meat and milk industry are exposed to intensive impact and wearing loads and complex corrosive media (fats, salts, organic acids, disinfectant solutions, etc.), aggravated by the fact that the surface of the floor must be rough (to avoid slipping) and yet smooth (for sanitary and hygienic purposes).

Considering these requirements, polymer compositions based on IKAS-4 indene-coumarone-acrylate resin, epoxy-diane resins (ED-16, ED-20) and EIS-1 alkylresorcinol resin were studied. The properties of the indene-coumarone-acrylate compositions were found to be unsuitable for enterprises in the meat and milk industry. Epoxy resins are more reliable and universal for these purposes.

The most effective modifiers of epoxy-diane and alkylresorcinol resins are aliphatic epoxy resins; however, their extensive use is at present limited by their high cost and scarcity. Alkylresorcinol, bitumen and tar compositions have good elasticity and sufficiently good physical and mechanical properties. However, their resistance to hot corrosive media is not high, which limits their area of application.

Compounds containing (over 10 percent) liquid rubber are low in

strength, thermal stability, and corrosion resistance. However, their high specific impact toughness allows these compositions to be recommended for the construction of elastic interlayers for monolithic mastic flooring.

The use of vegetable oils, particularly castor oil, as modifiers, significantly improves the ease of working with mixtures, their resistance to the effects of corrosive media, strength and adhesion to the substrate. Castor oil is particularly effective when combined with thixotropic additives - aerosil, butasil.

Based on the studies performed, a three-layer floor-covering design made of mastic and polymer-concrete compositions was developed.

A469 Levchenko, A. I., "Selection of Basic Materials and Parameters of Initial Concrete Mixtures for Polymer-Treated Concrete Linings, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 98, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

One efficient area of application of polymer-treated concrete is the lining of water-intake structures, subjected to abrasive wear and the impact of sediment.

The wear resistance of polymer-treated concrete is influenced by the parameters of the concrete mixtures, type of filler and saturating material.

The method of experimental planning was used to study the influence of the water-cement ratio, pouring properties of the mixture, type and particle size of the gravel on the wear and impact resistance of the polymer-treated concrete. It was established that the best wear resistance is achieved by polymer-treated concrete based on concrete with W/C = 0.4 to 0.45. As the viscosity of the mixture increases to 60 s, the resistance to wear increases, with a simultaneous decrease in impact resistance, meaning that the viscosity of the initial concrete mixture should be between 20 and 40 s.

The wear resistance of the polymer-treated concrete increases with increasing size of the aggregate. Therefore, the maximum aggregate size allowed by the state standard, depending on thickness of the slab, should be used.

The type of gravel, within the range of grades 600 to 1200, has no influence on wear resistance, but significantly influences the impact resistance.

Of the types of coarse filler polymer-treated concretes based on basalt gravel have the best wear resistance and strength.

The saturating materials studied included methylmethacrylate, styrene, and a mixture of styrene with technical divinylbenzene (DVB). The paper presents the results of testing of concrete saturated with these monomers for compressive strength, wear resistance, and shock resistance.

- A470 Limarenko, A. A., and Malyshev, L. L., "Prospects for the Use of Furan Polymer Concretes in the Floor Coverings of Animal Barns," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 75, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Barn floors are subjected not only to constant mechanical effects, but also to the influence of physical and chemical corrosion, resulting in relatively rapid failure. In the barns of animal farms in Krasnodar Krai alone, each year some 150,000 m<sup>2</sup> of floors must be repaired or reconstructed. Many years' experience in the operation of floors in barns at collective and state farms in Kuban' have shown that floors of polymer concrete based on FA monomer, urea-formaldehyde and other resins, are excellent for the construction of animal barns and complexes.

Sanitary-hygienic and toxicologic analysis of various polymer concretes based on FA monomer, used for covering floors in pig barns, have revealed that with a maximum ratio of polymer surface to barn volume of 0.2 m<sup>2</sup>/m<sup>3</sup>, it has no harmful influence on servicing personnel or on the animals, if the degree of polymerization of the material is at least 90 percent. The meantime between repairs of the floors with polymer coating is over 6 years.

- A471 Liupaev, B. M., "Estimate of the Effectiveness of Polymer Concrete and Polymer-Treated Concrete Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 118, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The use of polymer-concrete and polymer-treated-concrete structures in industrial construction depends on the effective utilization of the relatively expensive polymer materials they contain. A method is suggested for estimating the effectiveness of the design of the cross section of bending, noncentrally compressed, and noncentrally stretched structures with ordinary and prestressed reinforcement. The estimates are based on equations describing the relationship between the consumption of materials in the structure and the limiting states and other design limitations. These estimates are among the broadest of objectively well-founded estimates.

A472 Nagdeev, U. Kh., Khabakhpashev, K. G., and Sosin, V. V., "Study of The Physical and Mechanical Properties of Dispersely Reinforced Polymer Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 115, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Experiments involving pulling of sections of steel wire from a PTC matrix showed that the bonding strength  $\tau_b$  is increased in comparison with ordinary concrete by as much as 12 to 16 MPa. This causes a qualitative change in the nature of fracture of dispersely reinforced polymer-treated concrete (DPTC).

The ultimate tensile strength  $\sigma_p$  of the steel wire and  $\tau_b$  were used to determine the parameters of the fibers, based on the condition of breaking every other fiber in an arbitrary cross section of the product. It was found that where  $\sigma_p = 680$  MPa, and the fiber diameter is 0.48 mm, their length should be 30 mm.

In the studies, the content of dispersed reinforcement ( $\mu$ ) was varied from 0 to 5 percent by volume, and W/C of the concrete from 0.44 to 0.75 with C:S = 1.3.

The test results showed that the properties of the new composite material are superior both to ordinary DC, and to PTC. The increase in tensile strength in bending is particularly significant, reaching almost 70 MPa with  $\mu = 5$  percent with PMMA polymer added at 8.5 percent by weight.

A473 Makhmudov, Sh. M., and Alimov, S. A., "Water and Salt Resistance of Polymer-Silicate Solutions," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 148, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Since 1976, the Laboratory of New Structural Materials and Parts of SANIIRI has been studying water- and salt-resistant compositions based on liquid glass for use in reclamation construction projects.

The studies have involved sodium liquid glass with modulus 2.8, density 1.4 to 1.45 g/cc (GOST 962-41), sodium fluosilicate (GOST 87-57), furyl alcohol (STU 89-257-62), polyester resin PN-1 (STU 30-14088-63),



the high-molecular-weight fractions of type "K" polyisocyanate still residue, and local fillers.

Heat treatment with a dry heat-transfer medium or in steam chambers has been used to accelerate the curing of the polymer silicates, with the selection based on the composition of the polymer silicates. The most effective mode of heat treatment of polymer silicates is heating to +80 to 120 C for 10 to 12 hours.

The water resistance of heat-treated specimens, after holding in tap water for 540 days, is 0.75 to 0.85, as opposed to 0.52 for control specimens. The water stability coefficient of normally cured specimens at 60 days of age is 0.92 to 0.96, while that of control specimens is 28 percent lower. The stability of polymer silicates in mineralized water is higher than in drinking water.

The shrinkage of polymer silicates is 2 to 3 times less than that of analogous silicates systems, while polymer silicates modified with PN-1 polyester resin and furyl alcohol are shrinkage-free. They are also free of dimensional change due to swelling in mineralized water. Based on the results of the developments, sewer pipes, slabs for canal linings and troughs for solar desalinators have been manufactured.

A474 Makienko, M. I., "Engineering and Economic Evaluations of the Production of Polymer-Treated Concrete Products Using Radiation Technology," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 133, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The development of a technology for the manufacture of polymer-treated concrete materials and the study of their properties has allowed us to determine some of the best areas for application of products and structures made of PTC materials. These products include PTC pipe.

Engineering-economic calculations of the cost of modification of nonreinforced concrete pipe on pilot-scale installations were performed. The influence of the productivity of the installations, type of gamma-radiation source and type of initial pipe on the effectiveness of production of polymer-treated concrete pipe was determined.

The calculations show that if large radiation-chemical production facilities are set up, the cost of modification of products and structures made of PTC will be about 270 to 350 rubles/m<sup>3</sup>; however, the improvement in properties and durability achieved by this treatment is so great that the final result is a significant savings.

A475 Maksimov, Iu. V., "Use of Polymer Treated Concretes with Special Properties in Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii,

Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 79, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Saturation of concrete with polymerizing compositions not only increases its strength by several times, but also gives it a number of properties which are absent or nearly absent in the initial material, the most important of which are high density and impermeability, electric insulating properties, resistance to the cyclical effects of high (up to +80 C) and freezing temperatures, as well as abrasive wear, chemical stability and many others.

The economic effectiveness of the use of polymer-treated concretes is best seen in special types of structures which utilize the positive properties of this material to the maximum.

Among such special structures are: electric-insulating traverses and masts for electric power-transmission lines, troughs in the salt-water basin of solar-desalination installations, structural elements of buildings used for animal husbandry, well hatch covers, structures in multistory chemical-industry production buildings, tunnel tubing, etc.

This paper describes the use of polymer-treated concretes in electric insulating power transmission lines, power transmission line masts, troughs used in solar greenhouse desalination plants, structures used in animal husbandry and hatch covers for inspection wells. Among other areas of specialized construction in which polymer-treated concrete may be effective are: underwater storage containers and other submerged structures used on the continental shelf; cooling towers; stationary scaffolding and equipment-access towers; mine supports; pilings and supports for construction in permafrost areas, etc.

A476 Maksimov, Iu. V., Kasymov, I. K., Zikeev, L. N., and Iusupov, R. A., "Study of Properties of Polymer Treated Concretes Used for the Manufacture of Power Transmission Line Masts," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 117, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Scientific Research Institute for Reinforced Concrete Products, in cooperation with Tashkent Polytechnical Institute, has studied the physical and mechanical properties of centrifuged concrete, saturated with methylmethacrylate. Experimental prism specimens measuring 7 by 7 by 28 cm were cut from reinforced concrete columns 560 mm in diameter.

The concrete prisms were saturated with polymethylmethacrylate by two methods:

the autoclave method (using the known technology of loading under a vacuum and excess pressure);

the centrifuge method (using pressure and centrifuging).

The monomer was polymerized in the concrete by the thermocatalytic method.

The results of the physical and mechanical testing of the treated concrete prisms are presented in the paper. The test results indicate that saturation of centrifuged concrete with methylmethacrylate allows the prism strength of the initial concrete to be increased by an average factor of 2, achieving a concrete strength of over 150 MPa, allowing this material to be used for the manufacture of power transmission line masts.

A477 Mamatov, Iu. M., "New Furan Binders for the Production of Chemically Stable Polymer Concretes and Mortars," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 6, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer materials based on epoxy, polyester and acrylic resins, although they do have good physical and mechanical properties, have low resistance to heat and chemicals in a number of corrosive media, and furthermore, are comparatively expensive.

Polymer concretes and mortars based on furfural-acetone monomers (FAM, FA), furan-epoxy (FAED-20), furan-phenol carbamide ("Furatol"), furan-phenol (2FS) and other monomers are promising materials. For example, polymer concrete based on furan-phenol carbamide binder has minimal water absorption when compared to polymer concrete based on FAM monomer, and a higher speed and degree of curing. It can be successfully used in hydraulic construction.

A polymer concrete based on furan-epoxy binder (FAED-20), used to protect hydraulic structures, has recently become widely known. Thanks to its resistance to wear by the bed load, impact strength and waterproof properties, this type of polymer concrete is used to protect concrete surfaces, replacing chilled cast iron.

Polymer concrete based on 4FA monomer with lignin filler has high compressive strength (40 MPa). This is explained by the fact that the material based on 4FA monomer polymerizes in 10 min, i.e., 4 to 9 times more rapidly than compounds based on FA and FAM monomers. After 6 hr, the compound is more than 90 percent cured, allowing these materials to be used for emergency repair of foundations and floors, and for equipment linings. Usually, materials based on FA monomer are used for these purposes (e.g., in the cellulose-paper industry); these materials, in spite of their good physical and mechanical properties and chemical stability, also have significant swelling in certain corrosive media, up to 9 percent. To avoid this, the material is modified with phenol alcohols, producing a furan-phenol binder called 2FS, which can be used

to produce materials with a more compact structure than those produced with FA, FAM, or 4FA binders.

In the production of mineral fertilizers, acrylic acid nitrile and ammonium nitrate, materials based on the binder "Polifuron-321," recommended for the protection of equipment in the chemical industry, have proven to be highly stable.

Furan binders, elasticized with epoxy and polyester resins, viniflex and polyethylene, which have high specific impact toughness (up to 6 kgf·cm/cm<sup>2</sup>), are used for the construction of monolithic floor coverings.

In the future, the Research Institute for Plastics plans to continue this work in the area of improvement of the properties of materials and their binders by modification and plasticizing of new compounds, which should be highly effective. Work will be continued on the creation of new, highly effective binders for the production of polymer concretes and polymer mortars, intended to protect containers and construction structures for the chemical industry.

A478 *Namykina, O. A., and Meredov, K. M., "Polymer-Silicate Concrete for Sections of Solar Desalinators," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 167, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Analysis of the operation of solar desalinators has shown that as they are used, they are subjected to complex physical and chemical effects, as a result of which many materials are rapidly broken down. A polymer-silicate concrete with known physical-mechanical properties and chemical stability was used as the basis for development of compositions for solar desalinators.

Improvement of this composition was achieved by increasing the strength and decreasing the permeability in salt solutions. For these purposes, finely dispersed impure sodium disilicate, unsaturated polyester resin (oligoester) and high-molecular-weight fractions of polyisocyanate were used. A composition of polymer-silicate concrete, modified by oligoester, added at 5 to 6 percent of the mass of the liquid glass, was experimentally introduced. The composition for sealing and cementing of sections of the heliodesalinators was developed considering the requirements not only of chemical stability, adhesion and impermeability, but also the deformation properties and capability of curing of the compositions in water. The optimal composition of sealing mortar for the troughs was developed on the basis of liquid glass, modified by increasing the content of high-molecular-weight polyisocyanate with the liquid glass: the polyisocyanate ration was 1:0.5 to 1:1.

Based on these studies, experimental troughs were made for sections of the solar desalinator from polymer-silicate concrete, modified with

furyl alcohol and oligester. The troughs were made in wooden forms lined with tin, according to working drawings developed by Giprovodkhoz Institute. The finished troughs were tested under natural conditions in an experimental area at the Institute of Physics and Technology, Academy of Sciences, Turkmenian SSR.

A479 Mangat, P. S., "Strength and Deformation Characteristics of an Acrylic Polymer-Cement Composite," Materials Construction Materials Structure, Vol 11, No. 66, Nov-Dec 1978, pp 435-443.

The time-dependence of strength and deformation properties of an acrylic polymer modified concrete has been investigated up to 600 days under wet and dry curing conditions. Ordinary portland cement mixes of proportion 1:2:3 (by weight) were used and the water cement ratio was adjusted to achieve reasonably constant workability for the control and modified mixes. The validity of a standard expression defining the stress-strain relationship of plain concrete has been extended to polymer concrete.

A480 Mangat, P. S., and Evans, D. A., "Influence of Polymer Admixtures on the Strength, Deformation, and Fracture of High Strength Concretes," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 67-87.

The use of polymer emulsions to produce very low water-cement ratio concretes has been investigated and the strength, deformation and fracture behavior of the material studied. Four types of polymers were used - acrylic, modified acrylic, styrene acrylic and styrene butadiene. The investigation was carried out on ordinary portland cement mixes with proportions of 1:1.5:2.5, 1:2:2 and 1:2.5:1.5 (by weight) and a water-cement ratio of 0.3 was maintained throughout. Three types of curing regimes were adopted - dry, wet/dry, and wet. The results indicate that polymer addition causes a marked increase in the cracking strength of the concrete matrix, while the critical stress at the onset of dilation is unaffected. The stress at the onset of cracking for plain concrete is 42 percent of its ultimate strength and increases up to 53 percent of the ultimate strength of a polymer modified mix containing 25 percent admixture (by weight of cement). The longitudinal strains at first crack and at ultimate stress also show significant increases due to polymer addition.

The compressive strength of polymer modified concrete decreases with increasing polymer content; reductions relative to the unmodified mix range between 22.7 and 25.7 percent, under different curing conditions, for a 25 percent polymer mix. The corresponding results for the flexural strength indicate an increase of up to 43 percent under dry curing for 180 days.

A481 Manson, J. A., et al., "Use of Polymers in Highway Concrete," National Cooperative Highway Research Program Report 190, 1978, Transportation Research Board.

The researchers first demonstrated in the laboratory that polymer impregnation of structurally sound, typically salt-contaminated concrete could be achieved to considerable depth provided the concrete is brought to a bone-dry condition. It was shown also that impregnation arrested corrosion of the reinforcing steel, virtually eliminated freeze-thaw damage, and substantially increased resistance of the concrete to chemical attack. Water absorption and loss by abrasion were decreased severalfold. With promising results having been achieved in the laboratory, activity was transferred to the field where demonstration projects were carried out on two bridge decks, both structurally sound and one severely salt-contaminated. Using gas-fired infrared heaters for drying the concrete, moderate pressure to aid monomer impregnation, and hot water to cause polymerization, it was demonstrated that deep (up to 4 in. (10 cm)) polymer impregnation could be achieved under field conditions. The equipment and techniques developed for the demonstrations are of a nature to permit scaling up for practical use. This research employed a methyl methacrylate mixture, although other monomer systems probably can be used.

A482 Marchiukaitis, G. V., "Peculiarities of the Design of Reinforced Polymer-Treated Concrete Bending Structures, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 78, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer-treated concrete is a new composite material, the matrix of which consists of the concrete framework, while the filler consists of a polymer with a deformation capacity of 10 to 15 times greater than that of the matrix. Our experiments, and the data from the literature, show that saturation with polymers can cause the compressive strength of heavy concrete to increase to 200 MPa, the tensile strength - to 16 MPa, the modulus of elasticity - to  $6.5 \cdot 10^4$  MPa. Poisson's ratio increases by a factor of 1.6, compressibility and extensibility by up to 2 times, the bonding of the concrete with reinforcement - by a factor of 5. This improvement in properties depends basically on the extent to which the pores are filled with the polymer and the consumption of polymer. The theoretical principles of creation of polymer-treated concretes in the USSR were developed by a well-known specialist in the area of the theory of concrete technology. Doctor in Technical Sciences, Professor Iu. M. Bazhenov. On his initiative, studies are under way on polymer-treated concrete, as well as work on the creation of effective types of reinforcing structures, requiring the development of methods of their design in various stages of stress-strain state, considering the peculiarities of the polymer-treated concrete as a material.

Since the strength of polymer-treated concrete is always greater than 100 MPa, calculation of the load-bearing capacity of reinforced

bending elements by means of the existing formulas in SNiP II-21-75 is impossible. After producing complete  $\sigma$ - $\epsilon_1$  diagrams of materials and calculating the loadbearing capacity by means of a computer, the researchers have developed a method for calculation of the limiting height of the compressive zone similar to that used in the planning norms. The paper includes equations used for calculating depth of compression block as well as crack width determination.

The agreement of the calculated data with the experimental data was satisfactory within the limits of accuracy of the calculation, as was the case for the method used in the planning norms for ordinary, reinforced-concrete structures.

A483 *Mat'iazov, S., and Chekhovskii, Iu. V., "Saturation of Concrete Through the Contact Zone Between Aggregate and Solution," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 88, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Studies were performed to determine the possibility of saturating only the contact zone between aggregate and paste in concrete, in order to simplify the technology of manufacture of polymer-treated concretes.

We demonstrated earlier that the contact zone between aggregate and paste is saturated three times faster than the body of the solupaste in concrete. Studies were performed on concrete mixtures, the coarse aggregate in which had no separation, i.e., the grains were in contact with each other. The following concretes were used:

with limestone gravel - 1:3.5:5/c:s:g (by mass), W/C = 0.5;

with granite gravel - 1:3.5:7.7/c:s:g (by mass), W/C = 0.4.

The tests were performed on cubes with an edge length of 7 cm and beams measuring 7 by 7 by 28 cm.

Dried specimens were saturated for 2 hr under atmospheric conditions in a methylmethacrylate monomer containing 5 percent giperiz and 10 percent cobalt naphthenate, percent of MMA mass. After saturation, the specimens were placed for 10 min in a high-viscosity composition used earlier in order to eliminate evaporation and leakage of the monomer. Polymerization was performed in water at +80 C.

The test results indicate that specimens containing limestone gravel increase their bending strength by a factor of 7, their compressive strength by a factor of 7.8, after treatment, while specimens containing granite gravel show strength increases by factors of 5-6 and 5, respectively.

A484 *Matkov, N. G., "Strength and Deformation of Polymer-Treated Concrete Compressive Elements with Transverse Reinforcement, Partially Saturated with Polymer," Increase in the Service Life of*

Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 114, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Special studies were performed in the Laboratory of Reinforced-Concrete Structures, using concrete and reinforced-concrete specimens (measuring 20 by 20 by 80 cm), partially saturated to a depth of no less than the protective layer (20 to 100 mm). The standard used consisted of the initial concrete and reinforced concrete prisms, with simultaneous testing of ordinary and saturated cubes measuring 15 by 15 by 15 cm. The experimental specimens were saturated with methylmethacrylate, using both the thermocatalytic and radiation methods of curing. The thickness of the saturated layer was determined approximately on the basis of the consumption of monomer and by sawing prisms and cubes in half. The consumption of polymer for partial saturation of the experimental specimens averaged as much as 5 to 7 percent by volume, depending on the porosity of the cured concrete and the depth of saturation.

The basic results of the comparison of strength and deformation characteristics of untreated and reinforced, partially saturated specimens for the two curing methods showed that the strength increase factor for reinforced-concrete specimens varies between 1.5 and 2.5, in comparison to the strength of the untreated specimens. This great spread in the results can be explained by the partial saturation of the surfaces of the specimens (the interior of the concrete was not saturated).

A485 McClain, R. R., "Epoxy Modified Cement Admixtures," Second International Congress On Polymers in Concrete, Austin, Tex., Oct 1978, pp 483-501.

Two epoxy resins and companion curing agents designed for the modification of portland cement compositions have been utilized in laboratory and field application testing. The effects of modification with these systems on various strength, durability, and working characteristic parameters of a typical concrete have been studied in this work. Performance improvements gained over other polymer modified concrete types are noted. The proper design and use of epoxy modified concrete mixes are outlined. Repair and resurfacing of a highway bridge deck with an epoxy modified concrete is described in detail and results of subsequent inspections of this deck are documented.

A486 McNerney, M. T., "An Investigation Into the Use of Polymer-Concrete for Rapid Repair of Airfield Pavements," Report No. CEEDO-TR-78-10, Jan 1978, Civil and Environmental Engineering Development Office, Tyndall AFB, Fla.



An investigation of a high-strength, fast-setting mixture of methyl methacrylate and dry aggregate was conducted. The resulting polymer-concrete (PC) was very strong, durable, and bonded excellently to concrete. Tests were conducted to determine the variables affecting the polymerization time and strength of polymer-concrete. Field tests were conducted to interstate highways and a major airport taxiway which demonstrated the feasibility of making laboratory tests of a 3-ft by 6-ft area repaired by PC and an individual PC slab under repeated loadings of simulated truck and aircraft traffic demonstrated the excellent strength and durability of the material. A cost analysis found the cost of monomer to be approximately \$10/cu ft. for most repairs.

*A487 Mikul'skii, V. G., et al., "Investigation of the Possibility of Using Polymer Concretes and Polymer-Cement Concretes in Atomic Technology," 1978, USSR.*

The use of polymers in atomic technology is developing in the following directions:

- (1) Protective coverings of equipment and premises of radiochemical works and nuclear installations;
- (2) Polymer components, including pipelines, packing, and hermetically sealing articles;
- (3) Electric and heat insulation, and polymer aggregates;
- (4) Polymer-containing screens for biological shielding against radiation.

The use of polymer-cement concretes and polymer concretes in atomic technology has practical interest. These compositions have a high hydrogen content, due to the presence of a polymer binder. Furthermore, in comparison with cement concretes, polymer-cement concretes and polymer concretes have higher physicomachanical characteristics: strength and deformability, resistance to wear, durability in aggressive media, etc.

*A488 Mikul'skii, V. G., et al., "Investigation of the Possibility of Using Polymer Concretes (PC) and Polymer-Reinforced Cement Concretes (PPCC) In Nuclear Engineering;" Translated from Russian by Bureau of Reclamation, Denver, Colo., 1978.*

The use of polymers in nuclear engineering and technology is developing in the following directions:

- (1) Protective coverings for the equipment and buildings of radiochemical and nuclear facilities;
- (2) Polymer compounds, including pipes, and sealing and jointing materials;
- (3) Electrical and thermal insulation, polymer aggregates;
- (4) Polymer-containing shields for protection from irradiation.

The use of polymer-portland cement concretes (PPCC) and polymer concretes (PC) in nuclear engineering is of practical interest. Those materials have high hydrogen content due to the presence of the polymer filler. In addition, compared with portland cement concretes, PPCC's and PC's have superior mechanical and physical properties: strength and deformability, abrasion resistance, stability in corrosive environments, etc.

The investigations show that polymer concretes and polymer-portland cement concretes may be used as effective fillers for the design of modular-disassemblable shields for reactors and accelerators due to their increased hydrogen content and the possibility of using heavy fillers.

The good mechanical and physical properties of these materials permit their use for the structures and protective jackets of high-pressure vessels, and for the trim and floors of nuclear engineering installations.

Polymer concrete materials, particularly those based on epoxy, bind floors required under conditions of radioactive contamination.

Storage pits for radioactive wastes, trays, and channels occupy a large volume in nuclear engineering installations. The use of polymer concretes for lining these structures is extremely promising. The stability of polymer concretes under conditions of liquid environments and radiation is being studied at the present time.

A489 Mikul'skii, V. G., "Repair and Protective Coating of Reinforced-Concrete Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povysheniei Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 11, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The use of polymer compounds to repair concrete and the construction of various protective coatings for concrete and reinforced-concrete structures represent the most economically favorable and technically desirable solution to this problem. Considering the high cost of polymers, such a combination of cement concrete and polymer in the form of thin coatings actually yields a qualitatively new material without significantly changing the existing manufacturing technology, and provides protection from the harmful effects of usage factors, and furthermore, gives structures new properties.

Concrete and reinforced-concrete structures may have various defects, such as cracks, chips, etc., arising during the process of manufacture or use. Repair using polymer compositions can fully restore the lost qualities of the products.

Interesting studies are underway in the area of the use of various inexpensive polymer compounds to repair defective concrete. Polymer composites based on furan-epoxy resins can reliably cement new concrete to old concrete if concreting operations must be interrupted, when it is necessary to seal the seams between structures, during repair operations, etc. All of these operations are being successfully performed in the construction of the Andizhanskii reservoir dam.

Thin polymer coatings used in road construction can increase the durability of pavement by several times. The Leningrad affiliate of SOIUZDORNII has studied the physical and mechanical properties of epoxy compounds with various modifiers. The selection of compounds plays an

important role in the construction of paving for bridges with variable weather conditions involving fluctuating temperatures. The same requirements are placed on airfield pavement. Furthermore, runway pavement is also exposed to jet engine heat and lubricating oil. The results of studies in this area will allow polymer compounds to be used to restore damaged sections rapidly, to improve the profile of pavement, etc.

At the Tselinograd Construction Engineering Institute, studies have been performed on the use of epoxy polymer solutions to construct floors in slaughterhouses. The results produced have been sufficiently encouraging to allow broad-scale introduction to production.

In addition, polymer coatings not only increase the corrosion resistance of structures, but also improve their strength and deformation properties. According to the Moscow Institute of Railroad Transport Engineering, when polymer coatings are applied to concrete, its compressive and tensile strengths increase. The results of studies performed at Mordov State University confirm that reinforced-concrete structures with polymer coatings have better usage characteristics under conditions of dynamic loading.

A490 Mukhibova, N. Z., "Modification of Composites Based on Polymer-Silicate Binder with Compounds Containing the Isocyanate Group," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 147, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Polymer Concrete Laboratory of the Scientific Research Institute for Reinforced Concrete Products, with the direct participation of the author, has developed formulas for polymer-silicate mortars with various contents of polyisocyanate.

Type "K" polyisocyanate is a side product in the production of di- and polyisocyanates, and contains from 22 to 29 percent NCO groups.

The work was performed in two main areas:

the influence of the quantity of polyisocyanate on strength characteristics;

the change in strength characteristics upon long-term exposure to salt and water.

As the studies showed, the introduction of polyisocyanate partially increased the strength of specimens (of material) and greatly increased the stability upon holding in water and aqueous salt solutions.

Whereas the stability coefficient  $K_{st}$  of standard specimens, determined by holding in water and salt, is 0.83 and 0.76, respectively, following introduction of (e.g., 50 percent) polyisocyanate  $K_{st}$  increases to 1.34 and 1.09 (storage time 6 months).

This confirms once more the assumption that the introduction of

polyisocyanate causes the structure of a material to become compact and practically impermeable.

Based on this, we can state that the use of polyisocyanate as a strengthening additive increases the area of application of polymer-silicate solutions and concretes (in salt solutions and water).

A491 Nabokov, B. F., "Study of Polyester Polymer-Concrete Structures Reinforced with Fiberglass," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 66, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Tests were conducted of the bonding of fiberglass reinforcement (FR) with NPS-609-21M polymer concrete.

The work was performed under the direction of Candidate in Technical Sciences V. E. Beliaev. The specimens were reinforced with FR 6 mm in diameter, the short-term strength of which is 1378 MPa, creep not over 6 percent, relaxation - 8.5 percent. The compressive strength of the polyester-polymer concrete averaged 84 MPa, the modulus of elasticity - 26,300 MPa. To determine the influence of the depth of placement of the FR and the thickness of the protective layer of polymer concrete on bonding forces, tests were conducted involving pulling of fiberglass reinforcing rods 6 mm in diameter out of polymer concrete prisms measuring 100 by 120 mm from depths of: 42 mm (7 d), 60 mm (10 d), 90 mm (15 d), 120 mm (20 d), 150 mm (25 d), 180 mm (30 d), 240 mm (40 d), and 258 mm (43 d).

Protective layer thicknesses of 1.5 d and 3 d were used. Based on the results of the tests, it was determined that the optimal depth of placement is 43 d, with a thickness of the protective layer of at least 3 d. Tests of ordinary and prestressed beams were also conducted under conditions of short-term and long-term loading. In all, six beams and six prisms were tested in each series. After molding of the specimens, they were held for one day at +18 to 20 C, relative humidity 65 percent, then for the next day they were heat dried at +80 C. After completion of the process of creep, produced by compression for two months, the beams were tested under short-term and long-term loads. The results of the long-term tests showed that the load-bearing capacity of the beams decreases with time, while deformation increases. However, the crack-resistance factor increases to 1, i.e., cracks do not appear in the beams upon long-term loading.

A492 Nagaraj, T. S., Sundara, K. T., Iyengar, R., and Viswanatha, C. W., "Strength of Polymer and Polymer-Fibrous Concretes," Polymers in Concrete - International Symposium, SP-58, pp 139-160, 1978, American Concrete Institute, Detroit, Mich.

With the continued research efforts, presently the techniques of production of polymer-impregnated concretes have been fairly understood. Measured and evaluated mechanical properties and durability aspects of this material reveal that dramatic improvements are possible, thereby offering great potential to this material in building industry.

This investigation attempts to make a closer examination of the mechanisms of strength mobilization in polymer-impregnated concretes. It has been possible with limited experimental data, to delineate the influence of mutual strength of polymerized matrix and coarse aggregates on the overall strength of polymerized concretes. The influence of fibres in polymer-fibrous concretes on overall strength and ductility has also been examined.

A493 Nawy, E. G., Ukadike, M. M., and Sauer, J. A., "Optimum Polymer Content in Concrete Modified by Liquid Epoxy Resin," Polymer in Concrete - International Symposium, SP-58, pp 329-356, 1978, American Concrete Institute, Detroit, Mich.

Full utilization of concrete performance characteristics is restricted by its low tensile strength, susceptibility to severe moisture and temperature changes and chemical attack in adverse environment.

Low viscosity resin with hardener is used in this investigation, mixed under normal temperature conditions in the concrete mix. After developing the best combination of resin and hardener, the effect of water/cement ratio and the polymer/cement ratio on the tensile and other properties of concrete were studied.

The investigation showed that the rate of increase of slump due to the increase in the polymer/cement ratio (P/C) is less than that due to increasing the water/cement ratio (W/C). It also showed that the P/C optimum ratio within the workable range varies between 0.3 and 0.45 for any practicable W/C ratio below 0.6.

It is also demonstrated that liquid polymers of the type used give better mix results when their viscosities are kept low as the ratio of the resin to the hardener is kept close to the optimum stoichiometric ratio of 100:68 in this investigation.

Compressive strengths of 12,218 psi (858.9 kg/cm<sup>2</sup>) and tensile splitting strengths of 1,186 psi (83.4 kg/cm<sup>2</sup>) were obtained for W/C = 0.2 and P/C = 0.4. At a W/C ratio of 0.045 and P/C ratio of 0.6, the tensile splitting strength increased significantly by 30 percent to 1,538 psi (108.12 kg/cm<sup>2</sup>) and the compressive strength to 13,531 psi (951.2 kg/cm<sup>2</sup>). The control specimens with P/C ratio = 0 and a typical W/C = 0.4 showed a tensile splitting strength of 603 psi (42.4 kg/cm<sup>2</sup>) and the compressive strength of 4,882 psi (343.2 kg/cm<sup>2</sup>). Thus, the polymer modified concrete in this investigation showed a tensile splitting strength increase of 255 percent and a compressive strength increase of 277 percent in the respective strengths of the control cylinders.

The energy absorption characteristics of the polymer modified concrete were almost 3-1/2 times the control specimens making such concretes better suited to such structures as bridge decks and other dynamically loaded structures in addition to their superior serviceability

performance in crack and deflection control due to their high tensile and compressive strengths as well as their higher resistance to aggressive environment.

A494 Nekrasova, E. I., "Optimization of Thermocatalytic Curing of Methylmethacrylate in Concrete by Experimental Planning, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 82, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Hydraulic concrete with an initial strength of 56 MPa under laboratory conditions is dried, evacuated, and saturated with methylmethacrylate. Polymerization is initiated with benzoyl peroxide and performed at +80 C in a heating medium (water). The optimization parameter ( $y$ ) is the compressive strength of the polymer-treated concrete specimens. The concentration of initiator ( $x_1$ ) is varied between 0.6 and 3.4 percent, the heat treatment time ( $x_2$ ) between 2.4 and 6.6 hr. A central composite rotatable, uniform planning  $2^2$  matrix is achieved with an arm length of 1.41. A second order regression equation is derived:  $y = 160 + 27x_1 + 0.6x_2 - 34x_1^2 - 5.6x_2^2 = 4.5x_1x_2$ . The maximum strength of the polymer-treated concrete at the center (170 MPa) is determined with coordinates corresponding to a benzoyl peroxide concentration of 2.55 percent, heat treatment time 4.24 hr.

The studies established the optimal conditions for curing of the monomer in the concrete and the basic differences in comparison with block polymerization of the pure monomer.

A495 Nianiushkin, Iu. I., "Effectiveness and Reliability of Silicate-Polymer Concretes as Protective and Structural Anticorrosion Materials, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 146, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The National Scientific Research Institute for the Protection of Metals from Corrosion, in cooperation with a number of research and planning institutes, has been conducting work for some five years, studying and improving the properties of silicate-polymer concretes, and also developing elements and structures based on these concretes, as well as techniques for their manufacture. During the last three years, the use of these corrosion-resistant concretes at chemical-industry enterprises and heat and electric powerplants has saved some 2 million

rubles. Some individual elements and structures of silicate-polymer concretes have been in use for over four years.

The use of silicate-polymer concretes is particularly effective for the construction of chemical drains. We refer primarily to structures which collect chemical wastes and the bases of evaporative cooling towers. It has been found possible to manufacture precast reinforced elements for collector units of both heavy ( $\gamma = 2.2 \text{ t/m}^3$ ) and light ( $\gamma = 1.7 \text{ t/m}^3$ ) structural silicate-polymer concretes, with masses of individual precast elements of 3 to 4 t. The use of precast elements, in combination with monolithic silicate-polymer concrete, can reduce the time required to manufacture new collectors and repair old ones by a factor of 2 to 3, while decreasing their cost by a factor of 4 to 5. The experience of the use of these structures over a period of more than two years has shown that the strength of the material remains unchanged, and that reinforced structures are also fully preserved, with no signs of corrosion.

High economic effectiveness and reliability have also been achieved by the use of monolithic silicate-polymer concrete as an impermeable, corrosion-resistant material, replacing acid-resistant brick and a substrate of polyisobutylene in cooling-tower bases.

The use of silicate-polymer concrete as a monolithic protective lining for the repair of structures has been found to be particularly effective for the gas-exhaust structures of thermal electric powerplants burning high-sulfur fuel oil. After three years of operation, the material not only has not lost strength, but is actually 1.8 times stronger.

A496 Nikulin, A. V., "The Use of Transverse Spiral Reinforcement in Compressed Steel-Reinforced Polymer-Concrete Elements in Structures with Circular and Combined Cross Sections," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 57, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The use of transverse reinforcement in the form of spirals, rings or nets in compressed reinforced-concrete elements leads to a significant increase in their load-bearing capacity, as well as the deformation of the concrete. The author has suggested and developed an upright (pile)-type structural element, consisting of a steel-reinforced polymer-concrete tubular shell with a spirally reinforced framework and a concrete core formed by filling the cavity in the shell with concrete mixture.

Specimens of nonreinforced and reinforced FAM resin-based polymer concrete 25 by 29 and 55 by 29 mm in cross section, 9 to 90 cm in length, were manufactured in a laboratory at Leningrad Polytechnical Institute. The work was performed in cooperation with and under the leadership of

Candidate in Technical Sciences V. Ye. Beliaeva. Reinforcements of 0.9 percent, 3.14 percent, 4.9 percent, and 9.84 percent were used for the reinforced specimens 59 by 29 mm in cross section.

Testing was performed under normal temperature and humidity conditions, and also at elevated temperatures. The specimens were heated at the assigned temperature for at least 4 to 5 hr, after which they were tested. The rate of load application in the short-term loading tests was at least 60 MPa/min. Between 5 and 8 cross sections of specimens (4 to 5 specimens of each cross section) were tested at temperatures of 35, 60, 100, and 140 C. The test results showed that the longitudinal bending factor is independent of temperature and practically independent of loading duration.

A497 Obolduev, A. T., "Highly Effective Polyester Polymer Concretes, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 20, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A series of new types of polyester-polymer concretes has been developed on the basis of type NPS-609-21m, NPS-609-22m, NPS-609-22s, PN-62 and PN-63 resins, which have low toxicity and (with the exception of NPS-609-21m resin) low flammability, making them effective from the standpoint of hygiene and fire safety. These polymer concretes also have good water and corrosion resistance, while retaining good strength properties in comparison to polymer concretes based on general-purpose, polyester-styrene resins. In terms of sanitary-hygienic characteristics, the materials are approved by the USSR Public Health Ministry for use in the construction of industrial buildings, warehouses, and various supplementary structures.

The use of the resins significantly increases the fire resistance of polyester-polymer concretes; they are particularly effective when combined with flame and heat protection. This has been confirmed by flame testing of steel-polymer-concrete slabs measuring 1100 by 1100 by 60 mm. Flame testing did not cause early failure of the polymer concrete. Thus, the tests showed that bending elements of polyester-polymer concrete made with low-flammability resins (particularly PN-62 resin) have good fire resistance.

A498 Ohama, Y., "Determination Methods for Working Life of Polyester Resin Concrete, Polymers in Concrete - International Symposium, SP-58, pp 31-40, 1978, American Concrete Institute, Detroit, Mich.

The objective of this study is to find out appropriate methods of determining the working life of fresh polyester resin concrete. Three types of methods tentatively specified to establish a standard test method of working life determination for it are given and their



applicability to fresh polyester resin concrete prepared with various mix proportions and working life is discussed. The tentative mix proportions are outlined as follows:

(1) Penetration method - Based on penetration depth of steel rod into fresh resin concrete.

(2) Pull-out resistance method - Based on pull-out resistance (measured by spring balance) of steel rod embedded, from fresh resin concrete.

(3) Finger-touching method - Based on the sense of touching through polyethylene film on fresh resin concrete by fingers.

It is concluded that penetration, pull-out resistance and finger-touching methods are satisfactorily applicable to the determination.

A499 Ohama, Y., "Development of Concrete-Polymer Materials In Japan," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 121-137.

In recent years, progress in a wide range of research and development activities concerning concrete-polymer composite materials, has been made in Japan. Concrete-polymer materials include polymer-modified (or cement) concrete (PCC), resin concrete (REC) and polymer-impregnated concrete (PIC). This paper reviews the present state of research and development of concrete-polymer materials. These materials are widely used in numerous applications in which their excellent properties, such as high strength, watertightness and high durability, have the advantage over those of traditional cement concrete. It is very important in the practical development of concrete-polymer materials that good balance between cost and performance required be achieved in any applications.

A500 Ohama, Y., Selected Bibliography on Polymer (or Plastics) Concrete, Nihon University, College of Engineering, Japan, Oct 1978.

This bibliography contains 1615 references pertaining to polymer-modified concrete, resin concrete, and polymer-impregnated concrete. The references compiled from publications, collected by the author for the past 20 years. The bibliography is divided into two parts: Part 1, the bibliography written in English, German, and French; Part 2, the bibliography written in Japanese. Especially the latter includes the references of studies conducted solely in Japan. The references of Russian work in polymer concrete were not listed in this bibliography.

A501 Okopova, R. M., "Furan-Epoxy Resins for the Repair of the Concrete Linings of the Banks of Hydraulic Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 43, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Ukrainian Scientific Research Institute for Hydraulics and Reclamation has developed repair substances based on type FAED-20 furan-epoxy resin, synthesized by a division of the Scientific Research Institute for Plastics. The addition of alkylbenzyltrimethylammonium chloride (ABDM), C<sub>17</sub>-C<sub>20</sub> fraction, at 0.5 to 1 percent of the mass of the binder, allows the substances to be poured directly onto water-saturated concrete. The fillers used include screened granite, andesite powder, portland cement, sand, and polyethylene polyamine as a curing agent.

The adhesion strength, water resistance, and freezing resistance of the substance was studied in tests involving bonding of specimens in both the air-dry and water-saturated states.

The studies have established that the furan-epoxy compound produces strong bonds with dry concrete (4 to 5 MPa), stronger than the cohesive strength of the concrete, as well as strong bonds (2.5 to 3 MPa) with water-saturated concrete.

Following long-term exposure to water, specimens bonded by the furan-epoxy compound retained some 80 to 85 percent of the strength of control specimens, whether originally bonded in the air-dry or water-saturated state; the freezing resistance is high, with bonds retaining 70 to 80 percent of their strength after 300 freezing-thawing cycles.

A502 Orentlikher, L. P., *"Using New Organosilicon Compounds in Construction,"* Translated from Russian by Bureau of Reclamation, Denver, Colo., 1978.

At the present time, organosilicon compounds are used in residential and civil construction and in the construction materials industry as hydrophobicizing fluids in order to increase water resistance (for example, GKZh-10, GKZh-11, GKZh-94, and others) and also as paints (KO-174, KO-194, etc.). Organosilicon fluids and film-forming agents have been used to date only with organic solvents (toluene, benzene, etc.) and have not been used independently.

The organosilicon polymer proposed in this article has all the positive properties of organosilicon compounds, while a number of their shortcomings are significantly reduced.

The distinguishing features of this film-forming agent are as follows:

- It is a single-component composition.
- Its predetermined high properties can exist and are retained in an aqueous emulsion system (just as in an organic solvent solution).
- It has great adhesive properties for most structural materials.
- It can harden without the use of catalysts.
- It allows bonding of moist materials.
- It has high adhesion with most materials, whereas other organosilicon polymers have less adhesion than epoxy, alkyd, melaminoalkyd, and other compounds.
- The bonding material itself is nontoxic.
- It is highly water repellent.

- It has low molecular weight and the branched cross-linked structure of a polymer, resulting in a number of important technical properties.

- Its water-repelling properties are retained over a long period of time.

A503 Otrep'ev, V. A., "Bending Reinforced-Concrete Beams of Modified Acid-Resistant Concrete, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 159, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Acid-resistant liquid-glass-based concrete, modified with polymer additives, cured by an accelerated method, and subjected to dry heat, has the strength and deformation properties necessary for use in load-bearing structures. At the Central Structures Laboratory of the Scientific Research Institute for Reinforced Concrete Products, the author has studied the strength and deformation properties of bending reinforced-concrete beams of concrete with a strength of 35 MPa, containing 0.4 and 1.7 percent reinforcement. A series of beams was tested, using various modes of loading in various environments. Testing of the beams to failure after 3 months holding in 30 percent sulfuric acid (series I), and testing of identical beams held in air (series II) showed that the strength of the beams was practically identical and is easily estimated by calculation using the norms for ordinary reinforced concrete, by basing the calculations on a reduced area. The stress curves in the compressed portion of the cross section of the beams indicated stresses 30 to 40 percent less than the theoretical stresses calculated according to SNIIP II-21-75.

Testing of bending beams under long-term loading (series III) showed that with a beam loading of  $0.4 L_{\max}$ , the deformation stabilized after 20 to 25 days.

In tests under long-term loading at the very high level of  $0.6 L_{\max}$  for 300 to 350 days, some redistribution of forces in the cross sections was observed. The stresses in the concrete decreased, while the stresses in the reinforcement increased by 6 to 10 percent. Exposure of the loaded beams to sulfuric acid, which was then washed off with water, caused a slight increase in deformation, by 3 to 6 percent, during the initial period, but after 1.5 to 2 months, stabilization occurred.

A504 Papova, O. S., "Prospects for Development, Compositions, Properties, and Technology of Polymer-Cement Structural Materials, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti

Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),  
Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 135, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The results of a number of years of research have shown that, in order to change the properties of structural concretes, it is desirable to introduce organic compounds to them as additives. Organosilicates, aliphatic epoxy resins and resin No. 89 have been used in construction. The resins are introduced at 0.15 to 2 percent of the mass of the cement with the curing water, which does not change the method of selection of compositions of the concrete or the ordinary manufacturing technology. All resins, to various extents, influence the plasticizing and stabilization of mixtures, modify the structure of the pore space and the products of hydration of the binder which, in turn, determine all of the physical and mechanical properties of the concretes and their durability.

All resins plasticize concrete mixtures, either by changing the surface tension of the liquid phase and acting as surfactants, by changing the wettability of the surface of the minerals which make up the aggregate for the concretes, or by creating stable air entrainment. It has been shown that resin No. 89 and aliphatic epoxy resins plasticize concrete mixtures of varying mobility (the cone slump of plastic concrete mixtures is almost doubled, the pourability of stiff mixtures changing from 195 to 180 s to 110 to 100 s). This allows, while using mixtures of varying mobility, a decrease in the water-cement ratio or cement consumption. Concrete mixtures containing water-soluble resins retain better mobility for 1.5 to 2 hr than do mixtures containing SDB additive.

It has been found that the introduction of water-soluble resins to the composition of concrete mixtures increases the grade of the concrete, in terms of water impermeability, decreasing the kinetics of capillary uptake of water by a factor of 5 to 8. The gas permeability, even of such porous compositions as cement-clay packing mortars with W/C = 0.85, can be decreased from 11.5 mдарcy (control specimen without additives) to 0.8 mдарcy in a specimen containing 5 percent TEG-1 resin. The increase in the density of concrete resulting from the introduction of water-soluble resins leads to an increase in its resistance to freezing. However, as laboratory studies and tests of cores drilled from a block of the dam of the Zeyskii hydroelectric powerplant have shown, it is better to use organosilicon polymers such as GKZh-94 to increase the cold resistance of concretes.

Studies performed earlier showed that water-soluble resins increase the crack resistance of concrete by a factor of 2 to 6, depending on the composition and the usage conditions of the structures. The reasons for this effect are the decrease in shrinkage deformations of the concrete, the increase in tensile strength and deformation during extension and bending, without decreasing the compressive strength. As a result of this, the boundaries of microcrack formation  $R_t^0$  and  $R_t$  are shifted into the area of high stresses.

This study presents the results of the studies of a group of authors who have shown that the introduction of water-soluble aliphatic

epoxy resins types DEG-1, TEG-1, MEG-1, resin No. 89, and organosilicon polymers types GKZh-11 and GKZh-94 to structural concretes results in significant improvement of the most important properties defining durability of construction structures.

The level of introduction of concrete with water-soluble resin additives to construction, with significant savings, allows us to state that these materials should be used in all cases when it is necessary to produce structures with high levels of water and gas impermeability and crack resistance.

The prospects for their use in industry and hydraulic construction depend on the volume of production of resins.

A505 *Patty, T. S., "Petrographic Identification of Polymer in Surface-Treated Bridge Decks," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 245-253.*

Since 1973 polymer-impregnated concrete from demonstration and full-scale experimental bridge deck projects in Texas has been examined microscopically for polymer identification. Several petrographic techniques, including low-magnification stereoscopic examinations, thin-section and polish-section microscopy, and observations with the scanning electron microscope, have recently been employed by the Materials and Tests Division of the Texas State Department of Highways and Public Transportation to identify polymer systems in bridge deck cores. It was found that acid etching and color enhancement of the cement paste with phenolphthalein aided in low-magnification microscopical determination of polymer penetration. Neither the technique utilizing thin-section analysis with transmitted polarized light nor the observations using the scanning electron microscope proved to be practical in the evaluation of PIC cores. Petrographic examination of polish sections viewed with reflected polarized light at magnifications ranging from 200 to 400X was found to be the most effective means of identifying polymer systems. The recognition of discontinuities within the anticipated polymer saturation zone, along with other features possibly related to variations in monomer loading, curing, and moisture content, suggests that petrographic analysis has merit in evaluating polymer treatments.

A506 *Paturoev, V. V., "Problems of the Technology and Prospects for Application of Polymer and Reinforced Concretes in Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 3, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The model suggested by the author for the formation of the bonding mastic (microstructure and macrostructure) in polymer concrete, which is

formed by integration with the aggregate, has permitted the development of a method for the calculation of economical compositions of polymer concrete with stable physical and mechanical properties, determined in advance.

The bonding mastic, depending on the morphology of the supermolecular formations, determines the strength and rheologic characteristics of polymer concretes (shrinkage deformations, creep deformations, relaxation processes). The properties of the macrostructure are determined by the strength and packing density of the aggregate, the adhesion interaction of the mastic with the aggregate and the presence of various defects. Experiments have established that the optimal properties of bonding mastics can be achieved when the specific surface of the aggregate is 3000 to 5000 cm<sup>2</sup>/g and the polymer content of the polymer-aggregate system is optimal. The optimal polymer content is determined in practice by the packing density of the aggregate. Ordered, oriented polymer structures are formed at the phase-division boundary, consisting of supermolecular formations of globular or fibril type, which determine the basic properties of the microstructure. For the specific surface mentioned above, the quantity of aggregate should be between 100 and 150 percent of the quantity of polymer, by mass.

Studies of the morphology of the supermolecular formations in the microstructure of polymer concretes and the natural internal stresses have been conducted, in cooperation with the Institute of Physical Chemistry, Acad. Sci. USSR, and have shown a close interrelationship between changes in the supermolecular formations depending on the polymer-aggregate ratio, chemical composition of the oligomer and nature of the aggregate, which directly influence shrinkage stresses. Methods have been developed and suggested for directed alteration of the morphology of supermolecular structures and the corresponding shrinkage stresses.

It is noted in the report of Professor S. S. Davydov that the principles of structure formation of polymer concretes have been advanced in the direction of further improvement at the Moscow Institute of Railroad Transport Engineering. We should note particularly the disagreement between specialists at the Research Institute for Reinforced Concrete Products and the Institute for Railroad Transport Engineering on a number of important questions in this area.

The physical and chemical principles of structure formation which have been developed (methods of estimation and of decreasing natural internal stresses, design characteristics and characteristics of chemical stability) have allowed the Polymer Concrete Laboratory to develop the basic principles of a plant technology for series production of polymer concretes. Based on this information, Giprotvetmet, Goskhimproekt, "Proektkhimzashchita" Institute and other organizations have developed and produced a series of standard working drawings for chemically resistant reinforced polymer concrete structures.

PAM-based polymer concrete should be cured using new types of curing agents, including GSK (report of S. I. Kotlik).

In developing compositions for light and superlight polymer concrete (in addition to Keramzit and Agloporit), expanded extenders such as perlite, volcanic ash, blast-furnace slag, slag-sital and

schungite should be more widely used. Sand and the fine fractions should be made on site by grinding of these same aggregates.

A507 Paturoev, V. V., and Krasovitskii, A. S., "Heat Insulating Foam Polymer Concrete for Underground-Heating Lines," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. N. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 12, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

One trend in the solution of the problem of creating durable and effective heat-insulating structures for underground-heating lines is the use of strong polymer materials capable of providing thermal and hydraulic insulation, combining the properties of plastic form and structural polymer concretes (foam polymer concretes).

As a result of combined operations by the Scientific Research Institute for Reinforced-Concrete Products and the National Scientific Research and Production Institute for the Power-Engineering Industry, foam polymer concrete based on furan resins and polyisocyanates (still residues) have been developed, with the following basic properties:

Density	300-600 kg/m <sup>3</sup> ;
Compressive strength	2-5 MPa;
Bending strength	1.5-3 MPa;
Adhesive strength (bonding with a metal pipe) at t = 150 C with complete water saturation	0.5-1 MPa;
Thermal stability	150-170 C;
Water absorption in 24 hr at t = +20 C	1.5-5% (by volume);
Heat conductivity in the 30-150 C range	0.06-0.12 kcal/m·hr·C

The compositions which have been developed are superior, in terms of many of the indices just mentioned, to heat-insulating materials available today, based on mineral or organic materials, and are available, relatively inexpensive, capable of being applied to the surface of metal pipes without preliminary treatment (i.e., without removal of scale, traces of rust, degreasing or application of anticorrosion coatings).

Experimental development work on the manufacture of standard specimens and full-scale sections of heating lines 100 mm in diameter and up to 3 m in length have shown that the technology of application of the foam-polymer concretes which have been developed is similar to the technology of manufacture of parts of cement concretes: It does not

require special equipment, is easily mechanized and automated, and allows the performance of insulating operations both in existing plants and at construction sites.

The results produced indicate the promise of the introduction of the foam-polymer concretes which have been developed for underground-heating lines, with and without conduits.

A508 Patureov, V. V., *"Strength and Deformable Properties of Polymer Concretes and Rational Fields of Their Application," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 567-573.*

Use of polymers for improving the properties of concrete and developing new effective concretes has resulted in a large group of special concretes (P-concretes) which show many positive and, in some cases, even unique properties.

According to the classification elaborated by the polymer concrete laboratory of NIIZhB, the P-concretes group involves polymer cement concretes, polymer concretes, polymer silicate concretes, and concrete polymers. Only certain types of polymer concretes are considered in this paper.

A509 Patureov, V. V., *Technology of Polymer Concretes; Translated from the original Russian by Leo Kanner Associates, Redwood City, Calif., Apr 1978, for U. S. Bureau of Reclamation.*

The characteristics of the raw materials (synthetic resins, hardeners, and additives) of polymer concretes are presented, and their rheological and technological properties and the thermal and shrinkage stresses during their formation and consolidation are discussed. Data are presented for the design and calculation of optimum polymer concrete compositions, and a technical and economic analysis of the use of chemically stable reinforced polymer concrete structures is given.

The book is intended for scientific, engineering, and technical workers of scientific research organizations and structural materials industry plants.

A510 Peschke, H., *"18 Years Experience With Polymers in Concrete in Europe," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 447-460.*

Research and development contracts sponsored by the Federal Department of Transport, the Research Agency for Highway Systems, the Federal Highway Administration, and other federal and local agencies of West Germany that have been executed since 1960 have shown that acrylic polymer concrete, with reactive resins as the sole binder, can come the closest to meeting the demands imposed on the materials system, because of low shrinkage and other favorable characteristics.

This acrylic system consists of two components - a premixed powder that contains fine sand, polymers, initiators, pigments, etc., and a liquid monomer.



The West German Federal Highway Administration has just published Instructional Manual for the Maintenance and Rehabilitation of Concrete Road Surfaces, Part: Repair of Surface and Edge Damages Using Reactive Resin Mortars, which, among other things, spells out in detail what requirements the material systems as well as the substrate have to meet to result in full rehabilitation of concrete road surfaces, bridge decks, and structural concrete.

Minimum requirements and performance standards for field - as well as laboratory - tests are given which will, for the first time, enable engineers, etc., to decide whether or not the proposed material and/or substrate will perform in such a way in the field that its use for a particular application can be approved.

A511 Petrenas, I. I., "Study of the Crack Resistance of Concretes with Water-Soluble Resins," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 152, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Analysis of both theoretical and practical studies of the physical and mechanical properties of concretes shows that the factors determining the capacity of the concrete to resist crack formation are the bonding of the cement paste with the aggregate and the condition of the contact zone.

We have studied the influence of additives on those characteristics of the cement paste, before and after curing, which determine the bond strength. In our studies, we used commercially manufactured polymer materials - water-soluble resins produced on the pilot and full commercial scales. Studies were performed on portland cement of the Leningrad plant, synthesized with  $C_2S$ ,  $C_3S$ , and  $C_4AF$  clinker minerals, sea sand, and granite gravel in the 5- to 20-mm range.

The results of the studies of physical-chemical and cohesion properties of the cement-polymer paste confirmed the results obtained by O. S. Popova; the addition of resin changes the morphology and number of new formations, the degree of hydration of the cement, and the structure of the pore space of the cement paste.

Studies of the influence of additives on the rheologic properties of the wet cement and mortars showed that the introduction of water-soluble resins decreases the structural viscosity of wet cement and increases the wetting capacity of the composition for the surface of the aggregate particles.

The formation of more complete and intimate contact and the decrease in internal stresses explain the increase in the bond strength between the cement-polymer paste and the aggregate particles.

The selection of a crack-resistance criterion and the conduct of studies of the physical and mechanical properties of concrete

(composition 1:1, 5:3, W/C = 0.35), used directly or indirectly to answer the question of crack resistance, indicate that the introduction of the water-soluble resins in question to the concrete mixture increases the crack resistance of the concrete.

A512 Pimenov, A. N., "High-Strength Acid-Resistant Concrete Based on Liquid Glass and an Active Filler," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. N. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 160, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Scientific Research Institute for Reinforced Concrete Products, in cooperation with the USSR Ministry for Heavy Construction, has developed a high-strength acid-resistant autoclave cured concrete, based on sodium liquid glass and an active filler.

The physical and mechanical properties of this concrete depend essentially on the selection of its composition and curing mode. In this connection, an experiment based on preliminary mathematical linear programming (simplex method) was performed, the purpose of which was to determine those values of factors, i.e., those quantities of liquid glass, perlite flour and sand, as well as temperature and holding time, which provided the maximum strength.

The results of the experiment showed that the optimal concrete composition and curing mode allow the production of concrete with the following primary physical and mechanical properties:

Compressive strength	100-120 MPa
Tensile strength	14.5-15 MPa
Initial modulus of elasticity	40,000 MPa
Stability factor in 30% sulfuric acid	1
Stability factor in water	0.81 .

A513 Popava, O. S., Sataikin, A. V., and Krasovskii, P. S., "Gas Permeability of Concretes Containing Polymer Additives" (in Russian), *Sb.Tr., Leningrad, Inst. Inzh. Zheleznodorozh. Transp., No. 333, 1972, pp 84-94; Chemical Abstracts, 163384c, Vol 78, No. 26, 1978.*

To obtain concretes of min. gas permeability cement consumption with sp. surface 4600 to 5000 cm<sup>2</sup>/g should be 450 to 70 kg/m<sup>3</sup>. The use of resins No. 89 and TEG-1 decreases gas permeability by a factor of 2 to 7. With the increase of pressure and moisture the effect of the resin TEG-1 on gas permeability increases. By increasing pressure to 50 kg/cm<sup>2</sup> the coefficient of gas permeability of concrete with TEG-1 additive is decreased by a factor of 10 from those of concretes without additives. The fine porous structure of cement-polymer concretes can hold water securely and a high pressure is necessary for removing moisture from the capillaries.

A514 Popova, O. S., "Effective Areas of Utilization of Concretes with Water-Soluble Resin Additives," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 163, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Of all the organic compounds which are presently introduced to concrete mixtures as additives, the most technologically suitable are the water-soluble resins. The chemical industry produces the following resins in quantities sufficient for the requirements of the construction industry: carbamide resins (MMF-50, M-70, M-19-62, MF-17, etc.), alkylresorcinol resins, aliphatic epoxy resins (MEG-1, DEG-1, TEG-1, etc.), polyamide resin No. 89, polymers which are the products of processing of shale tar, and polyoxyethylene.

The results of studies of recent years have shown that water-soluble resins can serve as regulators of the rheologic properties of concrete mixtures, the processes of setting and curing of the binder, the structure of the pore space and products of hydration of cement.

Thus, in order to produce long-lived, water-impermeable concretes, it is necessary to change the structure of the pore space and the dispersion of the structural components of the products of hydration of the binder, which is possible by regulation of its setting and curing times. Almost all carbamide and alkylresorcinol resins are typical hydration retarders, while polyamide resins No. 89 and aliphatic epoxy resins accelerate the processes of setting and curing to varying degrees.

It is desirable to use aliphatic epoxy resins and resin No. 89 as additives to concrete, to increase the physical-mechanical properties and durability of the concretes.

To preserve the mobility of mixtures with identical plasticity, it is more expedient to use water-soluble resins than SDB plasticizing additive.

Thus, the results of many years of laboratory research and application of water-soluble resins in construction practice have shown that all resins can be expediently used to increase the mobility and stability of mixtures, the density and impermeability of concretes.

A515 Popko, V. N., Beinarovich, A. V., and Patukhov, V. N., "Properties and Structure of Polymer Cement Concrete with ED-20 Epoxy Oligomer," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 151, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A study was made of the properties of heavy portland-cement and slag-portland-cement concretes with the addition of up to 5 percent (of mass of cement) ED-20 epoxy oligomer and polyethylene polyamine curing agent.

It was found that the introduction of the epoxy oligomer had a plasticizing effect on the mortar and concrete mixtures, this effect being stronger, the higher the content of the additive. Introduction of 2 percent of the additive to the concretes allowed the W/C ratio to be decreased by 10 percent.

Introduction of the additive improved the physical and mechanical properties of the mortars and concretes. The addition of 1 to 2 percent oligomer to the concretes increased their compressive strength by up to 20 percent, their bending strength by up to 35 percent, and their tensile strength by up to 30 percent.

The water impermeability of the cement concretes was increased from V6 to V12. The adhesion strength of the polymer-cement concretes with the addition of 2 percent ED-20 increases by 20 to 30 percent following holding in moist air, by 40 to 50 percent following holding in dry air.

Combined studies of the structure of the cement paste as a function of the content of additive and curing conditions were performed by the RSA and DTA methods, as well as thermogravimetric and porometric methods, in order to determine the mechanism of influence of ED-20 epoxy oligomer on the properties of the polymer-cement mortars and concretes. It was found that the oligomer takes an active part in the formation of the structure of the cement paste.

A516 Popovics, S., and Tamas, F., "Investigation on Portland Cement Pastes and Mortars Modified by the Addition of Epoxy," Polymers in Concrete - International Symposium, SP-58, pp 357-366, 1978, American Concrete Institute, Detroit, Mich.

Laboratory experiments are reported with the intention to show the effects of epoxy modification of portland cement mortars in the presence or absence of accelerating and/or plastifying admixtures. One series of control and eight series of modified Ottawa-sand mortars were prepared on which the flow as well as the compressive strength were tested. The effect of epoxy addition on the hydration of portland cement was also investigated on two series of control and ten series of modified cement pastes by using a new method, the silylation.

The test results show considerable improvements in the workability of the epoxy-modified mortars, and strength increases, when an accelerating admixture was also used, up to 100 to 120 percent. It appears from the results of the silylation that these strength increases were caused mostly by physical factors.

A517 Proshin, A. P., "Use of Surface-Active Agents in Protective Polymer Materials," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet

Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 27, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Surface-active agents, or surfactants, allow the course of physical-chemical processes in multicomponent polymer materials to be controlled, particularly when highly dispersed fillers and pigments are used in the process of structure formation. Concentrating at the phase division boundary, the surfactants form thin adsorption layers and change the properties of the surface.

The Penzensk Institute of Construction Engineering is studying structure formation and destruction of polymer protective coatings based on thermosetting resins with surfactant additives. The experimental data indicate that cationic and nonionic surfactants help to decrease the contact-wetting angle of the furfural-acetone monomer, based on acid minerals, from 53-55° to 22-30°, and increase the adhesion by 18 to 35 percent. Cationic and nonionic surfactants have a significant plasticizing and delaying effect in the curing of furan-polymer solutions, while anionic surfactants act as curing accelerators.

Surfactants quite radically change the kinetics of the passage of corrosive media through protective coatings; their addition to polymer protective coatings in the optimal quantity helps to increase water resistance and life in solutions of acids, alkalies, and other corrosive media.

A518 Prusinski, R. C., "Study of Commercial Development in Precast Polymer Concrete," Polymers in Concrete - International Symposium, SP-58, pp 75-102, 1978, American Concrete Institute, Detroit, Mich.

The author traces the development and the art of an idea from its conception through a step-by-step process which evolves into end products. These have had a direct positive economic impact on the construction industry over the last two decades. He gives evidence of an ever expanding market in the immediate future where contemporary needs can be fulfilled with contemporary materials.

A519 Putliaev, I. E., "Prospects and Basic Trends in the Development of Polymer-Cement and Polymer-Silicated Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 5, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Intensive research is underway both in the USSR and abroad,

directed toward qualitative modification of concrete, and in some cases, when its use is clearly undesirable, the development of new types of concrete (polymer concrete, polymer-silicate concrete and polymer-treated concrete).

Modern polymer chemistry has developed products (modifiers) which are suitable from the mechanical, physical, and chemical standpoint for combination with the components of cement concretes, radically changing their properties. These modifying polymer materials may be either liquid or solid. The liquids (monomers, oligomers, or polymers) may be water soluble (compounds of the vinyl series, aliphatic epoxy resins, etc.) or insoluble (unsaturated polyesters, epoxy diene resins, low-molecular polyolefins, etc.).

The modification of cement concretes by polymers allows a significant increase in their strength, density, chemical stability and other physical-mechanical properties, allowing a significant increase in the quality of construction work, a decrease in the consumption of cement and an increase in the durability of industrial buildings and structures.

Of the special concretes which have been developed and introduced at the present time, we shall analyze the polymer-silicate concretes, the primary binder in which consists of the soluble silicates of alkali metals, with silicate modulus 2.8 to 3.2. The value of these concretes is largely a result of the extensive raw-material base of soluble alkali metal silicates, as well as the fact that they contain no explosive, flammable or toxic materials. Also, their chemical stability, particularly their acid resistance, is significantly greater than the acid resistance of the polymer concretes. Since the formation of the structure in these systems is achieved by the siloxane bond, with an energy of up to 80 kcal/mol, it is quite realistic to expect the achievement of high strength in composites.

The polymer materials used to modify concretes based on liquid glass can be subdivided both as to their nature and as to the mechanism by which they act on the components of acid-resistant concrete: e.g., sealing or dispersing materials (furan, phenol, and other resins), water-binders (compounds with the -NCO group, etc.), shrinkage-reducing compounds (oligoesters, etc.), compounds which delay curing (sulfanol, organosilicon liquids) and pore-filling compounds (colophony, sulfur, etc.).

Work performed in the last few years on alteration of the mechanism of curing of the liquid glass binder, based on the fact that the alkali in the system is not neutralized to form brittle products, but rather enters into a chemical reaction with a thermodynamically unstable component - tetra-hydrosilicate - is also quite important. The opal-like structure of the binder, which is the main structuring component with the traditional curing mechanism, is, in this case, merely an intermediate product in the formation of an alkali metal hydrosilicate of the general formula  $nR_2O \cdot mSiO_2 \cdot hH_2O$ , with a high silicate modulus. The curing of the acid-resistant concrete by this mechanism assures thermodynamic stability of the concrete and increases the water and alkali resistance of the product. The strength of the concrete is increased by a factor of 2 to 4. With a stoichiometric relationship between the liquid glass and the active filler, the concrete becomes

impervious to acids, water, and alkalis. All of these improvements allow the manufacture of load-bearing reinforced structures from acid-resistant concrete.

A520 Putliaev, I. E., and Shesterkina, N. F., "Concretes Based on Liquid Glass for Construction Structures, and the Technology of Their Manufacture" Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 136, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

At the present time, intensive research is being conducted to improve the structure of concrete. Various types of additives are introduced to concretes, with various mechanisms of action on the components of the acid-resistant concretes. These include particularly sealers (furan, phenol, and other resins), water binders (compounds containing the -NCO group, mineral hydraulic binders, etc.), shrinkage reducers (oligoesters, etc.), and additives to retard curing (sulfanol, organo-silicon fluids).

Among important works of the past two or three years are developments involving a change in the mechanism of curing of the acid-resistant concretes. The basis of this curing mechanism is the fact that the alkali in the system is not neutralized, but rather enters into the reaction, forming an alkali-metal oxide hydrosilicate. The opaline structure of the binder ( $\text{Si(OH)}_4$ ), considered the main structure-forming component in the traditional mechanism of curing, is in this case an intermediate product, with the formation of a hydrosilicate  $n\text{R}_2\text{O} \cdot m \cdot \text{SiO}_2 \cdot h\text{H}_2\text{O}$ . It should be noted that the properties of acid-resistant concrete change quite basically in this case: The concrete becomes structural in the full sense of the word.

One important technological problem for high-strength acid-resistant concretes is the problem of selecting a technology for compacting. This problem has not been sufficiently studied for ordinary polymer-silicate concretes, either.

Some of the technological processes of polymer-silicate concretes studied at the Scientific Research Institute for Reinforced Concrete Products are worthy of more detailed analysis.

The process of manufacturing acid-resistant concrete based on modified liquid glass includes four main technological steps: preparation of materials; preparation of the concrete mixture; molding of the products; and curing of the products. The first two processes do not differ significantly from the processes involved in the preparation of ordinary cement concrete. The basic difference here lies in the sequence of introduction of components to the mixer. The molding process, as is true for cement concrete, consists of the operations of preparation of the forms, pouring and compacting of the mixture and striking of the forms. For low-strength, acid-resistant concretes with various polymer

additives, the method of vibration compacting, using standard equipment, is applicable. The length of vibration varies between 20 and 60 sec, depending on the shape and size of the structure. When products are molded of high-strength concrete, which is a semidry mixture, rolling or vibration pressing are the most efficient methods of compacting, the selection being based on the shape of the product. The load applied may vary from 50 to 500 g/cm<sup>2</sup>.

Curing of products of acid-resistant concrete is the longest technological process. In contrast to cement concrete, the curing of concrete based on liquid glass must occur under air-dry conditions or with dry heat. The curing of products of high-strength concrete must be performed in an autoclave at a pressure of 9 to 13 atm. gauge and a temperature of 175 to 190 C. The curing of acid-resistant concretes can be intensified, we believe, by the use of fast-setting silicate glasses, the development and application of a two-stage curing method, and also by the development of methods of curing of concrete in an electromagnetic field, with heating by radiant energy, electric heating, etc.

The materials presented at the conference indicate effective areas of application of polymer-silicate concretes of ordinary and increased strength. These are primarily columns and beams for the supporting frameworks beneath baths in nonferrous-metal electrolysis shops, elements of scrubbers, vats, and foundations beneath equipment, the construction of chemical drains, large slabs for acid-resistant flooring, and solar desalinators. The areas of application of polymer-silicate concrete, particularly high-strength types, may be significantly broader than those just noted. Roofing slabs, elements of smokestacks, pile foundations, pipes for the transportation of corrosive fluids, drainage canal elements and many other products can be made of these types of concrete.

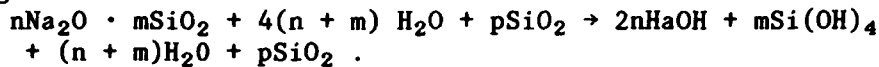
A521 Putliaev, I. E., "Means for Improvement of Mortars and Concretes Based on Polymer-Silicate Binder," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 165, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Highly filled compositions based on liquid glass characteristically have great potential capabilities for improvement of their physical-mechanical and chemical properties. The prerequisites for this include high strength and chemical stability of the silicate systems, provided by the siloxane bond. The disagreement between the potentialities and practical results achieved is explained primarily by two factors, particularly by the presence of a thermodynamically unstable component - tetrahydrosilicate - the adhesion bonding the artificial conglomerate.

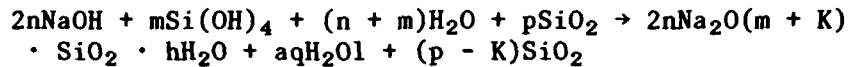
Since tetrahydrosilicate remains in the system only if the alkali is neutralized, the process of curing must be performed after excluding electrolytes from the system, including sodium fluosilicate. Studies



conducted at the Polymer-Concrete Laboratory and Central Corrosion Laboratory of the Scientific Research Institute for Reinforced Concrete Products, together with the Engineering Administration of the USSR Construction Ministry, have established that curing systems based on liquid glass can occur as follows:



In this state, at a temperature of 50 to 80 C, the silica gel precipitates and free alkali is formed, then they react with each other, forming at +150 to 200 C, alkali metal hydrosilicate with high silicate modulus:



With the optimal content of liquid glass and, consequently, of water, this curing mechanism can produce practically 100 percent systems of the form



which assures their high strength (compressive strength over 120 MPa), impermeability and high resistance to acids, water, and alkalies.

A522 Rakhmanov, V. A., Kravtsov, V. I., Sukhanov, M. A., and Tsupkov, I. A., "Dynamic Properties of Polymer-Treated Concrete with Single and Short-Cycle Repeated Loading," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennyykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 108, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A study is presented of the influence of single and short-cycle repeated loading on the strength and deformation properties of polymer-treated concrete (PTC) specimens and the concrete matrix (CM).

The specimens used were prisms 4 by 4 by 16 cm in size, made of a cement-sand concrete with the following composition: C:S = 1:3, W/C = 0.4. The specimens, dried at 105 to 120 C to a residual moisture content of 0.3 percent, were saturated with methylmethacrylate and a polymerization initiator, and thermocatalytic polymerization was performed.

The studies were conducted on type MTS 810 and MTS 819 electrohydraulic testing systems.

Under static loading ( $\dot{u} = 0.0035$  mm/s), the strength and deformation properties of the PTC are higher than those of the CM: The prism strength ( $R_{pr}$ ) is 3.3 times higher ( $R_{pr}^{CM} = 34.2$  MPa), longitudinal ( $\epsilon_1$ ) and transverse ( $\epsilon_2$ ) deformations are 2.2 and 1.8 times higher, respectively, and the modulus of elasticity is 30 percent higher.

As the deformation rate increases, the strengths of the PTC and CM increase, the PTC being more sensitive to the loading rate. Thus, the

dynamic strengthening factor ( $K_{ds} = R_{pr}/R_{pr}^{st}$ ) of the PTC was 14 percent greater than that of the CM ( $K_{ds}^{CM} = 1.1$  at a loading rate of 50 mm/s).

Under dynamic loading, the maximum longitudinal and transverse deformations of the PTC decreased by approximately 30 percent, while the values of  $\epsilon_1$  and  $\epsilon_2$  of the CM remained practically unchanged; the modulus of elasticity increased in both cases: for the PTC - by 40 percent, for the CM - by 30 percent.

The dynamic loading of the PTC is described by a practically linear  $\sigma$ - $\epsilon$  diagram.

Fatigue testing was performed, involving a study of the relatively short-cycle area of endurance of the material ( $N \leq 10^4$  cycles), in a mild loading mode at a frequency of  $\omega = 6$  Hz, cycle asymmetry factor  $\rho = 0$ , with three levels of load. For the control concrete, the cyclical stresses varied within the limit  $\sigma_a = (0.84 - 0.95)R_{pr}$ , for the PTC  $\sigma_a = (0.90 - 1)R_{pr}$ .

Short-cycle fatigue equations were produced for the PTC and CM:

$$\sigma/R \text{ (PTC)} = 1.125 - 0.056 \log N,$$

$$\sigma/R \text{ (CM)} = 1.09 - 0.073 \log N.$$

Based on the results of the studies performed, we conclude that PTC has superior dynamic properties in comparison to the CM.

A523 Rep'ev, E. N., and Sadovskii, G. P., "Minimization of the Consumption of Resin in Polymer Concrete, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 33, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The largest item in the cost structure of polymer concretes is the cost of the resin; therefore, minimization of the consumption of resin, without deterioration of the quality of the polymer concrete, is an important scientific and practical problem, the solution of which determines the area of application of polymer concretes.

The consumption of resin can be minimized by the use of aggregates of the optimal particle-size distribution, assuring the minimal pore space of the mixture of aggregates, and by introducing finely milled extenders with the optimal parameters.

In order to find the optimal particle-size distribution of aggregate with maximum grain size 20 mm, a third-factor, simplex plan was used to study the porosity of a four-component aggregate mixture.

The variables used were: content of aggregate in the 10- to 20-mm fraction ( $x_1$ ), 2.5- to 5-mm fraction ( $x_2$ ), 0.6- to 1.2-mm fraction ( $x_3$ ), 0.15 - [?0?].3-mm fraction ( $x_4$ ). The results of the experiment were used to construct a model of the cavity space of the mixture of aggregates in the vibration-compacted state as a function of the percent

content of each of the four fractions.

Based on analysis of a model of several compositions which were near optimal, a particle-size distribution was selected with a total pore volume of 20.8 percent and a specific surface of 32.2 cm<sup>2</sup>/g.

Combined studies of the primary physical-mechanical properties were conducted, including creep and the corrosion resistance of concretes of the optimal composition.

A524 Ronin, V. P., "Optimization of the Process of Polymerization in the Technology of Polymer-Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 83, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Process is polymerization of the mixture of monomer and polymerization initiator, dispersed in the pore spaces of the silicate matrix of the cement concrete. A number of factors are of determining significance in this case, including: the sealing medium, the method of polymerization, composition of the saturating mixture, and parameters of polymerization processing.

Full factor experiments were utilized to generate mathematical models of thermocatalytic and radiation-chemical methods of polymerization of the binary system technical styrene plus lauroyl peroxide in the cement paste mass. The optimization parameters selected were  $R_c$ , the compressive strength of the polymer-treated concrete, as well as the degree of conversion of the monomer -  $\alpha$ . The experiments were conducted on cylindrical specimens 20 mm in diameter and in height, made of a cement paste (grade 400 cement of the Volgovyskii Cement-Slag Combine). Thermocatalytic polymerization was performed at an experimental installation of the Minsk Scientific Research Institute for Construction Materials, radiation-chemical polymerization on a universal gamma installation (the UGU-200) owned by the Institute of Nuclear Power Engineering, Academy of Sciences, BSSR, at a radiation intensity of 400 r/s. The mathematical models produced allow quite effective regulation of the parameters of the technological process of production of polymer-treated concretes and their optimization. The results can be directly applied in automation.

A525 Rosebashvili, K. I., "Study of Polymer-Treated Concrete Under Repeated Loadings," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 112, Jan 1979; Translated from the Russian by Engineering Services

Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The polymer-treated concrete specimens which we studied were made as follows: Prisms 4 by 4 by 16 cm, made with basalt gravel 5 to 10 mm in diameter, were dried, vacuum treated, saturated with methylmethacrylate and radiation polymerized.

The static prism strength of the polymer-treated concrete was  $R_{ps} = 118.7$  MPa. Endurance testing under the influence of compressive loading was performed with a cycle asymmetry factor of  $\rho = 0.3333$

The maximum stress in the cycle of testing of the specimens was varied between 0.71 and 0.89.

The endurance limit produced is somewhat higher than the relative endurance limit of ordinary cement concrete. This increase in endurance limit is apparently explained by the increase in density and homogeneity of the material, as well as the minimization of the adsorption effect, which decreases the strength and deformation capacity.

A526 Ryb'ev, I. A., Sokolov, G. V., Shelukhina, I. V., and Shpungin, E. I., "Some Properties of Cement-Polymer Concretes with Optimal Structure," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 142, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Gor'kii branch of "Giprodnornii" has been studying optimal-structure cement-polymer concretes based on organosilicon fluids with the purpose of maximum utilization of these products in road construction. Gravel and sand from the Kama estuary deposits, M500 portland cement from the Alekseevskii Cement Plant and GKZh-10 organosilicon fluid were used. The variation in strength characteristics of the cement paste as a function of GKZh content was determined. It was found most effective to add GKZh at 0.15 percent of the mass of the cement; the optimal water-cement ratio (W/C) is 0.25/1 ( $R^* = 92.6$  MPa).

The following equation describes the variation of compressive strength of the optimal-structure cement-polymer concrete (R) as a function of the activity of the binder:

$$R = \frac{R^*}{[(W/C)/(W/C)^*]^n}$$

where  $R^*$  is the strength of the cement paste with the optimal water-cement ratio and the optimal quantity of GKZh-10 additive, MPa; (W/C) and  $(W/C)^*$  are the water-cement ratios of the cement-polymer concrete of the optimal composition and the cement paste with GKZh added; n is an exponent, reflecting the quality of the aggregate, and is equal to 1.48.

Cement-polymer concretes based on GKZh-10 organosilicon fluid, like ordinary concretes, follow the general rule of the strength of optimal-structure conglomerates, expressed by the equation

$$R(W/C)^n = \text{const.}$$

where  $R$  is the strength of optimal-structure cement-polymer concrete with GKZh-10, MPa.

The impermeability to water, resistance to freezing, and strength of such concretes follow from the general theory of structural materials based on binders. The deformation properties of ordinary and cement-polymer concretes were studied. It was found that in a concrete of nonoptimal structure without additives, intensive microcrack formation begins with a load of 0.35 to 0.4  $R$  (where  $R$  is the failure load), as opposed to 0.5 to 0.55  $R$  in optimized concrete structures. The addition of GKZh-10 raises this limit still further - to 0.6 to 0.7  $R$ .

The experiments showed that:

the introduction of an organosilicon fluid has a positive influence on the basic properties of concretes, the effect of the additives being particularly great in concretes of the optimal structure;

destructive processes in cement-polymer concretes of optimal structure, based on organosilicon fluids, develop at later stages of loading;

cement-polymer concretes based on organosilicon fluids follow the rule of strength and the range rule of the general theory of structural materials based on binders, and optimal compositions can be planned by the methodology of this theory;

the use of ultrasonic methods to study the deformation properties of concretes is quite effective.

A527 Sarnitskaia, S. Z., and Takhirov, M. K., "The Life of ATsF Polymer Concrete in Corrosive Media," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 18, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Tashkent's GipronIIPoligraf and TashIIT Institutes have developed compositions and manufacturing technologies for an acetone-formaldehyde polymer concrete, type ATsF, based on acetone-formaldehyde resins, true aqueous solutions of low- and high-molecular-weight products of the polycondensation of acetone and formaldehyde. Depending on the required viscosity, the water content of the resin is 10 to 25 percent.

ATsF polymer concretes exposed to machine oil, water and 10 percent solutions of NaOH and  $H_2SO_4$  showed that the water resistance of polymer concrete is decreased by 16 to 32 percent and is essentially determined by the type of curing accelerator (GKZh-10 or NaOH) and the filler. Specimens filled with electrothermal-phosphorus slag and lead-zinc tailings were most resistant to water, alkalies, and oil. Their

resistance factors were  $K_{ct} = 0.8-0.84$ ,  $0.86-0.9$ , and  $0.93-0.98$ , respectively.

The acid resistance of specimens of ATsF polymer concrete can be significantly increased by modifying the binder by the use of polymers and oligomers which help to stabilize the double and single ester bonds. Epoxy diene polymers are effective modifiers for ATsF resin. It was established that as the content of epoxy resin increased from 10 to 50 percent, the strength indicators ( $R_{com}$ ,  $R_{bnd}$ ) of the polymer concrete increased from 66 and 16.8 MPa to 84.9 and 25.6 MPa, depending on the type of finely dispersed filler, while the stability coefficients after 360 days exposure to a 10 percent  $H_2SO_4$  solution were  $K_{ct} = 0.25-0.4$ .

However, an increase in the quantity of the epoxy component leads to a significant increase in the cost of the binder.

The acid resistance of polymer concrete can be increased while decreasing its cost by modifying the binder with water-soluble oligomers. A study of the structure of modified-polymer concrete of this type showed that the introduction of the oligomer allows a decrease in the number of hydroxyl groups and assures stability of the single ester bond in the system. The stability coefficient increases to 0.4-0.65.

The studies showed that the compositions which have been developed can be used under conditions of exposure to water, machine oil, and 10 percent acid and alkali solutions.

A528 Scanlon, J. M., "US-USSR Scientific Exchange Program In The Field of Polymer Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 527-533.

Included in the International Congress official program are three papers presented by three members of the USSR Polymer Concrete Scientific Exchange Team, and we the members of the US Polymer Concrete Scientific Exchange Team would like to believe that we have contributed to international relationships by getting them to participate.

In the effort to improve US-USSR relationships, many exchanges and cooperative agreements have been consummated by the United States and the Soviets. Cultural, educational, scientific, and technical exchanges have long constituted an important element in our relationships with the USSR. Since 1958, the two have signed a continuing series of bilateral agreements to promote such activities and to provide the framework for their implementation by both private and governmental organizations. The 1975 Helsinki Final Act also supports increased contact and exchanges.

The current US-USSR "umbrella" agreement on cultural relations was signed in Washington, D. C., June 19, 1973. To put exchange activities on a firmer basis, the agreement was made valid for 6 years instead of for the 2-year periods characteristic of earlier agreements. Annexed to the agreement is a "Program of Exchange," which provides more detailed guidelines for implementing educational exchanges, performing arts groups, official publications (Soviet Life and America), and circulating exhibits.

In addition to its longer-term feature, the 1973 agreement foresaw

continuing expansion by establishing minimum-floor levels for several exchange categories, rather than setting maximum targets as in the past. Also, in the educational field, exchanges of university lecturers were added to existing programs for graduate students, senior scholars, and professional symposia participants. Activities in 1977 included the reciprocal exchange of nearly 50 graduate students, monthly distribution in the other country of 62,000 copies of "America" and "Soviet Life," respectively, and tours of six Soviet cities by the "Photography USA" exhibit. Under a separate agreement, the United States mounted a Bicentennial exhibit in Moscow in late 1976, and the USSR stages a similar event in Los Angeles in November 1977 commemorating the 60th Anniversary of the 1917 Soviet Revolution. Parallel to governmental programs, privately organized exchanges have been steadily growing in many fields - noteworthy development in 1976-77 was signature of the first two direct exchange agreements between Soviet and US universities.

A529 Schorn, H., "Time-Dependent Properties of Concrete Members Bonded by Polymer Mortar," SP 58-2, pp 21-29, 1978, American Concrete Institute, Detroit, Mich.

This paper presents results of experiments and a theoretical concept of composite systems consisting of portland cement concrete bonded by polymer mortars. Criteria for time-dependent shear failure are given. The criteria are based on the different deformation behaviour of portland cement mortar and polymer mortar.

A530 Sedov, L. N., Zil'berman, E. G., Mironov, V. V., and Mudzhiri, B. G., "Study of the Possibility of Curing Materials Capable of Polymerization in the Pores of Concrete at Room Temperature," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 91, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Methods are known for polymerization at room temperature by the use of a combination of a polymerizing liquid, an initiator and an accelerator. However, the use of this type of ternary system as a saturating material is undesirable, due to the extremely low viability of such mixtures. Some researchers suggest that the initiator be introduced to the concrete mixture before curing, the accelerator - in the polymerization fluid. They suggest benzoyl peroxide (BP) as an initiator which has no negative influence on the process of hydration. In our opinion, the use of BP, with its danger of explosion, in a concrete mixture is undesirable, since friction must be avoided, and it is virtually impossible to do this as the concrete mixture is mixed. Furthermore, it is practically impossible to distribute the initiator uniformly throughout the mass of the concrete mixture, since the

initiator is introduced in small quantities and is insoluble in water. Consequently, the probability of uniform interaction of the accelerator with the initiator and subsequent uniform polymerization of the composition throughout the entire mass is very low.

This paper suggests the use of water-soluble accelerators, to be introduced directly into the concrete mixture during the process of mixing. In order to assure better distribution of the accelerator throughout the entire mass, it can be introduced with the water.

Subsequently, after the corresponding molding, heat treatment and drying, the concrete can be saturated with the initiated polymerizing liquid, without requiring heating.

A531 *Serykh, R. L., "Short-Term Strength of Polymer-Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 106, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The results of experiments performed at the Scientific Research Institute for Reinforced Concrete Products and other institutes, studying the cube and prism strength of polymer-treated concretes (PTC), after statistical processing, yield stable correlation connections between the strength-increase factor and the strength of the concrete matrix (CM):  
for cube strength

$$K = \frac{\bar{R}_{PTC}}{R_c} = 0.93 + \frac{78.37}{\bar{R}_c} \quad (1)$$

for prism strength

$$K = \frac{\bar{R}_{PTC.PR}}{\bar{R}_{PR.C}} = 0.24 + \frac{101.85}{\bar{R}_{PR.C}} \quad (1)$$

In equations (1) and (2),  $\bar{R}_c$  and  $\bar{R}_{PR.C}$  are expressed in MPa.

During processing of the experimental data, it was established that the ratio of the standard prism strength  $R_{PR.PTC}^S$  to the cube strength  $R_{PTC}^S$  of the polymer-treated concrete is significantly higher than the same ratio for the concrete matrix, and reaches values as high as 0.85. The coefficient of variation of the cube strength of the polymer-treated concrete is measured from the experimental data and is equal to 0.16.



A532 Sheikin, A. E., and Solomatova, T. V., "A Particularly Light Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 28, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The density of polymer concretes is decreased by the use of keramzit [porous-clay filler - Tr.], agloporite, shungizite, and other light fillers, as well as the introduction of pores to the polymer matrix.

Recently, fillers such as ceramic porous granules with a compact crust, and expanded polystyrene beads strengthened with a polymer shell have been suggested. However, there is particular interest in the use of hollow, thinwall elements of glass, plastic, metals, slag, and other materials of various configurations (spheres, tetrahedrons, cylindroids), measuring from 0.005 to 0.025 m, as light aggregates, and microscopic spheres of glass and polymer materials, 10 to 50  $\mu\text{m}$  in diameter, as dispersed aggregates.

Concretes constructed using these aggregates characteristically have low density (700 to 1000  $\text{kg/m}^3$ ), while retaining high strength and structural integrity. The closed air cavities, evenly distributed through the volume of the concrete, give the material low heat conductivity and good sound-insulating properties.

A533 Shesterkina, N. F., "Some Problems of the Technology of High-Strength, High-Density Polymer-Silicate Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 144, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Materials which are based on dissolved liquid glass are promising structural materials, combining such valuable properties as resistance to acids, nonflammability, nontoxicity, and low cost. However, the extensive use of these materials in construction is being delayed, largely due to the unavailability of information on suitable technologies for manufacture, pouring, and heat treatment of products.

The polymer-concrete laboratory of the Scientific Research Institute for Reinforced-Concrete Products has produced basically new structural materials based on liquid glass, milled blast-furnace slag, finely milled alunite and perlite. The compressive strength of the materials ranges from 70 to 120 MPa. The materials are characteristically

resistant to acids, water, and both acid and neutral salts. The coefficient of stability in these media falls in the range of 0.80 to 0.99.

Studies have shown that the properties of a material depend on the modes of mixing, compacting, and curing of the material. For example, for slag-silicate concrete, vibration compacting and curing of specimens with mild, dry heating to +60 to 80 C, steam curing at +80 C and air-dry curing at room temperature are all used. Alunite- and perlite-silicate concretes are semidry mixtures, which should be compacted in forms by the application of a vibrating load or by heavy rolling. Molded products should be cured by dry heating to +160 to 180 C or autoclaved at +170 to 175 C, pressure 8 atm. gauge. Prepared mixtures of perlite-silicate concrete can be stored, if protected from contact with air, for up to 7 days before molding.

A534 Shipilevskii, B. A., "Polymer-Treated Concretes Formed on a Framework Which Changes Its Physical Chemical Properties, with a Sulfur-Containing Additive," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 92, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The essence of the production of the polymer-treated concretes is that, in accordance with the design strength and the purpose of the product or structure, a reinforcing framework, made of a monomer-oligomer composite, is manufactured in advance; this framework, like an ordinary steel framework, is placed in the mold and attached in place. Then the concrete mixture is poured into the mold, compacted by vibration, impact, or some other method. After a short period of time, following partial setting of the cement, the concrete mixture and framework are heated, accelerating the formation of the cement paste. When a certain temperature is reached, the framework melts. When this happens, the composition fills the cracks, pores, and cavities in the contact zone and forms adhesion bonds between the concrete and the polymer. With a further increase in temperature, the composition is converted to the polymer thermosetting state. Alteration of the formula of the composition is used to regulate its shrinkage and hardness, and consequently, the stress state of the material.

The epoxy compositions which have been developed have allowed the creation of effective polymer-treated concretes without changing the technological modes used in the plant to manufacture concrete and reinforced-concrete products, employing commercially available epoxy oligomers of types ED-20, ED-16, and technical piperidine.

After studying the reaction of formation of the epoxy-piperidine polymers, we have determined that it occurs in three stages. First the oligomer, bonding with the piperidine, forms an adduct which is solid at

room temperature and melts at +55 C. It is processed by free pouring of the melt into products of any configuration. The products are joined by thermal welding, like ordinary thermoplastics. After melting at over +70 C, active polymerization centers develop in the material and the adduct passes through a stage of gel formation to become a cross-linked trimer. We have shown that if certain sulfur-containing substances are added to the composition, thermal decomposition of which, with liberation of active atomic sulfur, occurs at 60 to 80 C, not only does additional chemical cross-linking of the epoxy composition occur, but also formation of chemical bonds between the concrete and epoxy polymer, on the basis of the sulfur bridges between the silicon and polymer, forming an organo-silicon polymer. Sulfur-containing substances, which are chemical modifiers of epoxy polymers, particularly the products of synthesis of piperidine and sulfur, such as piperidine trisulfide, have been found to be highly active. The consumption of the additive is only 0.03 to 0.15 percent of the mass of the monomer-oligomer composition. The additives used are easily soluble in piperidine, and it has been suggested that solutions, e.g., 1 to 5 percent piperidine trisulfide in piperidine, be used as curing agents. The introduction of the sulfur-containing additive to the composition results in an increase in the strength of the bond between the concrete and the polymer by 30 to 80 percent. The monomer-oligomer composition developed has also been used to obtain polymer coatings on concrete by a combined technology of formation of the concrete and the coating. The molds we have produced for the manufacture of precast reinforced-concrete products have been found to be 2 to 4 times more durable than molds previously used.

A535 *Shvidko, Ia. I., "Structural Polymer Concretes with Dispersed Reinforcement," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 49, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The durability of load-bearing structures in industrial buildings can be increased by the use of polymer concretes containing dispersed reinforcement. Studies have shown that the optimal quantity of fiber which can be effectively added to the composition of polymer concrete without disrupting the homogeneity of the mixture decreases linearly with an increase in the content of coarse aggregate.

A method has been developed for activation of the surface of reinforcing fibers in an ultrasonic field with an intensity higher than the cavitation threshold, with simultaneous static pressure. It has been established that this activation of fibers allows the strength and modulus of elasticity of reinforced polymer concrete to be increased by factors of 1.6 and 1.4, respectively (with 3 percent fiber content by mass), while simultaneously improving workability. The area of optimal

content of fibers in the polymer-concrete matrix is shifted to 4 to 4.5 percent, when this is done, without complicating the technological process, leading to an increase in strength by a factor of 2, in modulus of elasticity by a factor of 1.5.

The possibility has been experimentally demonstrated of producing reinforced polymer-concrete structures under compression in a press with a minimal content of FAM monomer (4.6 to 6 percent). The compressive strength produced in one such experiment was 60 to 80 MPa, the initial modulus of elasticity 32,000 to 40,000 MPa.

The mechanism of failure of reinforced polymer concretes has been studied, and the effect of dispersed reinforcement determined. A problem from the theory of elasticity, determination of the deformed state of a plane body with discrete inclusions of finite length, is studied. By representing the stress function in the form of a Fourier integral, this problem is reduced to solution of a Fredholm integral equation of the second kind.

Suggestions are developed for planning of special structures of reinforced polymer concrete, capable of operating for long periods of time exposed to corrosive media (box-section beams, flooring and roofing slabs, drainage systems, etc.).

A536 Sokolova, Iu. A., Sekerina, N. V., and Voskresenskii, V. A., "Polymer Concretes Based on Effective Colored Binders," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 13, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

During recent studies, the possibility of using organic pigments, including various types of nitrogen-containing vat, phthalocyanine, quinacridone and dioxazine pigments, for the production of colored polymer solutions and polymer concretes based on epoxy oligomers type ED-20 and ED-16, has been investigated.

Thermomechanical, thermogravimetric, dynamic, mechanical and other methods have been used to study the influence of organic pigments on the properties of epoxy binders. It has been found that small quantities of additive, in addition to the color effect, improve the properties of the polymer concretes: Strength, adhesion, water resistance, and resistance to thermal-oxidative destruction all increase.

A study has been made of the processes of aging of colored polymer materials and polymer solutions under atmospheric conditions (2 years), in an artificial weather chamber (900 hr) and by other accelerated methods: the stability of the materials when exposed to various corrosive fluids at normal and elevated temperatures has also been studied. It has been shown that these materials are color stable, and resistant to atmospheric and chemical effects under these conditions.

The optimal compositions of colored, epoxy-polymer coatings and

polymer solutions which have been developed have been tested under production conditions for decorative finishing of the exteriors of buildings and protective-decorative finishing of foundations beneath equipment at chemical enterprises. Their economic effectiveness has been calculated.

A538 Solodovnik, A. B., and Iokhanson, R. F., "Theoretical Aspects of the Forming of Polymer-Concrete Products," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 35, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The process of forming of polymer-concrete products is determined, on the one hand, by the rheologic properties of the mixtures used and, on the other hand, by the parameters of the forming mode. Frequently, for example, in forming of polymer-concrete pipe, it is necessary to use vibration (harmonic, pulsed, impact, etc.), for which the decisive parameters are the amplitude-frequency characteristics and the forming time. The presence of a relationship between rheologic properties of the mixture and the vibration fields, which develop within it, must be considered.

The paper presents calculations and theory to support the process. The method developed allows the types and sizes of products which can be formed using the vibration mode on existing equipment to be determined, and also allows the optimal forming modes to be defined.

A539 Solomakhin, V. D., Kudinova, V. D., and Shonorov, V. I., "Increasing the Durability of Arch-Type Scrubber Covers in the Production of Chemical Fibers," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 150, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

At most artificial-fiber enterprises, special devices called scrubbers are used for preparation and regeneration of process solutions.

According to a plan developed by "Proektkhimzashchita" Institute, scrubbers are protected from corrosion by pieces of acid-resistant materials. The covering arches of the scrubbers are most severely damaged in operation. According to the reports of artificial-fiber plants, the service life of scrubber covers is 1 to 2 years.

The Minsk branch of "Tekhnergokhimprom" Production Union has

suggested a more effective material for the construction of the arch diaphragm which covers a scrubber - polymer-silicate concrete.

The experience which has been gained in the construction and operation of covers of polymer-silicate concrete has indicated that they have both engineering and economic advantages over previous types (lower labor consumption, material consumption and cost, higher operating reliability).

The Minsk branch of the Production Union has developed a design for a dome-shaped scrubber cover. The new design reduces the consumption of polymer-silicate concrete from 35 to 18 m<sup>3</sup>, and decreases the cost of the cover. In February of 1966, this new design was put into use at the V. V. Kuibyshev artificial-fiber plant in Mobilev. The resultant savings were 35,000 rubles.

Now, the Minsk branch of "Tekhnergokhimprom" Production Union has developed a more economical beam design for the top cover, of reinforced polymer-silicate concrete. The new design has the following advantages over the old design: The concrete consumption has been reduced to 11 m<sup>3</sup>, construction of forms and concreting are simplified, and labor consumption is lower. The total savings achieved is 62,000 rubles.

A540 Solomatov, V. I., "Structure Formation, Technology and Properties of Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 7, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

As a result of many years of research performed by the Moscow Institute of Railroad Transport Engineering, the principles of structure formation in polymer concretes have been improved and the principles of the construction of organomineral conglomerates with properties determined in advance have been formulated. Furthermore, the nature, dispersion and quantity of aggregate have been optimized, recommendations have been given for the selection of rock and optimal polymer-aggregate combinations have been determined; in terms of their strengthening effect, silicates can be placed in the following decreasing order: amphibole, pyroxine, olivine, biotite, plagioclase, potassium and sodium feldspars; compositions have been developed which are filled with oxides and other materials (quartz, pyrite, fluorite, corundum, graphite, apatite, dolomite); it has been established that the optimal specific surface area of a filler is 0.15 to 0.3 m<sup>2</sup>/g, while the quantity should be limited to 30 to 33 percent of the mass per unit volume (about 55 percent).

It has been shown that the composition of fillers should be planned with a discontinuous particle-size distribution, and dense mixtures of fillers have been designed as a function of the size and number of fractions. The effectiveness of practical mixtures with a ratio of mean

dimensions of adjacent fractions of about 10:1 and a total number of fractions of 3 to 4 has been experimentally confirmed.

Based on the theory of structure formation, an approach has been developed for dispersed reinforcement of polymer concretes. Polydispersed reinforcement (consisting of two or more fractions) has been suggested, meaning that the polymer binder is reinforced by lengths of fiber (microscopic reinforcement) with dimensions comparable to the dimensions of the aggregate particles, and at the same time the macrostructure of the polymer concrete is increased by the introduction of longer elements (fibers, threads, sections of wire, plastic elements) of various shapes, the dimensions of which are comparable to the dimensions of aggregate grains. Composites of polymer plus dispersed reinforcement have been optimized and methods of polydispersed reinforcement developed.

This polydispersion requires the selection of the type and quantity of microscopic reinforcement on the basis of its specific surface, i.e., the rules for planning of polymer binders. Determination of the quantity of macroscopic reinforcement is based on analysis of the dimensions of elements ( $l/d$ ) and its strengthening effect. Requirements have been established for the orientation of polydispersed reinforcement in polymer concrete and its bonding with the polymers.

The positive aspects of the theory of structure formation have been revealed most completely in the development of a technology for polymer concrete production and a manufacturing-plant methodology for the production of reinforced polymer concrete products. One basic specific feature of the technology created is the separate preparation of the polymer binder and polymer concrete mixture: The polymer binder is prepared in a high-speed mixer by combining the resin, curing agents and fillers, after which it is mixed with the gravel-sand mixture in a special agitating mixer. The total time of the polymer concrete preparation cycle is 3 to 4 min. This separate technology assures equal strength of products, uniformity of distribution of catalyst and filler throughout the volume of the products, a significant reduction in the duration of manufacture of mixtures, the possibility of individual modification of the surface of fillers and extenders, the possibility of conducting the processes of preparing the binder and the mixture at different temperatures (with heating or cooling).

One good method of improving the physical, mechanical, and usage properties of polymer concrete is physical-chemical activation of the surface of the aggregate grains. This has been done most successfully using surfactants, fluorine-containing and carbon-containing compounds (by the State Scientific Research and Planning Institute for the Aviation Industry, Saratov Polytechnical Institute, and the Moscow Institute for Railroad Transportation Engineering). Optimization of the chemical and mineralogical composition of fillers and preparation of binary fillers, which have a favorable effect on structure formation and the properties of polymer concretes, have been quite effective.

A541 Solomatov, V. I., "Design of Reinforced Polymer-Concrete Structures by the Method of Limiting States," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978,

(Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 54, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The effectiveness of the use of reinforced polymer concrete results to a great extent from its high strength and chemical stability. Therefore, well-founded assignment of the state standard and design strengths of polymer concrete, considering the specific usage conditions, is of great importance.

This paper deals with the general design strength formula for polymer concretes and in particular with one of the formula coefficients, the chemical resistance factor. Derivatives are given for these formulae which are responsible for determining the chemical stability factor.

A542 Solov'ev, G. K., and Mdivani, O. D., "Polymer Concrete Based on Complex Binders," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 19, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The development of new, inexpensive, plentiful types of binders for the production of chemically-stable, polymer concrete is a pressing problem.

At the present time, the USSR has developed a broad range of compositions of light and heavy chemically stable polymer concretes based on various synthetic resins.

Polymer concretes based on furfural-acetone resins have been most thoroughly studied and are most widely used. Their high mechanical strength, in combination with chemical stability, allows various construction structures to be made of them. Polymer concretes based on carbamide and polyester resins have also been widely used.

The optimal relationship between MAK and PN-1 has been selected. The optimality criteria used were the compressive strength, water resistance, and completeness of curing.

The compound developed (MAK + PN-1) is cured with giperiz in the presence of an accelerator (cobalt naphthenate) at a temperature of at least +60 C.

Using this compound as a binder, we have produced heavy polymer concretes with the following mechanical characteristics:  $\gamma = 2400 \text{ kg/m}^3$ ,  $R_{\text{com}} = 90 \text{ to } 100 \text{ MPa}$ ,  $E = 25,000 \text{ to } 32,000 \text{ MPa}$ , with a resin-compound content of 8 percent by mass. Compositions have also been developed for



lightweight polymer concretes based on keramzit [porous clay filler] for the manufacture of precast slab flooring for barns, with the following mechanical characteristics:  $\gamma = 1200-1300 \text{ kg/m}^3$ ,  $R_{\text{com}} = 20-27 \text{ MPa}$ ,  $K = 0.45 \text{ W/m}\cdot\text{C}$ .

In conclusion, we should note that the cost of 1 kg of the compound is 35 to 40 kopeks, 30 to 35 percent less than the cost of FA monomer, and only twice as costly as the least expensive carbamide resin, UKS. The annual quantity of MAK wastes, according to preliminary calculations, amounts to several thousands of tons.

Thus, two problems are solved at once: On the one hand, a new, promising binder has been produced for polymer concrete and, on the other hand, wastes generated in the production of polymethylmethacrylate are used as one method of improving environmental quality.

A543 *Stambulko, V. I., and Stambulko, A. V., "Application of Induction Heating to the Manufacture of Polymer-Treated Concrete Products," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 129, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Many studies have shown that even slight residual moisture content in concrete before its impregnation has a great influence on the final strength of the polymer-treated concrete.

It would seem desirable to replace steaming in the manufacture of reinforced-concrete products intended for subsequent impregnation with induction heating. Studies performed at the Institute of Heat and Mass Transfer, Academy of Sciences, BSSR, and other organizations have shown that when reinforced concrete products are processed in an electromagnetic field generated by current at the standard line frequency, the required temperature and humidity mode can be created, not only providing for rapid curing of the concrete, but also drying the product to a predetermined final moisture content.

A number of experiments were performed with various concrete compositions in order to check the expediency of the use of induction heating.

A544 *Starkov, A. A., Mikhailov, G. K., Levushkin, V. A., and Okunev, V. P., "Automatic Testing of the Production of Polymer-Treated Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 100, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The development of equipment for automatic testing was based on the dielectric method, based on the interrelationship between dielectric characteristics and physical-mechanical properties of a material. The basic informative parameter is the dielectric permeability. An electrical-substitution circuit for the sensor plus material consists of a parallel-connected electric capacitance and resistance. As free moisture is removed from the initial concrete by drying, the resistance increases.

We have established that the electric capacitance of the concrete, after it is dried to constant mass, is independent of the frequency of the applied voltage, i.e., there is no anomalous frequency dispersion of dielectric permeability. On this basis, a system has developed for automatic testing of the drying process, which underwent production testing at reinforced-concrete products plant No. 7 of Glavmospromstroimaterialov in Moscow. The error in determination of complete elimination of free moisture is not over 0.05 percent.

When the monomer is introduced, a composite material is produced, the dielectric properties of which depend on the dielectric properties of the concrete and monomer, and the quantity and nature of distribution of the monomer in the body of the concrete.

A545 Sudakov, G. N., Dzhabarov, V. M., Maksimov, Iu. V., and Khor'kova, M. A., "Bond Strength of Reinforcement with Polymer-Treated Concrete, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 109, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

In 1976, the Scientific Research Institute for Reinforced Concrete Products of the USSR State Construction Commission undertook an experimental study with the purpose of making a comparative evaluation of the effectiveness of bonding of reinforcement with ordinary untreated and polymer-saturated concrete. The work was performed on specimens consisting of prisms measuring 14 by 14 by 7 cm, with centrally located deformed reinforcing bars 14 mm in diameter, class At-VI. The high elastic limit of this steel allowed significant forces to be created in the reinforcement with practically no plastic deformation.

The tests were performed by pulling the reinforcing rods from the concrete and polymer-treated concrete prisms. During the testing, the basic criterion used for bond strength was the load corresponding to the beginning of movement of the reinforcement in the concrete.

The significant increase in deformation, characterizing the moment when the reinforcement began to move in the concrete for specimens with polymer saturation, occurred at a load level of about 90 percent of the failure load, whereas in the ordinary concrete, the load at the beginning of movement was about 60 to 70 percent of the maximum load.

As the results of the experiment showed, the increase in cube

strength of concrete in compression produced by saturation of the concrete with a monomer, increases the bond strength by an average factor of 3.4. This effect is apparently related to an increase in the relative stress at the beginning of shear for the saturated specimens, as well as the relatively more rapid increase in tensile and shear strength of the concrete, resulting from its saturation with the monomer.

A546 Suleimanova, ZH. M., Ferdzhulian, A. G., and Cherikover, YE. M., "A Quick-Setting Adhesive Based on an Isoester Binder for Commercial and Residential Construction," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 25, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The polymer-concrete laboratory of the Scientific Research Institute for Reinforced Concrete Products has developed several adhesive compositions based on an isoester (IE) binder, containing a mineral filler. These adhesives characteristically gain strength rapidly and have high adhesion to concrete. The properties of these adhesives were studied on specimens using the standard methods, while the operation of the adhesive joint was checked using fragments of the same design as the joints.

The studies showed that IE-based adhesive gains the required strength at 18 to 20 C in 30 to 50 min; after 3 hr of curing, its compressive strength is 60 MPa. After one day, the strength of the adhesive is over 100 MPa. Its adhesion to concrete exceeds its strength, its adhesion to steel is about 30 MPa. Adhesives based on IE binder do not shrink (when necessary, expanding and self-sealing compositions can be produced, very important for reliable filling of channels and apertures). To make work with the adhesive more convenient, its individual components are premixed in part, so that the system as produced has few components. According to preliminary calculations, the cost of the adhesives will be 1/3 to 1/4 as great as the cost of epoxy adhesives. At the present time, further studies are continuing into the properties of these adhesives and the possibility of their use at below-freezing temperatures.

A547 Surov, A. N., Kreindlin, Iu. G., and Grigor'ev, E. V., "A Saturating Compound for Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 94, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Laboratory of Floor Materials of the Central Scientific Research Institute for Industrial Buildings has suggested a new saturating composition - a solution of polyisocyanate "K" in acetone - the still residue of fractional distillation of diphenylmethane diisocyanate. It cures in the body of the concrete under the influence of the moisture contained in the concrete; therefore, no treatment of the concrete or introduction of curing agents is required: After one day, the coating loses its tackiness, and after five days it is fully cured.

Wet concrete can also be saturated, i.e., the processes of manufacture of concrete products and application of the coating can be combined. The coating can be applied by the third to fifth day after pouring of the concrete, and improves the moisture conditions of curing of the concrete.

When polyisocyanate "K" is used, the water impermeability of the coating is increased by 50 to 80 percent, the wear resistance - by 40 to 60 percent in comparison to the most effective polyurethane varnishes.

This saturating compound is recommended for coating of floors, to reduce dust formation during wear, and also for finishing operations.

A548 Sviridov, V. G., Rusakova, T. V., Fetisova, I. B., and Nudel'man, Ia., I., "Organization of Quality Testing of Polymer Mortar Under the Conditions of a Construction Site," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primneneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 71, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Scientific Research Institute for Reinforced Concrete Products, in cooperation with GipronIIsel'khov, has developed nonwelded hinged-column joints made of epoxy polymer mortar, which have been used in the planning of the frame of a building to be part of a biologic-products combine (in Shchelkovo, Moscow Oblast, special installation administration of "Stal'montazh" Trust). The effectiveness of the use of polymer mortars for joints in precast reinforced-concrete elements results from their high strength, good adhesion to concrete and metal, as well as the significant decreases in both installation labor and metal consumed.

For the first time in construction practice, a laboratory unit has been set up at the construction site for preparation and quality testing of polymer mortars. The basic equipment used is as recommended by the Scientific Research Institute for Reinforced Concrete Products and the estimates office of the Institute, composed with the cooperation of "Stal'montazh" Trust.

Organization of the laboratory unit allows polymer mortar to be prepared from dry materials, regardless of weather, with quality testing of the polymer mortar at the construction site. The quality of the polymer mortar is evaluated on the basis of the results of testing of specimens 1 and 7 days of age. Specimens tested at 1 day of age were

stored under the open sky. The results of these tests were used to estimate the increase in strength of polymer mortars at the joints and to make the decision to remove the guides after installation of ties in accordance with the plan of organization of the operations.

Specimens tested at 7 days of age were stored under normal temperature and humidity conditions. The results of the testing served as a basis for checking the correctness of dosing of the ingredients, uniformity of mixing, etc. The results were processed by methods of mathematical statistics.

A549 Sypchenko, G. N., "Heat-Insulating Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 23, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Polymer-Concrete Laboratory of the Scientific Research Institute for Reinforced-Concrete Products has been working on the selection of compositions and determination of technologies, for manufacture and study of very light polymer concrete with a density of 400 to 500 kg/m<sup>3</sup>, based on water-soluble UKS carbamide resin. Carbamide resins are not expensive, have comparatively low toxicity, an extensive raw-materials base, and can be cured either cold or hot. However, one shortcoming of carbamide resins is that they contain up to 30 to 45 percent free water, resulting in deterioration of the physical and mechanical properties of the polymer concretes.

One possibility for bonding free water in the process of producing polymer concrete is to introduce polyisocyanates to the composition. Due to the presence of the reactive isocyanate groups (23 to 25 percent), polyisocyanates interact quite energetically with water. The reaction is accompanied by the liberation of carbon-dioxide gas, causing foaming of the composition. The processes of foaming and curing can be regulated and coordinated by varying the quantity of curing agent and the temperature.

Expanded perlite sand (75 kg/m<sup>3</sup>) is used as the filler.

The polymer concrete produced has a mixed porous-cellular structure. Its porosity averages 46 percent.

Full-load testing of specimens which had spent one year in corrosive media showed that the strength of the material in water and in a copper sulfate solution remains rather high (the strength factors were 0.82 and 0.76, respectively).

Weather resistance testing showed that the polymer concrete retains its strength properties with time.

Studies of the deformation characteristics of the material and of its behavior upon long exposure to compressive and tensile loads were also conducted.

Thus, the polymer concrete produced has good physical and mechanical properties for materials with its density and chemical stability, and can be recommended as a chemically stable, heat-insulating material for enterprises working with corrosive media.

A550 *Tatishvili, T. I., "Physical-Mechanical Properties of Polymer-Treated Concrete Produced by the Radiation Method," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 111, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The Laboratory of Physical and Chemical Mechanics of Concrete, Institute of Construction Materials and Structures, Academy of Sciences, Georgian SSR, in cooperation with the Institute of Physics, Academy of Sciences, Georgian SSR, has studied the modes of saturation of concrete with monomers, with curing of the monomers by the radiation method, and determined the basic strength and deformation characteristics of the polymer-treated concretes.

The effective technological parameters have been established for saturation of concrete with monomer:

drying of products at 120 C - 20 hr;

evacuation of products before saturation - 60 to 80 min;

residual vacuum - 666.5 Pa;

saturation - 40 to 60 min at gauge pressure  $4 \cdot 10^5$  Pa.

Polymerization of the saturated specimens by the radiation method was performed in a field of gamma radiation generated by the large irradiator of the RKPM indium-gallium radiation loop of the IRT nuclear reactor of the Institute of Physics, with a mean dose rate of 80 rad/s and a total dose of 2.3 Mrad, irradiation time - 8 hr.

Some of the physical and mechanical properties of the polymer-treated concrete are presented in the paper.

A551 *Timashov, S. L., Kolesnikov, A. I., and Bobriashov, V. M., "Dielectric Strength of Polymer Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 31, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The Central Scientific Research Institute for Construction Structures and the V. I. Lenin Power Engineering Institute have suggested that heavy- and superlight polymer concretes be used as dielectric and

chemically stable electric engineering construction materials. Since the capability of polymer concretes to resist corrosive media and withstand significant loads is manifested selectively, the task was set forth of determining the dielectric strength under pulsed-loading conditions in chemically corrosive media. The electrical resistance and sparkover voltage were determined on the surfaces of heavy and superlight polymer concretes, with testing of specimens:

- under normal exposure conditions;
- after soaking in water for 7 days.

After long-term soaking, the specimens were held under normal conditions and tested after 2 and 24 hr.

The tests showed that some types of heavy and superlight polymer concretes can be used for electric engineering purposes. Most promising are FAED heavy polymer concretes, FAM light polymer concretes and PPU-binder superlight concretes (polyurethane-foam based) with filler. UKS light polymer concretes with agloporite and keramzit aggregate, and MMA (methylmethacrylate) polymer-treated concretes manifested sharp reductions in dielectric properties, due to which their use for electric engineering construction under conditions involving long-term exposure to moisture is problematical. The electric resistance and sparkover voltage of FAED and PPU with fillers, following long-term soaking and drying under normal conditions, remained practically unchanged. These data indicate that under certain conditions, their dielectric properties may be comparable to the properties of electric-engineering porcelain. The cost of construction structures made of these superlight polymer concretes is significantly lower.

A552 *Tonkikh, G. P., and Rozental', N. K., "Protective Properties of Acid-Resistant Concrete for Steel Reinforcement," Increase in the Service Life of Industrial Buildings and by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 162, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The Scientific Research Institute for Reinforced Concrete Products has studied the passivating properties of acid-resistant concrete and the possibility of increasing them by the use of anodic corrosion inhibitors.

The passivating properties of acid-resistant concrete were determined by a potentiostatic method on prism specimens measuring 4 by 4 by 16 cm. The electrode used was V-1 wire, 5 mm in diameter. The following inhibitors were studied in the process of testing: sodium nitrite, effective in the alkaline medium of concrete, Katapin, which has a passivating effect in acid media, sulfanol as a plasticizer capable of increasing the density of the concrete, sodium nitrite plus Katapin, and sodium nitrite plus Katapin plus sulfanol.

The studies showed that the introduction of these inhibitors

significantly increases the steady potential from -650 to -350 mV, and also causes a decrease in the passivation current at  $E = +300$  mV from 18-20 to 2.5-3  $\mu\text{A}/\text{cm}^2$ , indicating an increase in the passivating properties of the acid-resistant concrete. The combined additive sodium nitrite plus Katapin plus sulfanol is most effective.

A553 Tresnak, Z., "Use of Polymers in Railway Track Formation, Permanent Way and Structures," Schienen der Welt, Vol 9, No. 6, Jun 1978, pp 392-396.

Among the materials used for the construction of parts forming the railway track bed and permanent way, as well as bridges and tunnels, polymers are becoming increasingly popular when they offer technical and economic advantages. The development of their use has not, however, been the same on all railways. From the answers to a questionnaire, a UIC working party has obtained a general picture of the use of polymers by 16 UIC member railways. The analysis of the 60 cases when polymers have been adopted has been published in the form of a UIC leaflet.

A554 Tsekhovoy, A. I., et al., "Uses of Asphalt-Polymer Concrete in Waterproof Linings of Ponds for the Storage of Wastes from Alumina and Aluminum Plants," Tsvetn. Met., 1978, pp 58-59.

Asphalt-polymer concrete linings were shown to be very cost effective used in ponds for storing the various (pH = 13) from alumina and production. Ponds of older design used two-layer polyethylene film over steel-reinforced concrete. Some data are presented on the new pond sizes and performance at various plants.

A555 Uginchus, D. A., Ulitina, G. A., Vandolovskii, A. G., and Omel'chenko, I. D., "Technology and Properties of Pressure-Bearing Polymer-Treated Concrete Pipe," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 120, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The material of pressure-bearing pipes, which experiences primarily tensile stresses, must have high density and good corrosion resistance.

We are developing a technology for the production of polymer-treated concrete pipe, designed for operating pressures of up to 2 MPa, with a ratio of wall thickness to inside diameter of 0.14-0.08:1. The pipe is formed by axial-rotary pressing, which yields a tensile strength of the concrete of 4 to 7 MPa; the maximum radius of the pores in the material is not over 1  $\mu\text{m}$ . We found that the use of limestone aggregate for high-strength polymer-treated concrete products is undesirable, since the aggregate limits the tensile strength of the material to



approximately 17 MPa. In our subsequent studies, we used quartz and granite aggregates.

Second-order composite rotatable uniform planning was used to produce a statistical model of the production process. The tensile strength of the pipe fragments were determined by hydrostatic pressure without loading of the ends. The material used to treat the concrete was methylmethacrylate, the method of polymerization was thermocatalytic, the initiators were benzoyl peroxide and cumene hydroperoxide.

A study was made of the variation of the tensile strength of the material of the treated pipes as a function of the following parameters: strength, drying time, vacuum treatment time, saturation pressure, and saturation time.

A556 Uginchus, D. A., "Directed Structure Formation of Polymer-Treated Concrete Compositions for Structures with High Specific Strength, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 84, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The role of the structure of impregnated concretes in the synthesis of strength can be reduced basically to the influence of porosity, and is well described by the formula of Ryskevich, which is correct for comparatively homogeneous materials (metal, ceramics, gypsum, hydrated single-mineral cement)

$$\sigma = \sigma_0 \exp(-nP)$$

The significance of the structure of such conglomerates as cement concrete in the synthesis of strength is much more complex and cannot be reduced to a function such as

$$\sigma = f(P)$$

Due to the increase in strength in the interface between aggregates and relics of clinker with the cement paste and the filling of microscopic cracks with polymer, the structure of impregnated concrete approaches the type of structure obtained by casting or sintering, and its strength can be increased primarily by increasing the strength of the initial concrete and by achieving maximum filling of the pore space.

Apparently, 6 to 7 MPa represents the ultimate tensile strength which can be achieved by cement concrete. The strength of the aggregates also places certain limits on the achievable strength. For example, when for Construction Materials, radiation-chemical polymerization on a universal gamma installation (the UGU-200) owned by the Institute of Nuclear Power Engineering, Academy of Sciences, BSSR, at a radiation intensity of 400 r/s.

The mathematical models produced allow quite effective regulation of the parameters of the technological process of production of

polymer-treated concretes and their optimization. The results can be directly applied in automation.

A557 Uvarova, I. B., and Pozhitnova, T. A., "Chemically Stable, Plasticized Composites Based on Epoxy-Acrylic Binder," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 24, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Polymer solutions based on epoxy resins are at present the most widely used types for seamless floors. However, the most suitable types of resin (ED-16, ED-20) are quite brittle and tend to form cracks, hindering their use as flooring.

One effective method of plasticizing epoxy resins is their modification with low-molecular weight, butadiene-acrylonitrile rubber of types SKN-10-1A, SKN-18-1A, and SKN-26-1A.

In order to produce a polymer solution which is easy to work with, an elevated content of solvent or liquefier must be introduced, leading to a significant decrease in the physical and mechanical properties and a chemically stable composition. The Polymer-Concrete Laboratory of the Scientific Research Institute for Reinforced-Concrete Products has developed polymer solutions based on epoxy resins, plasticized with low-molecular-weight rubbers. In order to decrease the viscosity of the compositions and improve their properties, low-viscosity monomers of the acrylic series were used. In this work, methylmethacrylate (methacrylic acid ester) was used. This binder system, called "epoxycryl" by the authors, consists of an epoxy resin, methylmethacrylate, rubber, aliphatic poly- or diamino and hydroperoxide.

By using a combined curing agent, it is possible to cure not only the epoxy resin, but also the active solvent and the rubber to the identical degree.

The general tendency of polymer solutions based on epoxycryl is to increase resistance to acids, particularly oxidizing acids. In comparison to polymer solutions based on epoxy resins, epoxycryls have higher resistance to acetic acid, as well as increased adhesion to concrete and steel (particularly with contaminated surfaces).

Coatings of polymer solutions based on epoxycryl binder were tested with sharp, cyclical-temperature changes: The temperature range was over 90 C, test time 25 days, number of cycles - over 70. After testing, no cracks were observed on the surface, nor was there any separation of the coating from the substrate.

A558 Vaschuk, V. Ia., "Mechanism of Strengthening of Concrete by Polymers," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti

Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),  
Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 102, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

It is known that saturation of cement concrete with monomers significantly increases its strength. This results first of all from a decrease in the residual porosity of the material by filling of pores and capillaries in the concrete with polymer. This conclusion is based on the fact that the function  $\sigma_c = f(\text{porosity})$  for polymer-treated concrete is the same as for concrete. For example, in cubes with edge length 7 cm, made of M500 cement, basalt gravel 5 to 10 mm in diameter and sand with  $M_{cr} = 3.1$ , the function produced was  $\sigma_c = 256(I-P)^{10^{-1}}$  MPa. This same function describes the strength of the same concrete saturated with methylmethacrylate (in the interval of residual porosity 0.03 to 0.18). For concrete saturated with styrene, the curve is shifted, without changing shape, in the direction of lower strength. This change in strength as a function of porosity corresponds to the general theory of strength of porous materials.

The strength of a polymer-treated concrete also depends on the nature of the polymer in the capillary structure. A higher modulus of elasticity of the polymer (or copolymer) results in higher strength of the polymer-treated concrete. The strength of concrete saturated with nonpolar monomers (styrene and a mixture of styrene with divinylbenzene) and polar monomers (vinyl acetate, methylmethacrylate, etc.) differs significantly. In the second case, the higher strength is provided by the interaction of the polymer with the cement paste, leading to significant changes in the properties of the polymer.

A559 Veiner, B. V., Voloshin, V. F., and Sirotnin, G. A., "A Decorative Polymer-Treated Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 121, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Work performed at the Minsk Scientific Research Institute for Construction Materials under the leadership of Prof. Iu. M. Bazhenov has demonstrated the possibility of polishing polymer-treated concrete made of ordinary concrete and polystyrene.

The possibility was studied of producing polymer-treated concrete products with surface finishes close to natural stone. Fillers made of igneous rock, as well as crushed marble, were used. The consumption of pigment was 5 to 10 percent of the mass of the cement. Tests of the cold resistance and the combined effect of freezing and thawing, wetting,

and drying and exposure to ultraviolet light were performed in a weather-imitating chamber.

A type BF-2 reflectance was used to determine the polishing qualities of the decorative products. The data produced were as follows: after grinding - 8 to 15 percent; after burnishing - 15 to 25 percent; after polishing - over 25 percent. On some polished specimens, the surfaces achieved readings of 40 percent and more.

The good decorative qualities of polymer-treated concrete, the possibility of imitating practically any natural stone material, in combination with good physical and technical characteristics, make polymer-treated concrete products quite promising for building facades, pedestals, underground passages, floors and architectural details.

A560 Vorob'ev, V. A., et al., "Polymer-Cement Mortar Coatings for External Finish of Concrete Surfaces;" Translated from Russian by Bureau of Reclamation, Denver, Colo., 1978.

One means of solving the problem of producing durable decorative coatings for large panel buildings is the use of polymer-cement mortar coatings. This has been facilitated both by the increase in the production of polymers and the decrease in their cost, as well as by achievements in investigating the properties of polymer-cement mortars and concrete. The experimental data accumulated to date have shown that composites consisting of polymers plus mineral binders must be considered new materials, in which the properties of the mineral binders and high-molecular organic substances mutually complement and improve each other, thus increasing the quality of the artificial stone made from them.

In recent years, polymer-mineral mortar finish coatings have become popular. These coatings are produced from sand-mortar compositions (polymer-cement or polymer solutions and sand with particle size not over 1.2 mm). They are applied to the surface to be finished in a layer 2 to 4 mm thick. Although they are considerably thinner and correspondingly consume less raw material than plaster, mortar coatings can cover small defects in the concrete surface, a significant difference from paint coatings.

The decorative effect of mortar coatings is achieved by the use of white cement and light-colored fillers in combination with alkali-resistant pigments, and also by the fine-grained finish achieved by pneumatic spraying of the composition onto the substrate. The decorative qualities of the mortar itself make decorative powder applications unnecessary.

A561 Viazemskaya, N. I., and Kalinin, E. V., "Experience in the Use of Epoxy-Resin-Based Polymer Concrete for the Repair of Wet Concrete in Hydraulic Structures," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 44, Jan 1979; Translated from the Russian by Engineering

Services Branch, U. S. Bureau of Reclamation Translation Group,  
Denver, Colo.

Since 1967, the Leningrad Institute of Water Transport has been studying the selection of compositions of epoxy polymer mortars and concretes for the repair of the wet concrete of hydraulic structures.

The studies have shown that polymer mortars based on type EIS-1 alkylresorcinol-epoxy resin, with polyethylene-polyamine (PEPA) as the curing agent, have good adhesion to wet-concrete surfaces, as high as 2 MPa with a water temperature of +18 C, and 1.3 MPa with a water temperature of 0.5 C (age of specimens at 28 days). The introduction of IP-1 surfactant at 2 percent of the mass of the binder increases the adhesion of these compositions to wet concrete to 3.2 MPa for a water temperature of +18 C and 2.3 MPa at 0.5 C.

The use of polymer mortars and concretes based on EIS-1 resin and PEPA curing agent in experimental operations involving the repair of locks along the V. I. Lenin Volga-Baltic waterway has confirmed their good adhesion properties; 7.1 m<sup>3</sup> of polymer concrete was used in all. At the Belousovskii Hydraulic Project, the polymer concrete was applied as a protective coating on the surface of protective at the upstream head of the lock. The total area coated was 120 m<sup>2</sup>. Fifty-five anchor bolts were installed using polymer mortar. At lock No. 3, 2 m<sup>3</sup> of polymer concrete was used to repair interlocking seals for the upper repair gates and the supports of seams allowing for temperature expansion and shrinkage of the lock. Epoxy polymer mortars were used to eliminate seepage of water through the concrete of the lock chambers, for underwater repair of concrete and for the repair of concrete surfaces. During the winter of 1976-1977, locks were repaired at ambient air temperatures below freezing, without heating the concrete.

A562 Voronin, I. A., and Bikbov, R. Kh., "Determination of the Strength and Deformation Characteristics of Circular Cross Section Polymer-Concrete Columns," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 65, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Specimens of columns of circular cross section and control prisms of the same polymer-concrete composition were subjected to short-term, compressive-strength testing in order to determine the possibility of using elements of circular cross section as columns under compression.

The following three-fraction composition of polymer concrete, expressed in mass percent, was found to be most acceptable in terms of ease of pouring to maximum density and minimum resin and hardener content for circular cross section columns with wall thicknesses of 22 to 24 mm;

Granite gravel, 3-7 mm	60
Quartz sand	20
Acid-resistant cement	7
Furfural-acetone monomer	11
Benzene sulfoacid	2

The maximum elastic and total deformation in compression, the modulus of deformation and the compressive strength were determined by short-term testing of the columns and prisms.

During the process of testing of the columns and control prisms, temperature, the variation becomes nonlinear, the nonlinearity being greater, the higher the temperature.

For each polymer concrete, there is a temperature of maximum deformation. When this temperature is exceeded, the strength of the specimens drops rapidly, with a simultaneous decrease in the maximum deformation.

During long-term testing, certain regularities of creep as a function of temperature and stress were determined. Creep and the process of attenuation of deformations are more clearly seen in heated specimens than in nonheated specimens. The creep deformation, with identical levels of stress, is less in heated specimens than in unheated specimens.

However, this regularity appears only for heating up to certain temperatures: Beyond these temperatures, a further rapid increase in deformations occurs, although at certain stress levels they tend to decrease. Based on the studies performed, it has been established that under certain conditions, the temperature coefficients and coefficients of duration are quite similar in value (0.4 to 0.5) for certain temperatures. Consequently, in practical calculations, it is possible to use stress-strain diagrams for various temperatures rather than stress-strain diagrams for short-term and long-term loading.

With identical values of initial modulus of elasticity, the columns and control prisms differed in the mean values of the indices tested: The strength of the columns was found to be less than the strength of the prisms by an average of 15 percent. This is explained by the more rapid development of transverse deformations in the hollow elements than in the prisms, and, to some extent, by the influence of the wall thickness of a hollow specimen on its strength and deformation characteristics.

A563 *Voznesenskii, V. A., and Buchinskii, A. V., "Optimization of the Formulas of Oil-Resistant Polymer Cement Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 164, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

The purpose of this work is to find formulas for polymer-cement concrete which are effective in terms of minimizing the criteria of oil stability  $M$  and shrinkage  $\delta_{sh}$ . The properties of the material are improved by simultaneously introducing three water-soluble, high-molecular additives,  $A_1$ ,  $A_2$ , and  $A_3$ , one of which helps to plug the pores, the second causing polycondensation of the third in an alkaline medium.

The paper presents mathematical models and equations to find model coefficients.

The results of the work led to two conclusions:

(a) the introduction of a combination of water-soluble, high-molecular-weight additives can significantly improve oil stability and other operational characteristics of polymer-cement concrete;

(b) the method of polynomial modeling, in combination with a dissociative iterative method of optimization and near-optimal search for compromise, is a very effective tool for the solution of complex problems relating to formulas and technologies.

A564 Webster, R., et al., "Rapid Patching of Concrete Using Polymer Concrete," Report No. CONF-780270-1, 1978, Brookhaven National Laboratory, Upton, N. Y.

One of the major problems confronting the highway industry today is the need for a rapid repair material for deteriorated concrete structures. High maintenance costs and traffic delays have created the need for a long lasting, rapid setting, concrete patching material. The use of polymer concrete (PC) as a repair material is discussed. Materials used to make polymer concrete composites are described, as is the procedure for placing polymer concrete patches. The placement of polymer concrete patches in the field by highway maintenance personnel using conventional concrete mixing equipment and techniques is also described.

A565 Zeldin, A., Kukacka, L. E., and Carciello, N., "Concrete Polymer Materials for Geothermal Applications," Report No. BNL-24215, Jun 1978, prepared for presentation at AIChE Symposium, Penn.

The feasibility of using a copolymer composed of styrene, acrylonitrile, and acrylamide or methacrylamide in the formation of a high-strength thermally and chemically stable polymer concrete for use in geothermal environments has been demonstrated. Specimens produced with the copolymer in conjunction with an aggregate containing sand and portland cement had compressive strengths in the range 25,000 to 30,000 psi at 20°C and were thermally stable up to ~240°C.

A study of the effect of monomer concentration on the properties of the polymer concrete indicated that the optimum concentration is in the range 12 to 13 wt percent. Increased monomer concentrations lead to a nonuniform polymer distribution within the composite, resulting in a deterioration of the properties. The optimum properties are obtained when the monomer is used in conjunction with an aggregate containing 70

to 80 wt percent silica sand and 20 to 30 wt percent portland cement.

The results from laboratory and field evaluations in progress indicate that the materials can be used for pipe or as protective liners on pipe and vessels in electric generating and direct utilization geothermal processes.

- A566 Zakharov, V. A., "Polymer Concrete for Highways and Methods of Its Improvement, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 74, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Leningrad affiliate of SoiuzdorNII has developed composite binders and polymer concretes based on type ED-20 and EIS-1 epoxy resins, as well as type PN-1 and PN-III polyester resins.

The materials which have been developed have been used in various projects in Leningrad: as thin pavings for city bus parking lots, on the draw spans of motor-vehicle bridges (the Grenaderskii and Dvortsov bridges, Lieutenant Shmidt Bridge, as well as a bridge in Klaipede, Lithuanian SSR).

The experience gained in using the material has shown that, in general, thin polymer-concrete pavement is quite satisfactory, although there are individual defects, resulting from improper performance of work.

It has been established that 30 percent residual petroleum asphalt should be added to the shale bitumens to increase the thermal stability of epoxy-shale composites. To assure reliable impermeability and retain stability of indices upon exposure to freezing and thawing, epoxy-shale composites should be modified by the addition of type DEG-1 epoxy resin or liquid thiokol type NVB-2. To improve the properties of the polymer concrete at low temperatures (down to -60 C), finely dispersed basic rock fillers should be used. Ethyl silicate at up to 3 percent can be added to the shale or petroleum plasticizer to increase the adhesion of composite-binder materials to steel.

In addition to improving the properties and perfecting the technology of preparation of composite-binder materials and polymer concretes, methods are now being developed for the construction of thin pavement for roads and bridges.

- A567 Zhavrid, S. S., and Malikhtarovich, V. I., "Bases of an Efficient Plant Technology for the Manufacture of Products and Structures of Polymer Compositions and Concretes Based on Carbamide Resins, Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),



Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 21, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The principles of an efficient plant technology for the manufacture of products and structures of compositions and concretes based on carbamide resins can be formulated only by considering the peculiarities of the structure-forming components and their properties, as well as the chemical nature of the product.

The technological principles which presently exist for the manufacture of products of cement concretes using hydraulic binders, asphalt concretes or polymer concretes (based on FAM, PN, ED, and other resins) cannot be fully applied to this case, since polymer compositions and concretes based on polymer resins have their own specific peculiarities.

We have attempted to formulate the bases of an effective technology for the manufacture of products and structures of carbamide resin-based compositions and concretes.

Since phosphogypsum, as a waste product of the Gomel' chemical plant, is stored in the form of a saturated-aqueous slime, the production of a binder in the form of a calcium sulfate hemihydrate from it requires heat treatment. Hydrolytic lignin also occurs in the moist state and requires drying. Therefore, the raw materials preparation portion of the process must include heat treatment of the phosphogypsum and drying of the lignin.

Studies have shown that heat treatment of phosphogypsum should be performed at 160 C for 2 hr. This process can be performed in drying drums or gypsum ovens. In the former case, subsequent grinding of granules of heat-treated phosphogypsum combined with the nonliquefied product is required. When cooking in a gypsum oven is used, the phosphogypsum produced is rather fine-grained (screen analysis >0.2 mm, not over 6 percent), so that it requires neither grinding nor screening.

A568 Zhirov, A. S., "Load-Bearing Structures with Improved Rigidity and Strength, Based on Lightweight Polymer Concrete," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 47, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Department of Construction Structures of the Moscow Institute of Railroad Transport Engineering has developed several designs, based on both traditional and new polymer materials. Corrosion-resistant composite structures based on lightweight concretes with polymer additives are particularly promising. This is especially true of combined elements consisting of lightweight reinforced polymer concrete, strengthened by a three-dimensional system of strong, rigid reinforcement. The compressed belt of the reinforcement system is made of high-strength cement or

cement-polymer concrete, combined into a monolith with the reinforcement which works in tension, e.g., as in a truss system for bending elements.

Factory testing of full-size structures has established that during the initial period of operation, the reinforcing system accepts up to 55 to 65 percent of the external load. Computer calculations show that as the deformation of the polymer concrete increases and its strength decreases due to exposure to corrosive environments, the load on the reinforcing system increases. As a result of this redistribution of forces, the reinforcement system may be required to accept as much as 75 to 85 percent of the external load. Rigid reinforcement systems not only allow successful solution of the problem of effective application of lightweight polymer concrete in load-bearing structures, but also reduce the required consumption of this expensive material by 30 to 40 percent, in comparison to reinforced polymer concrete structures made like ordinary reinforced concrete. Combined structures of this type have been used in a number of chemical-industry construction projects.

New structural elements, as well as a manufacturing technology for production of the elements, designed in consideration of the advantages and peculiarities of both traditional and new materials, allow successful solution of the problem of manufacturing effective corrosion-resistant structures, assuring further progress of construction techniques and technology.

1979

A569 Adomavichiute, O.-B. B., and Konchius, V. Iu., "Study of the Physical and Mechanical Properties of Latex-Cement Concrete," Summaries of Papers of the Republication Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The laboratory for modified construction materials of the Lithuanian Scientific Research Institute for Construction and Architecture has been studying the physical and mechanical properties of latex-cement concrete, to be used as a floor covering for industrial buildings, made using MKh-30 Shch dispersion.

The raw material for the manufacture of the latex-cement concrete specimens consisted of: portland cement of grades 400 and 500, produced by the Akmianskiy Cement-Slate Combine; lump granite 5 to 10 mm in diameter; sand with particle-size modulus  $M_k = 2.78$ ; and dispersion MKh-30 Shch (Tu 6-01-289-69). Dispersion MKh-30 Shch was stabilized by the nonionogenic surfactant OP-7 (GOST 8433-57). The stiffness of the mixture was assumed constant ( $CS = 3-4$  cm).

The best compressive strength was obtained in compositions with  $P/C = 0.025-0.075$  with moist storage of the specimens and with  $P/C = 0.05-0.1$  under dry-air conditions (see Table). Introduction of up to 10 percent MKh-30 Shch (as percentage of cement mass) increased the tensile strength with bending by about 50 percent. The impact strength reached its maximum at  $P/C = 0.075-0.1$ , increasing to approximately

twice its level in ordinary concrete. The wear-resistance of the latex-cement concrete under moist conditions was somewhat higher (up to 30 percent), and with air-dry curing was double that of ordinary concrete.

The latex-cement concrete containing MKh-30 Shch (7.5 percent of the mass of the cement) had the highest strength and impact resistance. The mechanical strength and impact resistance of latex-cement concrete increase significantly as time passes. In contrast to ordinary concrete, air-dry curing helps to improve the physical and mechanical properties of latex-cement concrete.

A570 *Adhesive Engineering Co., "A/E Begins Production of High Performance Polymer Concrete," Construction, Vol 14, No. 2, 1979.*

CONCRESSIVE® Polymer Concrete (CPC) - a rapid curing, high strength, moisture resistant acrylic mortar - is currently being introduced to the civil engineering community by Adhesive Engineering Company. The composition of CPC consists of a liquid, methyl-methacrylate-based "A" component, and a powder Part "B" component which contains graded silica sand, reactive polymers, initiators, and pigments. Once combined, the components polymerize quickly to a compressive strength of 8,000 to 10,000 psi. Full load bearing strength is reached within 3 hr at 15°F, and in 1 hr at temperatures of 75°F and above. Application temperature range is 15°F to 100°F.

The first installation of CPC took place in April 1979 at a San Francisco municipal railway maintenance station. There, approximately 5127 sq ft of concrete floor area adjacent to the facility's bus washing station was resloped to allow for proper water drainage into the tracks and away from the walls of the station. The CPC was chosen for use because of its rapid installation and cure speed, and because its high level of water impermeability provides a permanent maintenance-free surface. Another initial application was the 3-hr downtime repair of a deteriorated expansion joint on a Southern Utah viaduct on Interstate 15.

A572 *Alvert, O. K., "15,000 psi Concrete Achieved with Polymers," Concrete Construction, Jan 1979, pp 13-15.*

With the development of polymer concrete or impregnated polymer concrete, it is possible to achieve a compressive strength of 1050 kg/cm<sup>2</sup> (15,000 psi) or more. This technology has been used to reduce erosion by water of large hydraulic structures, to restore damaged concrete buildings and lay fast-setting industrial floor overlays.

During polymer impregnation the in-site concrete should be thoroughly dried, preferably the moisture contents should be reduced to 1 percent. The concrete is then impregnated with a monomer system and catalyzing agent to produce the final properties required. Full-scale tests of PIC techniques demonstrate that these can be used for repair of extremely porous, low-strength concrete.

A572 Bazhenov, Iu. M., "Improving the Properties of Concrete by Polymer Treatment," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

In recent years, studies have been expanded on the improvement of the properties of concrete by polymers. A technology has been developed for the new materials - polymer-treated concretes - significantly superior in their properties to initial concretes.

According to our studies, the strength of the concrete in compression and extension, after it is treated with special compositions, increases by a factor of 1.5 to 10, depending on the properties of the initial concrete and the polymer composition. The durability of the material increases significantly, particularly when exposed to corrosive media. For example, freezing of concrete in chlorides at -50 C has resulted in its failure after a few cycles, whereas polymer-treated concretes can withstand 100 cycles under these same conditions without visible signs of deterioration. The cold resistance of polymer-treated concretes under normal conditions at -20 C is as great as several thousand cycles. These materials are practically impervious to water. They can be given certain special properties: a predetermined electrical resistance, deformation capacity, permeability, etc.

Tests have shown that the properties of polymer-treated concretes remain practically unchanged upon long-term operation. At 10 years of age, after storage exposed to the air, the strength of the material in compression and extension remains practically unchanged. When stored in water, a decrease in strength of 5 to 10 percent is sometimes observed; however, this decrease occurs during the first few months of storage, after which the strength stabilizes. A similar phenomenon is observed in long-term weatherometer testing. Apparently, this results from certain changes in the properties of the thin surface layers and does not extend through the basic structure of the polymer concrete. For comparison, we should note that the changes in the properties of concrete tested in the weatherometer are frequently quite great.

Surface treatment of products and structures is quite promising for construction. In this case, with a relatively low polymer consumption of 1.5 to 2.5 kg/m<sup>2</sup>, a significant increase in durability and corrosion resistance of the structures is achieved, the structure of the material is stabilized, providing reliable operation of nonmetallic reinforcement and eliminating negative aspects related to the use of certain compositions which may expand, thus applying stresses. At the same time, the reinforcement is well-protected from corrosion.

A573 Degtiareva, L. I., et al., "Physical Chemistry of Processes of Strengthening of Cement Materials Upon Treatment With Organic Polymers," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

It has been established that the activity of the physical-chemical interaction of the mineral matrix with PMMA is practically independent of the degree of specific chemical interaction with the polymer, but rather is determined by the adsorption activity. For example, for C<sub>2</sub>A, B = 0.147, while the energy constant in the BET equation (based on adsorption of methanol) C = 70; for silica gel type KSK, B = 0.021 and C = 20.

The formation of the boundary layer of polymer of higher rigidity involves certain surface phenomena: limitation of the mobility of macromolecules, due to a change in enthalpy as a result of the adsorption interaction, and adsorption pressure. Geometric, conformation limitations are of great significance (according to Iu. S. Lipatov).

As a result, Young's modulus of PMMA in the boundary layers exceeds its value in the block by 1 to 2.5 orders of magnitude.

The maximum strength of a composite, with all other conditions equal, can be obtained by using the critical concentration of polymer in the system, i.e., by utilizing the entire volume of polymer in the adsorption layers. For PMMA, the thickness of the adsorption layer of which is  $7.2 \cdot 10^{-5}$  cm, this critical concentration can be achieved if the radius of the pores of the concrete is not over  $10^{-4}$  cm (1  $\mu$ m).

Unfortunately, it is difficult to fill the microscopic pores of the cement paste with the solution of catalyst in monomer, due to the molecular sieve effect. The sorption and IR spectroscopic data show that the concentration of catalyst in the microscopic pores is so low that the technology of treatment of concrete using catalysts is near the limit of the capabilities of the catalyst.

Treatment of concrete with high strength and small pore structure with linear polymers creates the genuine possibility of achieving composites with a tensile strength of up to 30 MPa.

A574 Dzhabarov, V. M., et al., "Influence of Physical-Mechanical Properties of the Initial Concrete On the Strength of Polymer-Treated Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Since the polymer is the scarcest and most expensive component of the composite, a decrease in the consumption of the treating composition while retaining high strength of the concrete-polymer, may also decrease its cost and increase the effectiveness of its use in construction. This work studies the influence of the physical and mechanical properties of the initial concrete on the consumption of monomer used in treating the concrete and the strength of the polymer-treated concrete produced.

The experiments were performed on cubes measuring 7 by 7 by 7 cm, made of concrete of five compositions with grade 500 portland cement from the Belgorod Plant; granite gravel with maximum particle size 10 mm, and ordinary construction sand with  $M_{cr} = 2.1$ . In all, 15 twin sets of specimens were produced for each composition.

After heat and moisture treatment, the specimens were modified with the polymer as follows: drying to constant mass at 120 to 130 C; evacuation at  $0.2 \cdot 10^{-2}$  MPa; treatment with a methyl methacrylate based composition under a pressure of 0.25 to 0.3 MPa and thermocatalytic polymerization of the monomers in the pores of the concrete.

The polymer-treated concrete cubes were compression tested 7 days after they were made.

A comparison of the indicators of strength and consumption of treatment composition shows that the most acceptable concretes for modification are those with cube strengths on the order of 30 to 40 MPa, which are widely used in construction, and allow polymer-treated concretes to be produced with compressive strengths of 130 to 145 MPa with a relatively low consumption of monomer, 125 to 130 kg/m<sup>3</sup>.

A575 Fontana, J., and Zeldin, A., "Concrete Polymer Materials as Alternate Materials of Construction for Geothermal Applications - Field Test Evaluations," BNL-25957R, Feb 1979, Brookhaven National Laboratory, Process Sciences Division, Department of Energy and Environment, Upton, N. Y.

A serious problem in the development of geothermal energy is the availability of durable and economical materials of construction for handling hot brine and steam. Hot brine and other aerated geothermal fluids are highly corrosive and they attack most conventional materials of construction.

Brookhaven National Laboratory has been investigating the use of concrete polymer materials as alternate materials of construction for geothermal processes. To date, successful field tests have been demonstrated at the Geysers, U. S. Bureau of Mines Corrosion Facility, and at the East Mesa Geothermal Facility. This report is a survey of field and laboratory evaluations of concrete polymer materials which have been shown to be durable and economical as alternate materials of construction.

A576 Galler, S., "Polymer Concrete Patching Comes of Age - 18 Years Late," Rural and Urban Roads, Vol 17, No. 11, Nov 1979, pp 32-33.

After more than 18 years of successful use in Europe, polymer concrete patching material is gaining acceptance as a road repair material in the U. S. To compile a track record of its performance, tests and demonstrations are being made. The Federal Highway Administration's sponsored reports on the tested qualities of polymer concrete list these features: good bonding to the original concrete; short cure-time to full load bearing; high chemical and abrasive resistance; minimal permeability to chlorides and water; high physical properties, including higher compression, flexure, and tensile strength than normal concrete; can be ultraviolet ray resistant; can be feather finished; and can be formulated for minimal shrinkage.

A577 Gorchakov, G. I., et al., "Strength and Deformation Properties of Concretes and Polymer-Treated Concretes," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The tensile strength during bending and modulus of elasticity were studied in specimens of concrete with the identical volumetric content of aggregate, but with varying quantities of cement paste. These compositions had a constant volumetric concentration of cement paste in the concrete, 20 percent, with initial water-cement ratios of 0.2 to 0.4. The studies were performed with grade M 400 portland cement, quartz sand with a water uptake of 7 percent, granite gravel with  $D_{\max} = 10$  mm, water uptake 4 percent. The compositions of the concrete specimens used are presented in the table. The consumption of aggregate was the same: sand 605 kg, gravel 1210 kg per  $m^3$ . Specimens measuring 4 by 4 by 16 cm were cured for 28 days under normal conditions. Some of the specimens were treated with MMA with subsequent radiation polymerization, radiation dose 2 Mrad.

Treatment of the concretes with polymers resulted in an increase in the strength and deformation properties in comparison to the initial concretes by a factor of almost 2. This is explained by the fact that the porosity is greatly reduced, to less than 1 percent. The polymer does create some stress as a result of shrinkage; furthermore, many defects in the concrete are "healed." The polymer covers the surface of the solid phase of the concrete, preventing the development of microcracks, and the high adhesion of the polymer to the concrete results in a great increase in the strength of the relatively weak bonds between the components of the concrete.

A578 Habercom, G. E., "Concrete Polymer Composites (Citations from the Engineering Index Data Base)," National Technical Information Service, Jul 1979.

The citations cover worldwide research on concrete polymer composites including both polymer aggregate concretes as well as polymer impregnated portland cement concretes. The reports discuss their production, hardening, uses, and properties. Also cited are studies on applications such as piping, building panels, bridge decking, tunnel supports, and highway pavements. (This updated bibliography contains 185 abstracts, 23 of which are new entries to the previous edition.)

A579 Ieremin, N. F., et al., "Heat and Moisture Insulating Cement-Polymer Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Introduction of polymers to concrete in order to give the concrete hydrophobic properties and greater durability is not effective for light heat-insulating concrete, since significant quantities of the polymer must be used to fill the pore space (addition of up to 130 percent polymer).

A light, heat and water insulating cement-polymer concrete has been developed, with an additive based on high and low pressure polyethylene production waste. The studies performed yielded an aqueous dispersion of low-molecular polyethylene, which was introduced to the concrete along with the water added for curing, without increasing the complexity of the process used for the manufacture of concrete products.

The studies performed for determination of the optimal quantity of LMPE to be added indicated that the best properties of the concrete were produced with a low-molecular polyethylene content equal to 2 to 4 percent of the binder by weight.

Laboratory studies and pilot-scale testing showed, the maximum increase in compressive strength of light concrete in both cases was 150 percent. This increase in strength can be explained by the plasticizing capacity of the polymer additive, which improves its pouring properties and cohesion, and decreases the water consumption of the concrete mixture. Water absorption is significantly lower in concrete with a polymer additive which has been subjected to heat and moisture treatment.

A580 Khozin, V. G., and Lipatov, A. A., "Pressed Slabs of Highly Filled Sand Polymer Concretes," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The creation of chemically stable structural polymer concretes requires the selection of a particle-size distribution for the mineral framework which will assure the optimal contact structure, of maximum density, with the minimum consumption of polymer binder. Polymer concrete materials of this type have high rigidity and are highly thixotropic; therefore, they should not be used in monolithic roofing, but rather should be formed into piece goods under pressure (by pressing, rolling, etc.), thus achieving the maximum density, and also reducing the consumption of polymer binder.

The authors have developed compositions for highly filled sand polymer concretes containing modified epoxy, furan and polyester resins, and a technology for the manufacture of high strength, chemically stable, impact resistant and wear resistant polymer concrete slabs by "cold" pressing. These slabs are intended for use as floor coverings in industrial and public buildings, as facings for walls and columns, as well as linings for process containers and installations.

The technology for production of polymer concrete slabs, which we have developed calls for the manufacture of 1- and 2-layer slabs measuring 300 by 300 by 30 and 500 by 500 by 50 mm, by "cold" pressing of polymer concrete mixtures with subsequent heat treatment of the slabs



formed outside the molds in heating chambers. In addition to the chemically stable slabs, 2-layer slabs can be produced in a broad range of colors.

A good combination of physical-mechanical and chemical properties of these slab products is achieved by the method we have developed for selection of dense sand compositions, the use of modified polymer binders, fiber fillers, and surface treatment of the fillers. High density of the material is combined with a low content of binder (4 to 6 percent in coarse grained mixtures, 6 to 10 percent in sand mixtures).

A581 Komokhov, P. G., and Petrova, T. M., "Mechanism of Action of Polymer Additives on Discontinuity of Structure of Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Studies at the Department of Construction Materials of the Leningrad Institute of Railroad Transport Engineering have convincingly shown that the multiphase and heterogeneous structure of concrete, with its locally stressed state, can be significantly improved by the introduction of small quantities of polymer additives.

The mechanism of action of additives such as water-soluble resins No. 89, DAS-4, DEG-1 and epoxy-treated raw rubber type PDI-ZAK, introduced in quantities of not over 2 percent of the mass of the cement, creating elastomers at the phase-division boundary with elastic heterogeneity of the elements of the structure of the concrete, consists in that they form an energy "damper" across the path of a propagating crack, in the form of a weak surface inclusion, not capable of returning a large portion of the energy expended in its deformation as crack growth energy.

In order to develop this theoretical idea, an attempt was made in the studies to determine by calculation the speed of propagation of a crack as a function of the macrostructure of concretes of equal strength. It was found that the characteristic of maximum extensibility of the concrete is a function of the crack growth rate. For example, the slowest growth rate of an existing microscopic crack in the structure of cement-polymer concrete of grade 600 with PDI-ZAK additive is 233 m/s, which corresponds to the greatest tensile strength of fine-grain concrete of 28 days age -  $3.02 \cdot 10^{-4}$ , 15 percent less than the crack growth speed in concrete with lump coarse aggregate and 10 percent less than the speed of crack growth in the same fine-grain concrete without the additive.

The results of endurance testing with a base of  $10^6$  cycles of loading and an unbalanced, unidirectional loading cycle of specimens measuring 4 by 4 by 16 cm, consisting of fine-grain concrete of grade 600 with a characteristic loading cycle  $\rho = \rho_{\min} / \rho_{\max} = 0.3$ , showed that the absolute endurance limit of the cement-polymer concrete was higher by as much as 36 percent, the relative endurance limit - by up to 20 percent, in comparison with ordinary concrete.

The results of laboratory studies have been tested in production of experimental batches of reinforced concrete pilings at the Chudovskiy Reinforced Concrete Pilings Plant. Standard piling crack resistance tests, as called for in State Standard GOST 10629-71, performed on pilings with DAS-4 additive, showed that after 1 day of curing, they could withstand a load in their middle cross section 35 percent greater, in transverse cross sections 25 to 30 percent greater, than called for in the State Standard.

Thus, the introduction of small quantities of polymer additives to the structure of high-strength concrete is a means of effectively retarding fracture, both during early structure formation and during the later use of load-bearing concrete and reinforced concrete products, due to the formation of the optimal structure of the concrete.

A582 Kosenko, V. S., et al., "Influence of Certain Operational Factors on the Strength of Polymer-Treated Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

One area which has clearly been insufficiently studied in the investigation of the mechanical properties of concrete polymer systems is their operational reliability: determination of long-term strength, determination of the influence of long-term and cyclical exposure to various temperatures, water, etc.

The studies which we have performed allow us to give a partial answer to some questions of this nature: what is the influence of cyclical heating and cooling in both air and water, as well as the influence of long-term exposure in water with slight temperature fluctuations?

Cyclic heating and cooling were performed in the following modes: I, heating to 50 to 70 C for 6 hr, with subsequent cooling to room temperature in 18 hr in air; II, same, but cooling in water and together with the water (which was heated to 50 C). A total of 110 cycles was conducted in both modes. The changes in weight and strength of the specimens were then measured.

For the ordinary cement concretes, tested in mode I, no significant changes occurred, as was to be expected, while when these specimens were tested in mode II, they lost up to 50 percent of their strength, with little change in weight.

However, the modified concretes (polymer-modified concretes) showed practically no change, either of weight or of strength, in either mode.

Long-term exposure to water at room temperature of specimens of the initial composition and modified compositions continued for 1440 days. Test specimens of the modified concretes were also exposed to ordinary room conditions of temperature and humidity for the entire period of the studies.

Ordinary concretes, as we know, tolerate long-term exposure to water quite well, but their water absorption averages 7 to 10 percent,

whereas the polymer-treated concrete absorbed only 0.97 percent water after 4 years (the specimens showed a 1-day absorption of 0.9 percent immediately after modification). The strength of the treated concretes remained practically unchanged.

A583 Kudzis, A. P., and Glebov, V. I., "Mechanical Properties of Centrifuged Polymer-Cement Concrete Subjected to Long-Term Compression," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Polyamide resin No. 89 is one of the most widely used polymer additives in concrete. Studies performed at the Vil'nius Construction Engineering Institute have shown the effectiveness of the use of this additive in centrifuged concrete in order to increase cold resistance and durability of the upright supports of power transmission lines and other such structures.

Most of the centrifuged structures are manufactured with prestressed reinforcement, evenly distributed throughout the length of the circumference of the cross section. Therefore, it was necessary to study the influence of long-term axial compression by forces of decreasing magnitude, such as those encountered in prestressed reinforcement, on the mechanical properties of the centrifuged polymer-cement concrete. Experiments were conducted on nonreinforced specimens of circular cross section, made of steam-cured centrifuged grade 700 concrete subjected to long-term loading in special presses which were placed in climate-testing chambers with automatic regulation of the temperature and relative humidity of the surrounding air.

A584 Kudzis, A. P., and Dvoskina, L. G., "The Influence of the Heat-Treatment Mode on the Strength of Polymer-Cement Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Results are presented from studies of the prism strength of ordinary and polymer-cement heavy concrete, following infrared irradiation. The influence of the heat treatment mode and duration on the strength of specimens measuring 10 by 10 by 40 cm was studied.

The basic results of testing of prisms under short-term static load at 28 days of age are presented in the report.

As a result, the following conclusions can be drawn:

(a) when there is not rigid mode of heat treatment, polymer additive No. 89 allows us to increase the strength of type M-300 heavy concrete by 30 to 60 percent;

(b) the use of polymer additive No. 89 allows a significant reduction in the duration of heat treatment of products, while slightly increasing the strength of heavy concrete;

(c) the time of holding of products before heat treatment is a significant factor in increasing the strength of polymer-cement concrete.

A585 Kudzis, A. P., and Valiunas, B. B., "Mechanical Properties of Polymer-Cement Keramzit [A Porous Clay Filler - Tr.] Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Studies have shown that the introduction of water-soluble polymer additives in relatively small quantities allows improvement of certain technological properties of keramzit-plus-concrete mixtures, a reduction in the consumption of cement, and also an increase in the physical and mechanical indices of the keramzit-concrete. Results are presented from studies of the influence of the addition of water-soluble resin No. 89 on the mechanical properties of keramzit-concrete used for construction.

It was found that the polymer additive resin No. 89 had a greater influence on the axial-extension tensile strength of keramzit-concrete than on its compressive strength. The introduction of the polymer additive increased the tensile strength by an average of 15 and 10 percent, respectively, for KP<sub>1</sub> and KP<sub>2</sub> keramzit-concrete. The increase in the strength R<sub>p</sub> of the polymer-cement keramzit-concrete can be explained by a decrease in the defects in the structure of the keramzit-concrete and an improvement in the bonding of keramzit gravel with the cement solution.

The experiments showed that the modulus of elasticity in compression of the polymer-cement keramzit-concrete at 28 and 100 days of age was 5 to 10 percent lower than that of type K cement. The modulus of elasticity in axial tension of the polymer-cement keramzit-concrete was slightly greater than the modulus of elasticity in compression.

A586 Kukacka, L. E., Fontana, J., et al., "Alternate Materials of Construction for Geothermal Applications," BNL-51036, Progress Report No. 18, Jan-Mar 1979, Brookhaven National Laboratory, Upton, N. Y.

A program to develop nonmetallic materials for use in geothermal processes is in progress.

The following are the highlights of the January-March 1979 activities performed under the Alternate Materials of Construction for Geothermal Applications Program.

Task 1. An RFP for work to develop sealing materials for use in drill bit seals, packers, logging equipment and blow-out preventors was advertised. Five proposals were received and one or more contracts will be awarded.

Task 1. Polymer concrete (PC) containing organosiloxane polymers has been found to be hydrothermally stable after 60 days in 25 percent brine at 300°C. The compressive strength of the composite is independent of temperature over the range 25° to 350°C. Possible applications

include protective liners and elastomeric seals. Work to extend the stability to 400°C is in progress.

Task 2. An RFP for the design and fabrication of PC pipe to be tested in direct utilization processes has been advertised. The purpose of the request is to obtain full-size sections for evaluation by potential users and to assist in establishing commercial sources of supply.

Task 3. PC containing 50 wt percent St - 35 wt percent acrylonitrile - 5 wt percent acrylamide - 10 wt percent divinyl benzene has exhibited the highest strength and greatest durability of any organic-based PC material to date. After 8 months in brine at 238°C, the strength is 204 MPa at 20°C and 162 MPa at 150°C.

Task 3. PC samples exposed for 2 yr to pH 1 HCl at 90°C have exhibited no deterioration.

Task 4. Samples and line pipe evaluated after exposure at Raft River for 18 months have exhibited no deterioration or scale accumulation. PC samples without cement as a constituent of the aggregate started to deteriorate after 90 days.

Task 4. A prototype PC-lined steam separator has been in operation at East Mesa for 30 days. No scale build-up on the walls of the vessel has been observed. Similar observations have been made for pipe in test for 408 days.

Task 5. A study on the economic impact of the use of nonmetallic materials of construction in direct utilization processes has been completed. Reductions in capital costs which translate into lower energy costs ranging from \$0.06/10<sup>6</sup> Btu to \$0.30/10<sup>6</sup> Btu were calculated. Based on the projected direct utilization applications in the Rocky Mountain area by the year 2000, these energy cost savings are equivalent to an annual savings of \$50 × 10<sup>6</sup> to \$300 × 10<sup>6</sup>.

A587 *Kukacka, L. E., et al., "Alternate Materials of Construction for Geothermal Applications," BNL-51096, Progress Report No. 19, Apr-Jun 1979, Brookhaven National Laboratory, Upton, N. Y.*

This is a program to develop nonmetallic materials for use in geothermal processes. Work accomplished during the period April-June 1979 is described in the current report.

The following are the highlights of the April-June 1979 activities under the Alternate Materials of Construction for Geothermal Applications Program.

Task 1. L'Garde, Inc. work has resulted in the development of high temperature (~260°C) elastomers for casing packer seals. The data indicate that the compounds are superior to commercially available materials. As a result, a contract has been awarded to L'Garde to assist in transferring the technology to industry.

Task 2. The technical feasibility of scale removal from polymer concrete pipe by use of cavitation techniques has been demonstrated.

Task 3. Laboratory testing of styrene-acrylonitrile-acrylamide-divinyl benzene polymer concrete indicates no deterioration after one year in 25 percent brine at 238°C.

Task 4. Visual inspection of polymer concrete pipe sections in test at the U. S. Naval Weapons Center for ~14 months indicated the pipe

to be in relatively good condition. The inside of the pipes were unattacked but the external surfaces were mildly etched from H<sub>2</sub>S.

Test cylinders exposed to 182°C brine in a steam separator at the SDG&E facility for 1379 hr did not deteriorate.

Task 5. A study to determine the potential cost impact of the use of nonmetallic materials in shallow wells utilized in direct utilization and ground water-coupled heat pump applications has been started. The work is being performed by the National Water Well Association.

A588 Kuntsevich, O. V., et al., "Properties of Concretes and Mortars Containing MMF-50 Resin," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

A study is made of the basic properties of concrete mixtures and concretes containing the water-soluble melamine-uria-formaldehyde resin MMF-50. It is desirable to introduce MMF-50 to concrete and mortar mixtures at 0.5 to 2.0 percent of the mass of the cement, as dry resin, depending on the effect required. To increase the strength and water resistance of concretes subjected to heat and moisture treatment, 0.5 to 1 percent of MMF-50 resin is added. If it is desired to produce a water-impermeable concrete from mixtures of higher plasticity, 1 to 2 percent of the resin must be added. MMF-50 resin is usually soluble in water and can be introduced to concrete mixtures together with the water for curing, with careful mixing.

The effect of plasticizing is similar to the corresponding effect achieved by introducing a superplasticizer. The resin halves the water yield. Concretes containing MMF-50 resin gain strength more slowly, but by 28 days, the strength of standard specimens and specimens containing the resin becomes equal for mixtures of equal mobility. The water resistance of the concrete is increased significantly by the addition of MMF-50 resin (for example, from V2 to V16-V18 according to State Standard GOST 4800-59).

A589 Kut'kov, A. A., et al., "Influence of Polyethylene Emulsion on the Physical and Mechanical Properties of Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

We studied the influence of polyethylene emulsion on the physical and mechanical properties of concrete used in irrigation construction. In order to determine the optimal polymer-cement ratio and an effective composition of concrete mixture, we used the mathematical-statistical method of experimental planning developed by Box and Wilson.

To determine the most effective composition of concrete mixture, we started with a composition used for the manufacture of troughs in an irrigation system. Calcium nitrate was used as a curing accelerator.

A full factor experiment was conducted. The independent variables used were: ratio of sand to total quantity of aggregate; quantity of polyethylene emulsion and calcium nitrate as a percentage of cement mass. The optimization parameter used was the compressive strength of specimens at 28 days of age. A statistical analysis was performed of the regression equation produced. Analysis of the results of the experiment indicates that the strength of the concrete increases with a decrease in the percent content of polyethylene emulsion and an increase in the quantity of curing accelerator. Several experiments were conducted in the direction of steep ascent. The optimal composition was found to be 0.04 percent polyethylene emulsion, 2.67 percent calcium nitrate, with a G:S:G ratio of 1:1.16:2.03.

The mechanical compressive strength of the concrete specimens containing 0.04 percent polyethylene emulsion increased in comparison to the strength of specimens without the additive by 30 percent, the bending strength - by 35 percent.

The curing conditions have a significant influence on the physical and mechanical properties of concrete which contains polyethylene emulsion. As a result of the studies performed, it was established that the optimum curing conditions for the concrete include holding of specimens for 12 hr at normal humidity, with subsequent heat treatment for 7 hr at 70 C.

A590 USSR Ministry of Reclamation and Water Management, Manual: For Construction of Precast Protective Linings From Furan Polymer Concrete for Hydrotechnical Structures, VTR-S-15-79, Feb 1979.

The present manual covers operations for construction of linings from precast polymer concrete (based on FA or FAM monomer) panels to protect hydrotechnical structures against bed load erosion.

These linings may not be used in potable water supply systems.

A591 Marchiukaitis, G. V., "The Application of the Theory of Brittle Fracture to the Calculation of the Strength of Concrete Treated with Polymers," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The treatment of concrete with polymers increases the strength of the bond between the cement paste and the aggregate, eliminates other defects in the concrete and thereby increases its overall strength. The degree of strength increase achieved in concrete by polymer treatment is

$$k_p = R_{pc} / R_c \quad (1)$$

Based on the theory of cracks of V. V. Panasiuk and following the investigations of A. Ie. Andreykin, V. V. Panasiuk and M. M. Stadnik, we can calculate the strength of a brittle body weakened by elliptical cracks.

This paper presents equations and theory that calculate the degree of increase in the compressive strength of the concrete resulting from

polymer treatment. The calculated results were compared with experiments performed by us and other researchers. It was found that the theoretical compressive strength exceeded the experimental strength by approximately 1.4 percent, the theoretical tensile strength was lower than the experimental tensile strength by an average of 1.5 percent (-4 percent and +15 percent).

A592 Marchiukaitis, G. V., "Influence of the Form of Full  $\sigma(\epsilon)$  Diagrams of Materials on Strength and Curvature of Bendable Reinforced Polymer-Treated Concrete Elements," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

There are at present no works available on the use of full  $\sigma(\epsilon)$  diagrams of materials to study the operation of reinforced polymer-treated concrete elements in various stages of their operation. There is also a need for more such studies on ordinary reinforced-concrete elements.

We studied the influence of the form of the  $\sigma(\epsilon)$  diagram of concrete and reinforcement on variations in the strength and curvature of reinforced polymer-treated concrete bending elements.

The analysis performed showed that the form of the  $\sigma(\epsilon)$  diagram of the concrete has some influence on the load-bearing capacity of the compressed zone, still greater influence on the curvature of the beams; the closer to the fracture stage, the greater the influence of the form of the diagram on the curvature.

A593 Ohama, Y., et al., "Effect of Coarse Aggregate on Compressive Strength of Polyester Resin Concrete," International Journal of Cement Composites, Vol 1, No. 3, 1979, pp 111-115.

Polyester resin concrete (or polymer concrete) was prepared with four coarse aggregates having different compressive strengths, and the effects of compressive strength and volume fractions of the coarse aggregates used on the compressive strength of the resin concrete were examined. Based on the results, an attempt to predict the resin concrete strength is proposed by applying the law of mixtures. Also, a nomograph for the quantities of the materials required for mix design of the resin concrete is presented.

A594 Okada, K., and Ohama, Y., "Improvements in Performance of Concrete by Use of Polymers in Japan," The International Journal of Cement Composites, Vol 1, No. 3, 1979, pp 181-190.

This state-of-the-art review deals with the present state of research and development of technology for use of polymers in cement concrete to improve its performance. The technology includes (1) partial or full substitution of its binder by polymers, (2) partial or full substitution of its aggregate by polymers, (3) polymer impregnation, and



(4) combination of (1) to (3). At present, polymer-modified concrete (mortar), resin concrete (mortar), polymer-impregnated concrete, and similar materials are produced by such technology, and are already commercially available in Japan. In particular, the paper describes the state of the technology in Japan which is under study or in practical use. Improved concrete performance results in the reduction of total cost due to the saving of concrete fabrication materials, the rationalization of concrete works and long service life.

A595 Peliksha, M. I., "Strength and Deformation on Indene-Coumarone-Acrylate Polymer Concrete at Various Ambient Temperatures," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Since approximately 1965, the Department of Reinforced Concrete Structures of the Vil'nius Institute of Construction Engineering has been studying the use of indene-coumarone-acrylate resins type IKAS and LKS for the bonding and repair of concrete, as anticorrosion coatings on concrete, and as binders in chemically stable polymer concretes.

The purpose of the present work was to determine the strength and deformation properties of the compositions IKAS-1, IKAS-3 and LKS-1 at various ambient temperatures (from -20 C to +80 C).

The studies were performed on polymer mastics based on LKS and IKAS-1 binders with the composition 1:3.6 (binder: milled diabase), IKAS-1 polymer concrete with the composition 1:3:2 (binder, milled diabase: granite gravel), as well as IKAS-3 polymer concrete with the composition 1:2:15 (binder: milled sand: river sand), i.e., the consumption of binder by mass in the mixtures studied was 22, 16.5, and 5.5 percent, respectively. The mechanical properties of the polymer mastics and concretes were determined using prism specimens measuring 4 by 4 by 16 cm, octahedrons measuring 4 by 4 by 20 cm, while the adhesive properties were measured using bonded concrete cubes 7 by 7 by 7 cm (tested in shear) and bonded concrete octahedrons 10 by 10 by 30 cm (tested in tension).

Results from the tests indicate that strength and deformation properties of the materials depend on the type of binder, composition of mixture, as well as the test temperature: the mastic based on LKS-1 binder has higher strength and lower deformation than the other binder: the mastics, in comparison to the concretes, have higher deformation capability, which is easily explained by the higher content of the viscous polymer in the mastics; increasing the test temperature causes a significant decrease in short-term strength and an increase in deformation of the specimens, while a decrease in temperature causes a moderate increase in strength and a decrease in deformation. At normal and low temperature, the specimens fracture in a brittle manner, at elevated loads - in a plastic manner, with "flow" of the specimen.

As the test temperature increases, the adhesion of the polymer mastics to the cement concrete decreases: at +40 C, failure of bonded specimens occurs partially through the adhesive joints, whereas at lower

temperatures, the failure occurs only through the concrete.

It follows from the experiments we have described that the polymer compositions IKS and IKAS should not be used as coatings in cases where the temperature periodically drops below the freezing point, or as adhesives for concrete subjected to high temperatures.

A596 *Peschke, H., and Dinitz, A. M., "Development of Performance Standards and Specifications for Polymer Concrete," Transportation Research Record N713, pp 17-19, 1979.*

Eighteen years of experience in West Germany have shown that pavement rehabilitation using polymer concretes containing reactive resins as the sole binder, especially those with methyl methacrylate-acrylics (MMA), produces a durable and highly skid-resistant road surface which, if applied early, can prevent major deterioration problems. Furthermore, the use of polymer concrete is cost effective if all factors are taken into consideration. The consistency of the fresh mortar must be such that it may be easily spread, consolidated, and screeded under the prevailing working conditions without forming voids at the contact areas or within the mortar. The pot life should be as short as possible but at the same time must be long enough to facilitate a careful application of the mortar. A very good bond is obtained by using primers that must possess a certain degree of water compatibility. The primer also prevents the binder from penetrating into the concrete substrate and the mortar from leaking. For maintaining continuously good skid resistance, the use of aggregate with different abrasion characteristics yield the best results. In order to prevent shear forces and thereby delamination along the interface of the polymer concrete overlay E-modulus, the product of the E-modulus and the coefficient of thermal expansion of the overlay should be about the same as the same product for the concrete substrate. To insure low shrinkage, it is extremely important to work with as low a binder proportion as possible. The West German Federal Highway Administration has published an instruction manual which details the cyclical freeze-thaw, pull-out flexural strength, and compressive strength tests needed to ascertain the suitability of a given polymer concrete for rehabilitating concrete roads and bridge decks. This paper appeared in the TRB Record No. 713, Culvert Corrosion, Porous Lane Marking, Membranes, Polymer Concrete and Reflectometer Evaluations.

A597 *Petrenas, I. I., "Influence of Polymer Additives on the Adhesion Properties of Mortars and Concretes," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.*

An analysis of studies in the area of adhesion showed that the bonding strength of cement paste to the surface of the aggregate, old mortar, etc., is determined by the physical and chemical condition of the surface layers, their structure, and the rheologic properties of the cement paste.

We have analyzed the influence of the addition of polymers - water-soluble resins - on the viscosity and wetting capacity of cement paste and on the phase composition, morphology and number of new formations, as well as the structure of the pore space of the cement paste.

The addition of resins changes the morphology and the number of new formations, the degree of hydration of the cement and the structure of the pore space of the cement paste.

The study of the influence of additives on the rheologic characteristics of the cement paste and solution has shown that the introduction of water-soluble resins decreases the structural viscosity of the cement paste, while increasing the wetting capacity of the surface of the aggregate.

The presence of a polymer in the area of contact with submicro-crystals of the new phase, the decrease in relative shrinkage deformations and the increase in plastic deformations of the cement-polymer paste facilitate partial relaxation of internal stresses.

The studies of the adhesion strength of cement-polymer paste showed that the introduction of resin additives in the optimal quantity increases the bond strength: with calcite - by a factor of 1.5, with quartz - by a factor of 1.2, with feldspar - by a factor of 1.5, with old mortar - by a factor of 1.6, and with concrete - by a factor of 1.5.

Thus, the introduction of resin additives improves the adhesion properties of solutions and of concretes, facilitating the formation of a more complete and tighter contact and decreasing the internal stresses at the boundary.

A598 *"Polymer/Concrete Mixture for Pipeline Protection," Soviet Invention, Patent No. USSR 635,065, Vol B, No. 36, 1979.*

The use of phosphoric acid and siloxane fluid in a mixture, also comprising triethanolamine, diethylene glycol, high molecular fractions of vat residues of polyisocyanates and mineral filler, inhibits the corrosion of metal pipes.

A599 *"Polymer Concrete Achieves Fast Structural Repair in San Francisco Airport Taxiway," AE Construction, Vol 14, No. 3, 1979.*

A repair method which achieves a permanent structural reconsolidation with a minimum of downtime is described. The key to the repairs is the injection of a fast-setting epoxy adhesive for rebonding cracks and delaminations, followed by patching of surface depressions with a rapid-curing, acrylic-based repair mortar. The adhesive injection serves to restore monolithic integrity to the crack plane, with structural bonds which exceed the compressive, flexural, and tensile properties of the concrete. Subsequent patching of spalls and potholes with acrylic mortar provides a permanent load-bearing surface approximately 1 hr after placement.

A600 *Popov, G. I., et al., "Strength, Crack Resistance and Rigidity of Bending Elements of Reinforced Polymer-Treated Concrete," Summaries of Papers of the Republican Conference, Physical and*

*Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.*

A beam 1200 mm in length, 150 mm high, and 100 mm wide was loaded with two concentric weights, spaced 140 mm from the transverse axis of symmetry of the beam. During the experiments, the deformation of the concrete was measured in the compressed and extended zones, and the bending of the structure was determined.

Beams were made of normally-cured concrete of grades M200-M500, with a density of 1600 to 2400 kg/m<sup>3</sup>, with heavy and light aggregates. The tensile zone of the elements was reinforced with type A-III and A<sub>T</sub>-VI reinforcement, without prestressing, the zone of compression, where the concentrated loads were applied, was not reinforced. The percentage of reinforcement varied from 1.6 to 8.53 percent.

Modified concrete was produced by the thermocatalytic method of curing of methyl methacrylate, initiated by porophor (0.3 percent of the weight of the monomer).

The sealing medium used was water. The amount added was 0.4 to 20.0 percent of the weight of the initial dry concrete. The strength of the concrete after treatment was 594 to 794 kgf/cm<sup>2</sup>.

The loss of load-bearing capacity of the beams was determined by the fracture of the concrete (polymer-treated concrete) in the compression zone, the nature of the fracture of the polymer-treated concrete being in general similar to the fracture of ordinary concrete of the same grade.

The elastic stage of work of the polymer-treated concrete with heavy aggregate is more highly developed than that of the untreated concrete. The total deformation of the polymer-treated concrete was greater than that of the untreated concrete.

In the compression zone, the outermost fibers, at loads of 85 to 90 percent of the fracture load, underwent elastic-plastic deformation, significantly exceeding the analogous deformations of the untreated concrete.

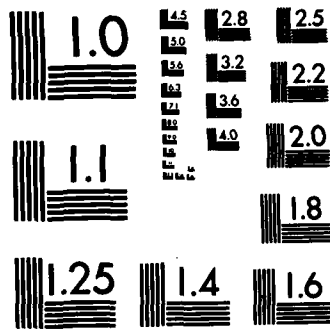
In beams of polymer-treated reinforced concrete, using the light aggregate, greater deformation was observed than in the untreated concrete.

The tests showed: for beams, treatment with a monomer increases the resistance of the zone of the concrete which is in extension to microscopic fracture; it increases the strength and the modulus of elasticity of heavy concrete.

A601 *"Protective Polymer/Concrete Coating for Metal and Concrete," Soviet Invention, Patent No. USSR 628,125, Vol B, No. 31, 1979*

Coatings, suitable for metal or concrete surfaces, containing resin, an amine hardening agent (e.g., diethylene triamine) and filler (e.g., powdered quartz), and propylene carbonate for improved adhesion.





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

A602 Schpey, R. A., "Composite Materials for Structural Design," Report No. MM-3724-80-1, Annual Technical Report No. 2, Jan-Dec 1979.

Summarized are research activities related to polymer-matrix composite materials in the areas of processing and dynamic mechanical testing, physical aging, delamination fracture characterization, temperature and moisture effects, finite element modelling of nonlinear viscoelastic materials, and neutron radiography. Also included are Abstracts of five M.S. theses and six papers describing several recently completed experimental and analytical research investigations of factors which pertain to processing, testing, and design of composite structures.

A603 Shriukshta, A.-A. L., "The Influence of Acid Corrosive Media on the Mechanical Properties of Polymer Concrete," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The purpose of the present work was to study the possibility of using polymer concrete based on indene-coumarone-acrylate resins for the construction of reservoirs to contain 2.5 percent solutions of sulfuric acid.

The experimental specimens used were prisms 4 by 4 cm in cross section and 16 cm high, made of polymer concrete of three compositions: composition A is 1 × 3 × 5.2 (LKS-1 binder × filler × granite gravel); composition B is 1 × 3 × 2.1 (LKS-1 filler × granite gravel); composition C is 1 × 3 × 5.2 (IKAS-1 binder × filler × granite gravel).

Seventy prisms were made from each composition, then placed in sealed glass vessels containing a 2.5 percent solution of sulfuric acid after 10 days of curing.

The compression testing of the prisms was performed after 15, 30, 60, 90, 180, and 360 days of storage in the corrosive medium at  $20 \pm 2$  C. The specimens were centered along their physical axis by means of four indicators on the side walls of the prisms.

The test results showed that the compressive strength of polymer concrete decreased by an average of 20 percent for all compositions, the strength reduction process being most rapid during the first 90 days. At 180 days of age, the compressive strength of polymer concrete stabilized for compositions A, B, and C at 350, 240, and 400 kgf/cm<sup>2</sup>, respectively.

The decrease in modulus of deformation of the polymer concrete of all three compositions was analogous to the change in strength. The final values of modulus of deformation, determined under loads amounting to 30 percent of the failure loads, were  $9 \cdot 10^3$ ,  $4.75 \cdot 10^3$ , and  $14 \cdot 10^3$  kgf/cm<sup>2</sup>, respectively.

The results of the studies allow us to recommend composition C, which has the best mechanical characteristics and is the least expensive, for the manufacture of reservoirs designed to contain dilute sulfuric acid solutions.

A604 Shvidko, Ia. I., "Mechanical Properties of Polymer Concretes Reinforced With Dispersed Materials," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Polymer concretes reinforced with fiber or small reinforcing elements dispersed through the volume of the concrete (reinforced polymer concretes) can be quasi-isotropic materials. Due to the heterogeneity of the structure of the dispersely reinforced polymer concretes, application of an external load causes the formation of a complex internal stress field, resulting from the differences in the physical and mechanical characteristics of the components and their interactions.

In a polymer concrete product of this type, the modulus of elasticity of the reinforcing fibers is usually several times greater than the modulus of elasticity of the polymer concrete (matrix), and they are less subject to deformation.

The dispersed reinforcement helps to increase a number of the physical and mechanical properties of the material - static and dynamic strength, crack resistance, wear resistance, etc., and in the future will apparently serve as the basis for the production of high-strength structural materials. Studies performed at the Moscow Institute of Railroad Transport Engineering have shown that dispersed reinforcement of a furan polymer concrete with separate steel fibers representing up to 1 percent of the volume of the product can increase the compressive and bending strength by factors of 1.3 and 1.8, respectively; the modulus of elasticity increases by approximately 20 percent. An increase in the endurance limit of 30 percent is also noted.

Combined studies of reinforced polymer concretes as structurally heterogeneous bodies were performed, considering the actual properties of their components, their interactions and the influence of these factors on the stress-strain state. Mathematical methods of experimental planning were used to establish the variation in strength of reinforced polymer concrete with various binders (epoxy, furan, carbamide) as a function of length and diameter of the reinforcing fibers, the content of reinforcing fibers, and the ratio of the modulus of elasticity of the fibers to that of the polymer-concrete matrix.

A605 Solomatov, V. I., et al., "Influence of Surface-Active Agents on Some Physical and Mechanical Properties of Polyester Polymer Mortars," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Mastics, polymer mortars, and polymer concretes based on polyester resins are finding increasing practical use. This results from a number of positive properties inherent in these compounds. However, in addition to the positive properties, compounds based on type PN-1 resins



also have certain shortcomings: an increase in water absorption and a decrease in water resistance, as well as greater shrinkage and other problems.

Several methods are known to improve the physical and mechanical properties of polymer materials based on PN-1 resin. One promising method, in our opinion, is the method of chemical modification of the surface of the mineral aggregate by means of surfactants.

In this work, we present the results of studies of certain properties of polymer mortars based on PN-1 resin with the addition of surfactants. The curing agents for polyester resin type PN-1 were cobalt naphthenate, 8 percent, and giperiz, 4 percent, of the mass of the resin. The aggregates used were quartz sand, milled limestone and milled coke. The resin-aggregate ratio varied from 0.10 to 0.25. The surfactants used were: cationic - alkamon OS-2, catapin K, balancer A and others; anion-active sulfanol, "progress" and others; nonionogenic - OP-4, OP-7, DB wetting agent and others.

Using the various compositions of polymer mortars, we determined: the quantity of heat liberated during curing and the maximum of the exothermic reaction; the dielectric permeability and dielectric loss angle tangent in the process of curing; the plastic-viscous properties of the polymer mortar mixtures; the kinetics of strength rise and shrinkage; the deformation properties; water absorption and water resistance; as well as the wettability and surface tension of the modified resins.

The studies showed that the anion-active surfactants decrease the maximum exothermic reaction, without changing the heat-liberation rate. The cation-active and nonionogenic surfactants increase the maximum temperature rise of the composition and the rate of rise to the maximum temperature. The increase in the rate at which the maximum temperature is reached indicates that the heat conductivity of the system is increased by a decrease in the defect density in the structure of the polymer solution.

A606 Solov'ev, G. K., et al., *"The Problem of the Influence of the Scale Factor on the Strength of Polymer-Treated Concrete Products,"* Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The theory of brittle fracture is based on the assumption that the strength of a body is determined entirely by the strength of the weakest primary element. A theory with this basis was suggested by W. Weibull, as well as Ia. I. Frenkel' and T. A. Kontorova. According to their theory, brittle fracture depends on the local stress at the point of the most dangerous defect in the structure. The larger a body is, the greater the probability of finding a primary element of low strength, and the lower the strength of the body as a whole. The variability of strength of brittle materials, like the scale factor, is a result of the statistical distribution of defects and is explained by means of the statistical theory of brittle fracture.

The paper presents equations for the transition from the results of testing of small specimens to estimation of the strength of materials in structures of full size.

A607 Sugama, T., et al., "The Effect of Tricalcium Silicate ( $C_3S$ ) on the Thermal Stability of Condensation-Type Polymer Concretes," Cement Composites, Vol 1, No. 2, Jul 1979.

A study has been performed to determine the effect of the use of tricalcium silicate ( $C_3S$ ) as an aggregate constituent on the thermal stability of polymer concretes containing condensation-type polymers such as phenol-formaldehyde, epoxy, and furan resins. The results indicate that the inclusion of  $C_3S$  in composites containing phenol-formaldehyde resin results in significant improvement in the thermal stability and physical properties. The improvements are attributed to a chemical reaction between the  $C_3S$  and the OH group in the polymer molecule. Specimens containing epoxy and furan resins did not show this effect and deteriorated rapidly in a hydrothermal environment.

A608 Taranenkov, S. K., and Khrulev, V. M., "Properties of Earth-Filled Polymer Construction Slurries," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

Earth-polymer slurries are produced using fine sand, clay, loess-like loam, with water-soluble phenol-formaldehyde and carbamide resins used as the binder. The phenol-formaldehyde resins recommended as binders include TSD-9 shale-phenol resin (TU 38-9-G-24-68). This resin contains 48 to 50 percent dry matter, is soluble in water, has a viscosity of 20 to 30 s as tested by the VZ-4 viscosimeter, and a pH of 8 to 9. The fillers used include loess soil with 20 to 30 percent carbonates.

When this soil is used, it is necessary that the curing agents not be acid. Therefore, 37 percent formalin is used as the curing agent. The loess is used at 40 to 50 percent of the mass of the resin. The compressive strength of specimens cured in air for 90 days is 16 MPa, after curing in water - 12 MPa. The material produced has high resistance to the effects of sulfate media.

The following composition is recommended for industrial use (mass parts): TSD-9 resin - 100; formalin - 30 to 40; water - 40 to 70; loess - 100 to 130. Depending on the content of loess, the viscosity of the composition may vary from 200 to 170 cp. Compositions can be effectively used for stabilization of sagging soils beneath the foundations of structures, as anticorrosion coatings for the protection of concrete structures from the corrosive effects of ground water, and as a packing material. Furthermore, when piles are placed in loess-loam and the polymer solution is simultaneously poured into the hole, a polymer lubricant, "jacket" is formed, significantly facilitating the driving of the pile; then, after the polymer cures, it aids in holding the pile in the ground.

Good results, in terms of strength, water resistance, and chemical stability of the earth-polymer slurries, can be gained by using carbamide polymers. Of the existing types of these polymers, the most suitable for the production of mortars is hardened K (MRTU-6-14-63-68), a polyvinyl alcohol-modified product of the condensation of urea and formaldehyde. Its advantages include its low content of free formaldehyde (0.5 percent), low initial viscosity (15 to 30 s in the VZ-4 viscosimeter) and its solubility in water in all proportions. In order to decrease the viscosity of the binder and the consumption of the hardener, mixtures of hardener K and standardized carbamide resin type UKS are used. In particular, this combined binder is used to manufacture earth-polymer slurries of fine-grained dusty-clay sand with a content 0.05 to 0.25 mm fraction of about 90 percent.

The compressive strength of the mortar after it has cured is 9.8 MPa for air curing, 5.2 MPa following curing in water. If the carbonaceous rock is neutralized by preliminary treatment with acid (hydrochloric acid solution), the compressive strength increases to 13 MPa. The curing agent used with the binder is a mixture of hydrochloric and oxalic acids. The materials produced can be used to protect underground structures from water seepage, to stabilize banks and foundations.

A609 Tolbert, R. N., and Hackett, R. M., "Viscoelastic Properties of Epoxy Polymer Concrete," Polymer Engineering Science, Vol 19, No. 11, Aug 1979, pp 795-799.

In the reported experiments, the viscoelastic nature of polymer concrete was investigated utilizing an epichlorohydrin/bisphenol A-type epoxy resin-aggregate system. Compression specimens were tested for linearity of viscoelastic behavior, the effect of size of mass on creep, and for determination of the specific creep compliance and the associated elastic modulus. The creep compliance was determined by least squares curve fitting of the experimental creep data. Collocation, a numerical Laplace transform inversion routine was used to develop the equation for the relaxation modulus.

A610 Vaitkiavichius, A. I., et al., "Study of the Physical and Mechanical Properties of Centrifuged Concrete Elements Modified with Monomers," Summaries of Papers of the Republican Conference, Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed.; Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

The purpose of the present work was to develop and improve a technology for the manufacture of polymer concrete centrifuged pipe, and also to study its physical and mechanical properties.

Concrete elements 500 mm in length, with inside diameter 150 mm and wall thickness 30 mm, manufactured in special forms on an axial centrifuge, were modified with monomers. After heat treatment in a laboratory steam chamber (preliminary holding 2 hr, temperature rise to 80 C in 2 hr, isothermal heating for 8 hr and cooling for 2 hr), the

elements were dried to constant weight at 80 to 95 C over the course of 2 days. The dried specimens were placed in a special thermocatalytic installation, in which they were vacuum treated at a pressure of 10 to 30 mmHg for 1 hr, then treated with styrene for 6 hr at a gauge pressure of 2 atm., created by nitrogen. The monomer was polymerized at 120 C for 24 hr. The polymerization initiator used was benzoyl peroxide, at 0.4 percent of the mass of the monomer.

The results of mechanical testing (compressive strength along the generatrix) of the modified centrifuged elements are presented in this report.

The results show that with a comparatively low degree of saturation (up to 3 percent of the mass of the concrete), a significant increase is achieved in the strength of a centrifuged element.

The greatest strengthening effect is achieved by modification of concrete elements using a minimal quantity of dispersed steel reinforcement (0.5 percent by volume).

A611 Werner, O. R., et al., "Concrete Repair and Maintenance," Water Systems Management Workshop, 1979.

Epoxy-bonded concrete. - When situations prohibit long wet-curing periods or when adequate wet-curing cannot be assured, chemical bonding agents may be used. Epoxy-bonding agents are the most widely used materials for such purposes.

Although epoxies and epoxy mortars are relatively expensive and hard to work with, they may be a logical choice because of their excellent resistance to freezing and thawing deterioration because of the rapid completion of repairs that is possible, resulting in early use of a structure, and because concrete bonded with epoxy will develop adequate bond strength when cured in the same manner as normal structural concrete, that is, with membrane-curing compounds or by other covering and sealing methods.

Epoxy adhesives called binders may also be used to produce complete repairs without use of portland cement or conventional concrete. Mortars may be manufactured from the binders and clean, dry sand. These mortars are particularly useful in patching spalls or cracks. Such repairs may be featheredged and cured quickly, especially when applied to warm surfaces and/or heated after application. Numerous kinds of repairs are possible with epoxy mortars. For instance, they are frequently used around the periphery of epoxy-bonded concrete to permit featheredging, instead of requiring additional excavation of old concrete.

A612 Zeldin, A., et al., "Organosiloxane Polymer Concrete for Geothermal Environments," Report No. CONF-790219-4, 1979, Brookhaven National Laboratory, Upton, N. Y.

The feasibility of using the products of free-radical copolymerization of modified organosiloxane in the formation of a thermally stable and chemically resistant polymer concrete for use in geothermal environments has been demonstrated. Specimens have been produced using mixtures of organosiloxane containing pendant vinyl groups and styrene

or different silicon fluids as a comonomer in conjunction with a free-radical initiator and several aggregate materials. The use of these monomers in conjunction with materials such as SiO<sub>2</sub> and portland cement to form polymer concrete results in composites with high compressive strength (80 to 100 MPa) and thermal and hydrolytic stability. The results from studies to determine the effect of variables such as particle size, type of cement, and sand-cement ratio are discussed.

A612(1) Hsu, H.-T., Fowler, D. W., Miller, M., and Paul, D. R., "An Investigation of the use of Polymer-Concrete Overlays for Bridge Decks," CFHR-3-9-71-114-7, Mar 1979, Center for Highway Research, Texas University at Austin, Austin, Tex.

An investigation was made to determine the feasibility of using a polymer-concrete(PC) overlay to improve the durability of a bridge by sealing the concrete against water penetration. The overlay consisted of a thin (approximately 0.5-in.) layer of polymer and aggregate. Fine aggregate was placed to a depth of 1/4 in., and 3/8-in.-maximum-size aggregate was placed and rolled into the sand. Two monomer applications were made. Durability tests, which included freeze-thaw cycling, water tightness, sandblast abrasion, and skid resistance testing, were performed on both treated and untreated slabs. The 24-hour water tightness test showed that the PC overlay could completely seal the concrete against water penetration, while the control specimens had about 2 in. to 2.5 in. (51 mm to 64 mm) of water penetration. The PC overlay proved to be more resistant than the control when subjected to the sandblast abrasion, especially after freeze-thaw cycling. Because the surfaces were sealed against water penetration, the PC overlay specimens showed a greater freeze-thaw durability than the controls, by a factor of at least two. Also, the PC overlay showed a better skid resistance than the control.

A613 Zeldin, A., et al., "Polymer Systems in Geothermal Applications," Journal of Applied Polymer Science, Vol 23, No. 11, Jun 1979, pp 3179-3191.

The feasibility of using a copolymer composed of styrene, acrylonitrile, and acrylamide or methacrylamide in the formation of a high-strength thermally and chemically stable polymer concrete for use in geothermal environments has been demonstrated. Specimens produced with the copolymer in conjunction with an aggregate containing sand and portland cement had compressive strengths in the range of 25,000 to 30,000 psi at 20 °C and were thermally stable up to ~240 °C. A study of the effect of monomer concentration on the properties of the polymer concrete indicated that the optimum concentration is in the range of 12 to 13 wt percent. Increased monomer concentrations lead to a nonuniform polymer distribution within the composite, resulting in a deterioration of the properties. The optimum properties are obtained when the monomer is used in conjunction with an aggregate containing 70 to 80 wt. percent silica sand and 20 to 30 wt. percent portland cement. The results from laboratory and field evaluations in

progress indicate that the materials can be used for pipe or as protective liners on pipe and vessels in electric generating and direct utilization geothermal processes.

- A614 Zeldin, A., et al., "Influence of the Ratio of Styrene and Acrylonitrile in Crosslinked Polymeric Binders for Use in High-Temperature Polymer Concrete Composites," Journal of Applied Polymer Science, Vol 24, No. 7, 1 Oct 1979, pp 1759-1765.

The feasibility of using a monomer composition based on a styrene-acrylonitrile copolymer as a binder in high-strength and chemically resistant polymer concrete was demonstrated earlier. From this work it is clear that properties of the polymer concrete composite are dependent on the styrene/acrylonitrile ratio. This paper deals with the study of the effect of the styrene/acrylonitrile ratio in styrene-acrylonitrile-acrylamide-trimethylolpropane trimethacrylate monomer formulations on the thermomechanical properties of polymer concrete composites.

- A615 Zeldin, A., Fontana, J., Kukacka, L. E., and Carciello, N., "High Temperature Polymer Concretes from Organosiloxane Resins," The International Journal of Cement Composites, Vol 1, No. 1, May 1979.

The feasibility of using the products of free-radical copolymerization of organosiloxanes in the formation of polymer concrete that is thermally and chemically stable in hydrothermal environments has been demonstrated. The use of organosiloxanes containing pendant organic groups in polymer concretes results in a composite with high compressive strength and thermal and hydrolytic stability. The effects of monomer and initiator concentrations and aggregate composition have been studied and the results are discussed.

- A615(1) Luttinger, M., Kistler, C. W., Grotta, H. M., and Sinclair, R. G., "Polymer Research in Rapid Runway Repair Materials," Battelle Columbus Labs, Ohio, Nov 1979.

Low viscosity, two-component epoxy resins were formulated for airless spray application over quartz or dolomite aggregates. The formulation selected for full evaluation was based on mercaptan curing systems. Trifunctional acrylate monomers were used in some formulations as modifiers. The resulting polymer concrete set up within 3 to 4 minutes after mixing at temperatures around 73 degrees F. Good cures within 1/2 hour of mixing can be obtained in wet environments down to 5 degrees C and in dry environments down to -25 degrees C. Good adhesion to wet aggregates requires the use of coupling agents, organofunctional silanes being preferred. Good bonding to asphalt and Portland cement concrete and good wear characteristics were demonstrated. Flexural strength properties are satisfactory after cool down both under dry and wet application conditions. While the polymer concrete is hot due to the exotherm of the curing reaction, flexural strength properties are low.

- A616 Fantalov, A. M., and Paturoev, V. V., "Highly Mechanized Production of Polymer Concrete Structures;" Translated from Russian by Water Power and Resources Service, Denver, Colo., 1980.

The possibility of producing polymer concrete with a homogeneous structure and constant physical and mechanical properties, and the cyclical nature or continuity of the production process (a situation determined by the size of the articles being fabricated and by the type of binder used) are features of the production procedure which was developed. Vibratory compaction, heat treatment of the castings and application of a protective coating are performed on a standard moving conveyor. The castings are heat-treated in special PAP furnaces following an accelerated schedule. The given production method is distinct in its universality; it is possible to fabricate articles with continuous, ribbed, and modular configurations and various dimensions from heavy polymer concrete or from light (with a keramzite or agloporite aggregate) polymer concrete.

This particular design is being applied in the construction of four highly mechanized plants for different branches of industry.

- A617 Ibragimov, M. N., "Prevention of Water Seepage Through Concrete with Polymer Mortar Grout;" Translated from Russian by WPRS Translations, Denver, Colo., May 1980.

An effective method for sealing slightly pervious concrete with aqueous solutions of carbamide resins has been developed and this method has been adopted in repair operations as a means of resinification. In essence, the method consists in injecting a gel-forming carbamide resin grout into the defective concrete through boreholes drilled into it or with the use of a special pressure plate. Oxalic acid, which will not corrode the unprotected steel reinforcement or the concrete, serves as the hardener for the carbamide resin. The hardening time of the resin is controlled, as a function of its concentration and the amount of acid added, from several minutes to 2 to 3 hr. The gel-forming grout is distinguished by low viscosity and it penetrates easily into fine cracks and voids. As a result of the resin impregnation, the defective concrete becomes impervious; its freeze-thaw durability and, accordingly, its service life are increased.

The compositions of systems recommended for grouting of concrete with different types of water seepage are given and applications in hydrotechnical and underground construction practice are described.

- A618 "Instructions for the Design and Manufacture of Reinforced Polymer Concrete Tanks," Russian Ministry of Nonferrous Metallurgy, Moscow, 1979; WPRS Translations, Denver, Colo., May 1980.

These instructions are intended for the analysis and design of various polymer concrete tanks used in the nonferrous metallurgy industry that are exposed to highly corrosive media. The polymer concrete is a

non-portland cement concrete of dense structure containing furfural acetone monomer (FAM) thermosetting resin and dense acid-resistant aggregates and microfillers.

In conformity to design and structural specifications, these polymer concrete structures also contain steel or fiberglass-reinforced plastic reinforcement, usually prestressed.

The principal requirement placed on the tank structures is long-term impermeability. Therefore, crack formation estimates are vital for these structures.

The limitations of the mechanized plant equipment must be considered in the design of the elements used in these precast and precast-monolithic structures. In precast structures, particular attention should be given to the strength, durability and impermeability of the connections, junctions and joints.

A619 Ironman, R., "Big Swing to Resin Concrete," Concrete Products, Vol 83, No. 4, Apr 1980.

Local authorities in Germany are now specifying resin concrete for all new water and sewage treatment plants. There are now seven factories in Western Germany engaged solely in the continuous production of resin concrete elements. These mass-production plants employ "carousel" turntables to feed molds to the casting machine at maximum speed with minimum handling. One plant, for example, uses the technique to produce facade panels at the rate of one every 30 sec. Another plant manufactures a complicated drainage-sump unit in only 5 min, including mold filling, curing, stripping and mold-repreparation times.

A recent development, patent pending, is a "sandwich" concrete pipe with a resin-concrete lining reinforced with glass fibers.

Resin concrete is considerably cheaper than the use of stainless steel, coated steelplate, aluminum, or asbestos-cement. In addition to municipal and industrial water-treatment installations, resin concrete products are also proving to be a major sales item for restaurants, slaughter houses, food-preparation plants, high-density apartment blocks, schools, and service stations where oil and grease separation is essential.

A620 Sugama, T., et al., "The Effects of  $\beta$ -C<sub>2</sub>S/Class H Cement Mixed Fillers on the Kinetics and Mechanical Properties of Polymer Concretes," Cement and Concrete Research, Vol 10, No. 3, May 1980, pp 413-424.

The effects of the inclusion of a hydraulic cement-type filler prepared with a beta dicalcium silicate ( $\beta$ -C<sub>2</sub>S) to Class H cement ratio of 1:1 on the hydrothermal stability of polymer concrete (PC) containing vinyl-type polymers having carboxylate groups in their molecules was evaluated. Studies were made of the mechanical properties, fracture energy, and kinetics of the cement-filled composites before and after exposure to a 25 percent simulated geothermal brine at 240°C. Excellent physical properties of the PC, developed by the appearance of a Ca-copolymer complex structure and hydration products formed during



exposure to hot brine, were obtained. The results indicated 103.9 MPa compressive strength, 7.3 MPa tensile strength, 6.0 MPa shear bond strength,  $4.40 \times 10^4$  MPa modulus of elasticity, and  $3.15 \times 10^3$  erg/cm<sup>2</sup> fracture energy. In addition, the activation energy for the thermal decomposition of the Ca-copolymer complex was calculated using an Arrhenius plot method to be 44.0 kcal/mole.

A621 Fowler, D. W., Paul, D. R., and McCullough, B. F., "Methyl Methacrylate Polymer-Concrete for Bomb Damage Repair, Phase I," Contract FO8635-79-C-0103, June 1980, Texas University at Austin, Austin, Tex.

Methyl methacrylate (MMA) polymer concrete appears to be a material which can be successfully used to rapidly repair bomb damaged runways. A research program is underway to develop monomer formulations, determine engineering design properties, develop repair procedures, conduct field tests, conduct analytical studies, and develop an implementation plan. Research in Phase I has emphasized materials characterization, development of preliminary repair procedures, and analytical and experimental behavior of repairs. Materials characterization studies have determined monomer formulations and polymer-concrete mechanical properties for a wide range of ambient temperatures. Possible solutions for reducing adverse effects on strength of polymer-concrete made with wet aggregate have been studied. The effect of MMA on bond to asphalt has been determined. The effect of aggregate size on mechanical properties has been investigated.

#### 1981

A622 Fontana, J., "Recommended Practices for the Use of Polymer Concrete," BNL-29351, May 1981, Brookhaven National Laboratory, Upton, N. Y.

An introduction to polymer concretes is given. Instructions for using polymer concrete patching materials and overlays are presented along with information on precast polymer concrete. (ERA citation 06:020526)

A623 Kukacka, L. E., "Concrete-Polymer Composites: Current Status and Future Research Needs," BNL-29501, Apr 1981, Brookhaven National Laboratory, Upton, N. Y.

When plastics are combined with mixtures of inorganic materials, high-strength, durable, fast-setting composites are produced. These materials are used in structural engineering and other applications, and as a result of the successes obtained to date, considerable research and development work is in progress throughout the world. One family of polymer-based composites receiving considerable attention is the concrete-polymer materials. Work in this area is directed toward developing new high-strength durable materials by combining cement and concrete technology with that of polymer chemistry. In addition to the significant property enhancement, many combinations of siliceous

materials with polymers require lower energy inputs per unit of performance than either component alone. (ERA citation 06:023939)

A624 Sugama, T., Kukacka, L. E., and Horn, W., "Water-Compatible Polymer Concrete Materials for Use in Rapid Repair Systems for Airport Runways," BNL-51390, Mar 1981, Brookhaven National Laboratory, Upton, N. Y.

Water-compatible polymer concrete (PC) formulations have been developed which appear to have potential for use in all-weather rapid repair procedures for bomb-damaged runways. Formulations consisting of furfuryl alcohol, water-saturated aggregate, dry silica flour, promoters, and catalysts produced composites with properties suitable for repair purposes when mixed and polymerized at temperatures from -20 to 30 C. Calcium-unsaturated polyester complexed PC also produced excellent properties. However, the early strength criteria, (200 psi (13.78 MPa) at 1 hr) and other requirements such as compatibility of the formulation with water and practical working times could be attained only at temperatures >20 deg C. This system can be polymerized under water. Studies of the polymerization reaction mechanisms, materials properties, costs, and potential placement methods were performed.

SECTION B  
POLYMER-IMPREGNATED CONCRETE

1967

- B1 Kukacka, L. E., Steinberg, M., and Manowitz, B., "Preliminary Cost Estimate for the Radiation-Induced Plastic Impregnation of Concrete," BNL-11263, Apr 1967, Brookhaven National Laboratory, Upton, N.Y.,

Results of investigations are reported which are devoted to production of plastic impregnated concrete by gamma-radiation-initiated polymerization of monomers in the aggregate. Emphasis was placed on economic aspects of such processes. It was found that impregnation and irradiation costs vary between 8 and 22¢/ft of total treated surface or between \$1.79 and \$4.60 per concrete section treated. Monomer and labor charges are the major fraction of the total. Labor makes up 40 percent of the cost and 1/8 in. penetration and 16 percent for full penetration.

Relatively low unit Co<sup>60</sup> cost requirements when compared with other costs are found. The cost estimate indicates relatively reasonable costs for improving the properties of concrete pipe. There appears to be sufficient incentive to continue further investigation and development of the radiation-induced plastic impregnation of concrete. In addition, it is suggested that conventional plastic impregnation be evaluated concurrently with the radiation-induced study.

- B2 Murata, J., and Kobayashi, K., "Durability and Watertightness of Concrete Impregnated with Epoxy Resins," RILEM Symposium, Synthetic Resins in Building Construction, Paris, Vol. 2, 4-6 September 1967.

This paper describes the great effectiveness of protective coatings for concrete consisting of epoxy resin when preceded by impregnation of the concrete surface with epoxy. From the results of hydrostatic pressure tests, immersion tests in inorganic acid solutions, and freezing and thawing tests, the following conclusions are obtained.

1. Treated concrete is capable of with standing the penetration of water even under pressures up to 250 kg/cm<sup>2</sup>.
2. Treated concrete shows hardly any corrosion from long-term immersion in 5 percent solutions of nitric acid and sulfuric acid.
3. Non-air-entrained concrete, if treated by this method, remains perfectly undamaged when subjected to repeated cycles of freezing and thawing.

1969

- B3 Dikeou, J. T., Kukacka, L. E., Backstrom, J. E., and Steinberg, M., "Polymer Concrete a Potential New Construction Material," Reprint of paper presented at 65th Annual ACI Convention, Chicago, Ill., 4 April 1969.

The impregnation of concrete with monomer followed by curing of the monomer with radiation originated with a suggestion by the Bureau of

Reclamation (USBR) of the U. S. Department of the Interior to the Division of Isotopes Development (DID) of the U. S. Atomic Energy Commission (US AEC) in 1965. The idea was transmitted to the Brookhaven National Laboratory (BNL) by the USBR and US AEC, and in late 1965 and early 1966 exploratory experiments were carried out at BNL. Mortar bar specimens were impregnated with several gaseous and liquid-phase monomers and polymerized in situ with cobalt 60 gamma radiation. It was found that complete penetration through the cross section of 1- by 1-inch (nominal 2.5- by 2.5-cm) bars could be obtained with a maximum weight increase due to polymer of up to 6.6 percent. The USBR measured some of the properties of these initial mortar bars impregnated with polymethyl methacrylate (PMMA) and polystyrene (PS). The main findings were (1) the compressive strength was increased by a factor of 2 to 2.4, (2) the absorption was decreased 80 to 98 percent, and (3) the impact hardness as measured by the "L" hammer increased by a factor of 1.4 to 1.9.

Another large-scale application was thought to be in concrete pipe. A preliminary cost estimate including a conceptual design of a plant to produce an unreinforced polymer concrete drainpipe was prepared by BNL. This analysis indicated that polymer concrete might possibly compete with protectively coated concrete and glazed pipe. As a result, a joint program was established between the USBR and BNL supported by the US AEC, USBR, and the U.S. Department of the Interior's Office of Saline Water (OSW). The long range objectives of the joint program are the investigation and development of a polymer concrete for application as a new and improved material of construction. The program includes the development of techniques for the preparation of the polymer concrete, the measurement of pertinent physical and chemical properties, the preparation of full-scale concrete products and the conceptual design and evaluation of various specific applications. Generally, the USBR fabricates the concrete test specimens and determines their physical and chemical properties; while BNL investigates the preparation techniques, impregnates and polymerizes the concrete test specimens, and develops conceptual process designs for production of polymer concrete products. A basic research effort is maintained at both laboratories to help understand the fundamental nature of polymer-concrete composites. Included in the program are treatments by thermal-catalytic means in addition to radiation polymerization before or after the concrete has hardened. A topical report covering all work conducted through June 1968 has recently been issued. This paper presents all of the essential information contained in the topical report.

*B4 Dikeou, J. T., "Development and Use of Polymers in Concrete," 1969, United States Department of the Interior, Engineering and Research Center, Bureau of Reclamation, Denver, Colo.*

Polymers in concrete include the following three general types of materials: polymer-impregnated concrete (PIC - precast portland cement concrete impregnated with monomer which is subsequently polymerized in situ); polymer-cement concrete (PCC - monomer is added during mixing of portland cement, water, and aggregate, followed by polymerization); and polymer-concrete (PC - a composite formed by polymerizing a monomer and

aggregate mixture). Major United States Government sponsorship of research on polymers in concrete was initiated in 1966 as a joint effort between the Bureau of Reclamation and the Atomic Energy Commission's Brookhaven National Laboratory. Prior to this, research on PCC and PC had been underway on a relatively small scale for a number of years. Studies dealing with monomer-polymer composite evaluation, process technology, applications development, and economic evaluation are described. To date, the most successful of these materials is PIC. Compared to conventional concrete, PIC shows impressive improvements in strength and durability. A number of Government agencies, industrial institutions, universities, and foreign firms are now involved in this research. Applications being studied include tunnel support-lining systems, bridge decking, piping, saline water distillation vessels, marine structures, mine supports, and building panels and beams.

B5 *Kukacka, L. E., Colombo, P., Steinberg, M., and Manowitz, B., "Concrete Polymer Composites for Underwater Applications," Civil Engineering in the Oceans II, pp 969-996, Dec 1969, Miami Beach, Fla.*

The work to date has indicated that remarkable improvements in the structural and durability properties of concrete can be obtained by monomer impregnation and in situ polymerization by either radiation or thermal-catalytic means.

The results generally indicate that the compressive and tensile strengths and the modulus of rupture are markedly increased by polymer loading. Concrete impregnation with a methyl methacrylate +10 percent TMPTMA mixture has given the greatest improvement in compressive and tensile strengths. Compared with a compressive strength of 5270 psi for the control, a strength of 22,490 psi was obtained for a sample containing 6.3 percent polymer. This corresponds to an improvement of 327 percent. An increase in tensile strength of 310 percent was also obtained.

In general, methyl methacrylate-impregnated specimens have given the greatest improvement in durability properties. No failures have occurred after exposure of >1 yr to sulfate brines and 15 percent hydrochloric acid. Exposure to 5120 cycles of freezing and thawing has resulted in essentially no attack. Acrylonitrile-impregnated specimens have given the smallest improvement in durability properties of the monomers tested. The degree of improvement appears to be a function of polymer content rather than of the method of initiating the polymerization.

Pull-out bar tests made on concrete-polymer containing steel reinforcing rods indicate bond strengths up to 700 psi, an improvement of 194 percent over that for the control. If reproducible, this could have a significant effect on the design of reinforced concrete structures by reducing the amount of steel required.

A number of potential applications for concrete-polymer are being evaluated in cooperative programs with several governmental agencies. The applications include corrosion resistant concrete for desalination plants, beams and wall panels in housing, underwater structures, bridge decks, roads, and protective barricades. The evaluation

of concrete-polymer preparation techniques, to investigate the use of additional monomers, and to study effects on properties of different types of concretes. Experimental programs are also under way at a number of governmental agencies on applications of specific interest.

- B6 *Manowitz, B., Steinberg, M., Kukacka, L., and Colombo, P., "Development of Concrete-Polymer Materials," BNL-13732, p 18, Jun 1969, Brookhaven National Laboratory, Upton, N. Y.*

Results of research indicate that preformed mortar and concrete can be fully impregnated with monomer and polymerized by either radiation or thermal-catalytic techniques. The polymer concrete formed has been found to have substantially improved structural and durability properties compared with those of conventional concrete. The improvement in properties appears to be a function of polymer loading. Maximum increases in strength up to almost four times the control specimen have been obtained. Thermally treated concrete polymer shows an approximate 7 to 15 percent lower strength value than the radiation-treated material but still much greater than that of control concrete. Remarkable improvements in durability properties have been obtained with all of the monomer systems tested. Methyl methacrylate appears to give the greatest improvement, acrylonitrile the least. Composites with compressive strengths  $>1330 \text{ kgf/cm}^2$  at a temperature of  $143^\circ\text{C}$  have been attained using a 60 percent styrene + 40 percent trimethylpropane trimethylmethacrylate solution. The high strength and anticipated resistance to brine and distilled water make this system a promising candidate for flash distillation units in water desalination plants. The impregnation of fiber reinforced concrete greatly improves the flexural strength. (auth)

#### 1970

- B7 *Auskern, A., "The Compressive Strength of Polymer Impregnated Lightweight Concrete," March 1970, Radiation Processing Section, Brookahven National Laboratory, Upton, N. Y.*

The strength of polymer-filled lightweight concretes can be seriously underestimated by using a simple porous solid model. This was the case for perlite concretes. However, for both foamed glass and Mearlcrete concretes the agreement between prediction and experiment is not too bad.

The reason for the serious discrepancy with perlite concretes may be that there is a perlite-polymer interaction resulting in a strong aggregate, and a system to which the simple porous solid model no longer applies.

- B8 *Berkimer, D. L., and Lott, J., Polymerized Lightweight Structural Elements, Construction Materials Branch, Department of the Army, Champaign; Presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, 28-29 Oct 1970.*

Results of flexural strength tests will be correlated with variations of strength and density of the polymerized foamed concrete with depth. Partial impregnation techniques will be presented, and effects of fabrication techniques on engineering properties of the "stress-skins" will be reviewed.

A foamed concrete panel with monomer impregnation and polymerization of the surface-region cement voids provides a prime example of a multi-functional structural element. The partial impregnation and polymerization of this lightweight concrete results in a "stress-skin" light weight building panel. The polymerized concrete near the surface resists flexural loads, and provides an impermeable layer resisting moisture with the environment. The foamed concrete innercore resists shearing and compressive forces, provides separation for the flexural-loaded "stress-skins", and provides sound and thermal insulation.

B9 Hills, P. R., and McGahan, D. J., "The Radiation Polymerisation of Impregnated Porous Materials;" Presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, 28-29 Oct 1970.

Recent work in the United Kingdom has encouraged the use of timber containing radiation polymerised resins (wood-plastic composites), and the present commercial production and utilization of these materials is described. The advantages and applicability of the radiation process are compared with alternative methods of composite formation.

Composite materials based on other porous substrates such as insulation and fibreboard and different types of concrete have also been prepared. The improved properties of these materials are illustrated and their relevance to the production of new constructional materials is evaluated.

B10 Pierlas, R., "Development of Radiation in the Building Industry, Conservatome, Courbevois;" Presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, 28-29 Oct 1970.

In the course of its work in promoting ionizing radiations, Conservatome - a branch of Saint-Gobain Techniques Nouvelles, has paid attention to the construction field, which constitutes a special sphere of activity for the Saing-Gobain/Point-a-Mousson group.

Two groups of applications can be distinguished:

1. The first consists of efforts to improve the characteristics of existing materials, particularly their mechanical properties.

This may be done either by impregnation in depth with monomers, followed by radiochemical polymerization (procedures leading to new materials such as wood plastic or resin-impregnated concrete) or by a mass cross-linking for certain plastics (polyethylene, PVC).

2. Finally, new colours can be developed for vitreous materials, so that with glass pastes, for example, it is possible to reduce the number of basic tints.

The main aim of the second group of applications is to give the



materials additional protection against external attack, particularly by atmospheric agencies.

By the use of low-energy electron accelerators (0.3 -0.6 keV) it is possible to graft certain monomers onto unsaturated polymers in the cold state.

In developing this technique, Conservatome has made an original contribution by studying a device which makes it possible to avoid the polymerization-inhibiting effect of atmospheric oxygen.

Estimates of the cost of these techniques are supplied for the two following applications:

1. Concrete piping impregnated with methyl methacrylate;
2. coal-coating.

*B11 Steinberg, M., and Colombo, P., "Preliminary Survey of Polymer-Impregnated Stone," BNL-50255, Sep 1970, Brookhaven National Laboratory, Upton, N. Y.*

A preliminary survey was performed to investigate the impregnation of a relatively weak porous Oregon volcanic tuff and a relatively strong dense sandstone with five different monomers: methyl methacrylate, chlorostyrene, 40 percent TMPTMA-60 percent styrene, 40 percent TMPTNA-60 percent chlorostyrene, and 60 percent polyester-40 percent styrene. Impregnation was performed by pressurizing stone specimens from one end and by a vacuum-soak operation. *In situ* polymerization was accomplished by both radiation and chemical initiation techniques. The effect of varying degrees of water saturation on the impregnation and properties of the polymer-impregnated stone was determined. The compressive strength of dry porous volcanic tuff can be increased by factors of at least 2 to as much as 5 over that of the unimpregnated control, depending on the monomer used and the weight loading. A maximum compressive strength value of 19,740 psi compared with a control value of 4,390 psi was obtained for dried tuff stone impregnated with 23.6 wt percent loading of 60 percent polyester-40 percent styrene by the vacuum-soak technique and *in situ* polymerization by radiation. For the more dense sandstone a maximum value of 28,780 psi, compared with a control value of 13,980 psi, was obtained for a 3.8 wt percent loading of chlorostyrene and polymerized by radiation. Radiation gave slightly better strength values than chemical initiation. The modulus of elasticity increased by factors of 2 to 3.5. Pressurization from one end gave lower weight loadings; however, strength increases were still higher by a factor of 5 than those for unimpregnated controls. Water saturation of the stone strongly reduced the ability of the monomer to impregnate the stone and displace the water. Water contents at 25 percent of maximum saturation markedly reduced the compressive strength of polymer-impregnated stone. Saturation beyond 25 percent and up to 100 percent had little further effect on the strength of polymer-impregnated stone. The 60 percent polyester-40 percent styrene gave a maximum improvement in strength of a factor of 2 for 25 percent to 100 percent water-saturated tuff stone.

B12 Steinberg, M., "The Preparation, Properties and Potential Applications of Concrete-Polymer Materials;" Presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, 28-29 Oct 1970.

Preformed mortar and concrete can be fully impregnated with monomer and polymerized in-situ by either gamma radiation or thermal-catalytic techniques. The concrete-polymer has been found to have substantially improved structural and durability properties compared with those of conventional concrete. The improvement in properties appears to be a function of the polymer loading. Maximum increases in strength are obtained by forming and curing the concrete, subsequent drying, evacuating, soaking the concrete in monomer, and initiating polymerization in-situ by Co<sup>60</sup> gamma radiation. Strength increases of up to four times the control specimens have been obtained. Water permeability, water absorption, and chemical attack by distilled water, sulfate brines, and hydrochloric acid have been reduced to negligible values compared with severe attack observed on the control specimens. The thermoplastic monomers, methylmethacrylate, styrene and chlorostyrene are of value for normal temperature applications. Crosslinked and thermosetting monomers such as 40 percent styrene -40 percent trimethylpropane trimethacrylate, diallyl phthalate, polyester-styrene, and epoxy-styrene impregnated in concrete allow the maintenance of strength and durability properties up to temperatures in the order of 150°C. Radiation treated concrete-polymer results in strength properties that are from 12 to 38 percent higher than thermal catalytically treated material. There appears to be little difference between the effect of radiation and thermally treated concrete-polymer on the durability properties except that which can be attributed to polymer loading. Polymer impregnated concrete containing light weight aggregate such as expanded volcanic ash is increased in compressive strength by more than a factor of 10. Concrete-polymer is being considered for construction of corrosion resistant sewer pipe, drain pipe, building block, underwater structures, large multi-stage flash distillation vessels, highway applications, and underground support systems. A preliminary comparison between concrete-polymer and other materials of construction indicate reasonable economic potential for certain applications.

B13 Steinberg, M., Kukacka, L. E., Colombo, P., and Nanowitz, B., "Preparation and Characteristics of Concrete-Polymer Composites," BNL-14350, p 27, Jan 1970, Brookhaven National Laboratory, Upton, N. Y.

Preformed mortar and concrete can be fully impregnated with monomer and polymerized in situ by either radiation or thermalcatalytic techniques. The concrete-polymer has been found to have substantially improved structural properties and durability compared with those of conventional concrete. The improvement in the properties appears to be a function of the polymer loading. Maximum increases in strength are obtained by forming and curing the concrete, subsequently drying,

evacuating, and soaking the concrete in monomer, and initiating polymerization by radiation. Increases in strength by as much as a factor of four over that of the control specimens have been obtained. Water permeability, water absorption, and chemical attack by distilled water, sulfate brines, and hydrochloric acid were reduced to negligible values compared with severe attack observed on the control specimens. The thermoplastic monomers methyl methacrylate, styrene and chloro-styrene are of values for normal temperature applications. Cross-linked and thermosetting monomers such as 60 percent styrene-40 percent trimethylpropane trimethacrylate, diallyl phthalate, polyester-styrene, and epoxystyrene impregnated in concrete allow the maintenance of strength and durability properties up to temperatures of the order of 150°C. Radiation treated concrete-polymer displays strength properties that are from 12 percent to 38 percent higher than is thermal catalytically treated material. Concrete-polymer significantly increases the bond strength and flexural strength of steel-reinforced and fiber-reinforced concrete. There appears to be little difference between the effects of radiation and thermal treatment on the durability of concrete-polymers except that which can be attributed to polymer loading. A preliminary comparison between concrete-polymer and other materials of construction indicates reasonable economic potential for certain applications. (auth)

*B15 Welt, N. A., "The Potential for Concrete/Polymer and Wood/Polymer Composites in the Building Industry;" Presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, 28-29 Oct 1970.*

In coming years, the building industry should be under growing pressure to utilize materials that require little maintenance once installed. Radiation Technology, Inc. (RTI) and our subsidiary Radiation Technology (Canada) Ltd. (RT(C)L) have been leaders in the development and commercialization of concrete/polymer and wood/polymer composites which are ideally suited for high strength, low maintenance applications.

These products are produced by utilizing a vacuum impregnation technique to force suitable monomers into the interstitial spaces of the wood or precast concrete, followed by a radiation or thermal polymerization step. The resulting concrete/polymer has greatly increased compressive and tensile strengths, increased modulus of elasticity, resists brine corrosion and will not exhibit freeze-thaw cracking. These properties lend themselves to applications in modular-type construction, indoor and outdoor terrazzo-like tile, window sills, drainage and water pipe.

The wood/polymer material exhibits excellent hardness and abrasion resistance, can be fire proofed and dyed a variety of colors. It is an ideal material for parquet and strip flooring as well as dimension stock for cabinets and for paneling.

- B16 Auskern, A., "A Review of Properties of Polymer-Impregnated Concrete," Proceedings, Conference on New Materials in Concrete Construction, University of Illinois at Chicago Circle, Chicago, Ill., Dec 1971, S. P. Shah, ed.

Incorporating a relatively small amount of a polymer in cured concrete or mortar alters the nature of the original material dramatically. A new and different structural material results with properties only remotely related to the starting materials. The properties reported here were developed from a very limited number of concretes. As work progresses on understanding the basic interactions between the cement, aggregate, and polymer phases, it should be possible to formulate polymer impregnated concretes with specific properties, just as it is now possible to formulate normal concretes with specific properties.

At present attempts to develop techniques for incorporating the monomer or polymer in the concrete mix rather than the cast concrete have been unsuccessful. Also, there has been little work done in impregnating existing concrete structures. So for the present, PIC is limited to precast concrete shapes.

In the decision of a concrete manufacturer to produce PIC, he must carefully evaluate the additional expense of installing the necessary monomer handling, impregnation, and polymerization equipment against the potential market for a new material derived from concrete with unique structural and durability properties.

- B17 Auskern, A., and Horn, W., "Some Properties of Polymer-Impregnated Cements and Concretes," Journal, American Ceramic Society, Vol 54, No. 6, Jun 1971, pp 282-285.

Polymer-impregnated cement and polymer-impregnated concrete were prepared by vacuum-filling cured and dried cement and concrete with a low-viscosity monomer and polymerizing the monomer by a thermal-catalytic of gamma-radiation method. The strength and durability of the products are significantly better than those of the unimpregnated materials. Some observations involving monomer loading, polymerization, and polymer distribution are discussed. A simple model is presented which describes the variation in strength of cement and concrete with polymer content: the model is compared with experimental results.

- B18 Berman, H. A., "Reduced Chloride Penetration by Polymer Impregnation of Cement," Interim Report, Staff Study No. 2311 071, 30 Nov 1971, Federal Highway Administration.

Experiments in which hardened cement paste specimens were exposed to a solution of deicing salt (1.2 N  $\text{CaCl}_2$ ) for a 2-month period indicated that prior polymer impregnation is effective in decreasing the penetration of chloride ion, especially deep-seated penetration. Impregnation resulted in a decrease in the quantity of chloride ion in the surface layer (top 1/8-inch) of the paste to one-fifth (1/5) of that

found in control specimens, and to only one-fiftieth (1/50) of that in controls at levels below the top 1/8-inch layer. The tests indicate that polymer impregnation is a possible method of preventing steel corrosion or surface scaling in bridge decks and concrete pavements by blocking the access of chloride ion to the interior of the concrete.

B19 Bezler, P., Hendrie, J. M., Hoffman, K. C., Oltman, A., and Reich, M., "Design Studies on Multistage Flash Distillation Vessels," p 95, Jul 1971, Brookhaven National Laboratory, Upton, N. Y.

A preliminary survey of vessels for multistage flash distillation units using concrete-polymer as a material of construction was undertaken. This material is made by the impregnation of concrete with a monomer that is subsequently polymerized and has improved mechanical properties as well as increased resistance to hot brine and distillates. Vessel designs for both a 50 and 15 psig operating pressure, all vessels suitable for vacuum service, were evaluated. Standard reinforced construction, prestressed construction and concrete-polymer lined ordinary concrete in both prestressed and reinforced construction were analyzed in detail. Stress determinations were made through the use of two computer stress codes based on the finite element method. Printouts of all the calculated results are provided. Successful vessel designs, as well as analysis limitations and areas for future study, are delineated and discussed. In the case of the 50 psig design basis vessel, the use of concrete-polymer material with prestressed construction permits a wall thickness of as little as 4 in. (Author)

B20 Cowan, W. C., "Applications of Concrete-Polymer Materials," Proceedings of the Conference, New Materials in Concrete Construction, University of Illinois at Chicago Circle, Chicago, Ill., Dec 1971.

The application of concrete-polymer materials is still an infant in the field of concrete construction. The question of feasibility for use can only be answered if investigations are continued. Preliminary results as to strength, durability, and economics look favorable to date. The investigation and development of improved construction materials have become increasingly important as the economy and needs of this country continue to grow. Increasing labor costs necessitate the utilization of materials that require lower maintenance expenditures and increased serviceability to provide more economical construction.

Applications of concrete-polymer materials that have been or are being investigated are concrete pipe, tunnel support and linings, desalting structures, concrete piles, precast bridge decks, and surface protection of cast-in-place bridge decks.

B21 Crow, L. J., et al., "Preliminary Survey of Polymer-Impregnated Rock," RI 7542, Jul 1971, U. S. Bureau of Mines.

A preliminary survey was performed to investigate the impregnation of relatively weak, porous volcanic tuff and a relatively strong, dense sandstone with five different monomers. Increases in compressive strengths by factors of 2 to 5, and elastic moduli by factors of 2 to 3.5, are reported for natural rocks (tuff, sandstone, decite), which were impregnated with five monomers (methyl methacrylate; chlorostyrene; 40 percent TMPTMA-60 percent styrene; 40 percent styrene); polymerization took place after monomers were forced into the rock. Impregnation was performed (1) by pressurizing rock specimens from one end, or (2) by a vacuum-soak operation. Polymerization was accomplished by either radiation or chemical initiation techniques.

Strength improvement is dependent on (1) the type of monomer used, (2) the amount of polymer incorporated into the rock, and (3) the degree of water saturation of the rock. Water saturation strongly reduced the effectiveness of the method for the polymer systems tested. The more viscous monomers (for example, 60 percent polyester-40 percent styrene) were more effective in displacing the water from the rock, and compressive strengths of wet rock were doubled with these systems. Water saturations ranging from 25 to 100 percent of maximum saturation gave essentially identical results.

*B22 Dikeou, J. T., et al., "Concrete Polymer Materials--Third Topical Report," USBR No. REC-ERC-71-6, Jan 1971, U. S. Bureau of Reclamation, and BNL No. 50275 (T-602), Jan 1971, Brookhaven National Laboratory.*

Investigations of concrete-polymer materials as of June 1970 under a joint program of the Bureau of Reclamation, Brookhaven National Laboratory, Atomic Energy Commission, and Office of Saline Water are reported. Three materials being investigated are: (1) polymer-impregnated concrete (PIC-precast portland cement concrete impregnated by a monomer system which is subsequently polymerized in situ); (2) polymer-cement concrete (PCC-monomer is added during mixing of portland cement, water, and aggregate, followed by polymerization); and (3) polymer-concrete (PC-a composite formed by polymerizing a monomer and aggregate mixture). Investigations indicate that the most successful concrete-polymer material for construction is PIC; however, present studies are including PC and PCC because of potential applications if feasible fabrication methods can be developed. Compared to conventional concrete, PIC shows impressive improvements in strength and durability. Tests show that PIC made with ordinary concrete has essentially the same properties as PIC made with a more expensive high-strength concrete. Applications for PIC being investigated are desalting plants, draintile, culvert and sewer pipe, beams and wall panels in housing, bridge decks, rods, luminaries, and underwater structures. Recommendations are given for future work.

#### SUMMARY

Three distinct types of materials are being investigated in the Concrete-polymer Materials Program. These are (1) polymer-impregnated concrete (PIC), precast portland cement concrete impregnated by a monomer system which is subsequently polymerized in situ; (2) polymer-cement

concrete (PCC), water and aggregate followed by polymerization, monomer is added during mixing of portland cement, and (3) polymer-concrete (PC), a composite material formed by polymerizing a monomer and aggregate mixture. Investigations to date indicate that the most successful concrete-polymer material for construction is PIC, which is now receiving the majority emphasis in the program.

Survey experiments on five new monomer systems for normal temperature applications in PIC have been performed. Of the five monomer systems studied, t-butyl styrene and polyester-styrene gave the highest tensile and compressive strengths in 3-inch-diameter by 6-inch-long cylinders. Vinyl chloride, a gaseous monomer, was very difficult to handle during polymerization and gave erratic results.

Two of the elevated temperature monomer systems, 60 percent styrene plus 40 percent trimethylolpropane trimethacrylate (TMPTMA) and 90 percent diallyl phthalate (DAP) plus 10 percent methyl methacrylate (MMS), were selected for additional study. Tests were performed to determine the glass transition temperature ( $T_g$ ), softening point temperature, and temperature for onset of decomposition of their respective polymers. Tests to determine the activation energy for decomposition and the coefficient of thermal expansion were also performed.

A number of various monomer systems have been used to prepare PC specimens including MMA, styrene, acrylonitrile, MMA plus TMPTMA, polyester-styrene, styrene plus TMPTMA, and DAP plus TMPTMA. These monomers were mixed with Ottawa sand and the specimens were polymerized by radiation and by thermal-catalytic methods. Normally 10 to 25 percent of monomer by weight of concrete was required to wet aggregate and produce a uniform specimen. The compressive strength of the PC specimens prepared in the manner varied from 10,000 to 17,000 psi. When the mixture of Type II portland cement and No. 30-mesh Ottawa sand was used as aggregate, 10 weight percent polyester-styrene provided specimens with a compressive strength of 23,500 psi.

A series of tests on drying concrete at temperatures ranging up to 482°F (250°C) indicated the compressive strength of MMA-impregnated oven-dried at 482°F was approximately the same as oven-dried at 302°F (150°C). Concrete curing conditions investigated were curing in lime saturated water for periods of 2, 7, and 28 days. In a study of the effect of aging prior to impregnation, specimens were impregnated with MMA at ages of 1, 28, and 63 days after the 28-day limewater cure, and polymerized by radiation. Compressive and tensile strengths of these specimens were lower than anticipated, averaging 13,740 psi in compression and 1,060 psi in tension. However, results indicate the age of concrete at impregnation or its initial strength does not significantly affect the final strength.

The trends observed in creep tests of PIC under 800 psi compressive load, discussed in the Second Topical Report, continued to be evident. Subsequent tests at higher loads at normal and elevated temperatures show substantially less creep than unimpregnated concrete.

All PIC specimens show improvements in freeze-thaw, sulfate, HCl, and H<sub>2</sub>SO<sub>4</sub> resistance as compared with unimpregnated control concrete. In the freeze-thaw test, the best durability results are being given by radiation-polymerized MMA specimens and thermal-catalytic polymerized MMA

plus 10 percent TMPTMA specimens, which have exhibited 0.5 and 0 percent weight losses at 7,220 and 4,660 cycles, respectively. Unimpregnated control concrete failed the test at 740 cycles, with a weight loss of 25 percent. Sulfate attack, as determined by the accelerated sulfate test, shows small expansions for all PIC at ages ranging from 300 to 720 days, except for radiation-polymerized acrylonitrile and radiation-polymerized chlorostyrene specimens, which have expansion of 0.462 percent at 540 days and 0.168 percent at 300 days, respectively. Unimpregnated control specimens have expanded 0.467 percent at 480 days. All PIC specimens have shown excellent durability in 15 percent HCl ranging from more than 178 to over 667 percent improvement over control concrete. Exposure tests to 15 percent H<sub>2</sub>SO<sub>4</sub>, which is much more severe than 15 percent HCl for concrete, have been concluded and show improvements for polymer-impregnated specimens ranging from 43 to 157 percent over unimpregnated control concrete.

The compressive stress-strain curve for MMA-impregnated concrete, disclosed the highly significant fact that deformation is linear up to 75 percent of ultimate strength and departs less than 7.5 percent from linearity at failure, whereas the deformation of unimpregnated concrete increasingly departs from linearity as the loading increases. PIC appears to show elastic behavior which will have an important bearing on structural design.

Four methods of nondestructive testing were evaluated for use with concrete-polymer materials.

Preliminary tests indicated gamma radiography could not distinguish between monomer and polymer, and could not detect the small amount of polymer present in impregnated concrete.

Neutron radiography did not give meaningful density measurements of impregnated concrete and could not distinguish between monomer and polymer or MMA and water.

Modulus of elasticity appears to satisfy some of the requirements for nondestructive testing of concrete-polymer materials, but under actual test extensive scatter in plots of strength versus modulus were encountered.

The Schmidt Impact Hammer has been used in nondestructive testing of conventional concrete. When this device was applied to PIC, a correlation was found between polymer loading and rebound number. An extensive series of tests with the hammer indicated that within limitations it may be used to evaluate PIC.

B23 *Flajsman, F., et al., "Polymer-Impregnated Fiber-Reinforced Mortars," Journal of the American Ceramic Society, Vol 54, No. 3, Mar 1971, pp 129-130.*

Mortar bars reinforced by chopped steel wire and fiber glass were impregnated with methylmethacrylate which was then polymerized with benzoyl peroxide at 75°F. Monomer loading was 10 wt percent, fibrous reinforcement 2 vol percent. Tensile, compressive, and flexural strengths were measured for control specimens (without reinforcement and impregnation), reinforced specimens, impregnated specimens, and impregnated and reinforced specimens. Flexural strength was increased



significantly by polymer impregnation (510 percent of control) and by fiber reinforcement (450 percent of control); the greatest increase was obtained with both polymer and steel fibers (2820 percent of control). This increase is probably caused by enhanced fiber-paste bonding with polymer impregnation.

B24 Haynes, H. H., and Albertsen, N. D., "Polymer-Impregnated Concrete Spherical Hulls under Hydrostatic Loading," p 42, Dec 1971, Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Eight spherical models with outside diameters of 16 in. and wall thicknesses of 1 or 2 in. were fabricated of polymer-impregnated concrete (PIC) having a uniaxial compressive strength of 21,000 psi. The spherical specimens were tested under hydrostatic loading conditions of short-term, long-term, and cyclic pressure. The test results show that the PIC spheres respond to hydrostatic loading with linearly elastic behavior and that the implosion pressures are greater by approximately 40 percent than those for similar regular-concrete spheres. Under short-term loading the specimens having a wall-thickness-to-outside-diameter ratio of 0.063 and 0.125 (1- or 2-in. walls to 16-in. OD) implode at average hydrostatic pressures of 4810 and 8475 psi, respectively. Classical elastic theory predicts the strain behavior and implosion pressures of the PIC sphere within engineering accuracy.

B25 Southwest Research Institute, "Impregnation of Concrete Pipe," p 78, Jun 1971, San Antonio, Tex.

The program was undertaken to investigate methods to increase the corrosion resistance, increase the strength, and reduce the permeability of concrete used in sewer line applications by impregnating the concrete pipe with relatively low cost resins such as asphalt, coal tars, linseed oil, sulfur, urea-formaldehyde, and others. Methods to accomplish this end were achieved and the materials, techniques of application, test results and economics are presented in this report.

B26 Manning, D. G., and Hope, B. B., "The Effect of Porosity on the Compressive Strength and Elastic Modulus of Polymer-Impregnated Concrete," Cement and Concrete Research, Vol 1, No. 6, 1971, pp 631-644.

Three concretes of widely differing water/cement ratios were impregnated with varying amounts of methyl methacrylate monomer. The monomer was polymerised thermally, using a free radical initiator. The compressive strength and elastic modulus of the polymer-impregnated concrete are shown to be a function of the total porosity of the concrete after polymer impregnation. The elastic modulus of the composite system can be explained on the basis of a two phase material: an aggregate phase and a polymer impregnated cement paste phase. A possible explanation of the role of the polymer is suggested.

B27 Marata, J., and Kobayashi, K., "Durability and Watertightness of Concrete Impregnated with Epoxy Resins," Synthetic Resins in Building Construction, Eyrolles, Paris, 1971, pp 439-447.

Experiments were carried out by the authors in which the surface layer of concrete was first impregnated with epoxy resin to fill the minute exposed pores on the surface as well as the voids underneath the surface. Two to three coats of epoxy resin were applied on top of the impregnated surface. It was established by the results that not only adequate corrosion- and weather-resistance could be obtained, but that perfect watertightness could be maintained against high water pressures.

The feature of this method of treatment is that extremely sure results are obtained without any special skills in processing. By first applying a treatment by impregnation of epoxy resin, the possibility of remaining of any pinholes which lead directly to the base concrete is removed, and even if there are defects in the hardened resin layer formed on the surface by coating, the damage to concrete is limited to very small local areas and there is very little danger of the entire concrete being led to disintegration.

B28 Steinberg, M., "Concrete-Polymer Materials Development, a Goal-Oriented Program," Brookhaven Lecture Series, BNL-50313, 6 Oct 1971.

The principles of applied research are briefly reviewed, and the concrete-polymer materials development program is described in detail as an example of goal-oriented research. In this program the ancient technology of concrete is mated with the recent technology of polymers. The composites are classified as polymer impregnated concrete (PIC), polymer-cement concrete (PCC), cementless polymer-concrete (PC), and concrete with coating in depth (CID). The tasks in the program include monomer survey, process technology, measurement of properties, applications development, economic evaluation, and administration. The materials obtained and their characteristics are described. The durability and structural strength of concrete-polymer are much improved over those of conventional concrete. A number of government agencies, industrial associations, universities, and foreign firms have taken up this research, and preliminary marketing evaluations are in progress. Major potential applications include piping, building panels, bridge decking, distillation vessels, and mine supports. Costs versus product value are briefly discussed.

B29 Steinberg, M., Colombo, P., Kukacka, L. E., and Manowitz, B., "Method of Producing Plastic Impregnated Concrete," U. S. Patent 3,567,496 (Cl 117-113), 2 Mar 1971.

A method of improving the physical properties of concrete bodies comprising impregnating the body with a mixture of monomer and polymerization catalyst and thereafter thermo-catalytically polymerizing the monomer in situ.

The invention described herein was made in the course of, or under a contract with the United States Atomic Energy Commission.

In this invention preformed solid concrete bodies are given decreased permeability and increased compressive strength by impregnating a preformed concrete body with from about 1.0 weight percent to about 30 weight percent based on the weight of the concrete, of a monomer selected from the group consisting of styrene, acrylonitrile, methyl methacrylate, isobornyl methacrylate, and trimethylolpropane trimethacrylate; and from about 0.1 weight percent to about 5 weight percent based on the weight of the monomer of a peroxide polymerization catalyst and thereafter maintaining the impregnated concrete body at a temperature ranging from about 50°C to about 85°C until said monomer has polymerized in situ.

B30 Steinberg, M., et al., "Concrete-Polymer Materials for Highway Applications," BNL-15395, Progress Report No. 1, Sep 1970, Brookhaven National Laboratory, Upton, N. Y.

Work to date has indicated that an increase in compressive strength of about three-fold can be obtained with both high and low quality concretes by impregnating the concrete with methyl methacrylate monomer and then polymerization by either radiation or thermal catalytic means. The strength of lightweight insulating concrete in some cases has been increased from a strength of 100 psi to about 4000 psi. Tests also indicate that creep is less than one-tenth that of the control concrete. The abrasive resistance of the concrete has been improved by a factor of about two. Impregnation of structural lightweight concrete has given compressive and tensile strengths of 18,000 and 2,000 psi, respectively. Efforts are now being made to prepare specimens of greater uniformity. Preliminary design studies using computer-coded finite element analysis were made to determine the feasibility of using concrete-polymer materials for precast bridge decks and breakaway lamp posts. Based on the limited data on properties, both applications appear attractive. Additional data under static and dynamic test conditions are required before a detailed structural design and cost estimate can be made.

B31 Steinberg, M., Kukacka, L. E., Colombo, P., and Manowitz, B., "The Preparation and Characteristics of Concrete-Polymer Composites," Multicomponent Polymer Systems, American Chemical Society, Washington, D. C., Adv. Chem. Series 99, 1971, pp 547-561.

Preformed mortar and concrete can be impregnated with monomer and polymerized by radiation or thermal-catalytic techniques. The resulting concrete-polymer has substantially improved structural properties and durability. Maximum increases in strength are obtained by forming and curing the concrete, subsequently drying, evacuating, and soaking the concrete in monomer, and initiating polymerization by radiation. Cross-linked and thermosetting monomers allow the maintenance of strength and durability up to temperatures of ca. 150°C. Radiation treated concrete-polymer displays strength properties from 12 to 38 percent higher than

thermal catalytically treated material. Concrete-polymer significantly increases the bond strength and flexural strength of steel-reinforced and fiber-reinforced concrete. There appears to be little difference between the effects of radiation and thermal treatment on the durability of concrete-polymers.

- B32 Tazawa, E., Hoshino, Y. E., Kobayashi, S., and Ifuku, N., "Fundamental Properties of Cementitious Products Impregnated With Resin," Concrete Journal, Vol 9, No. 1, Jan 1971.

Fundamental properties of cementitious products manufactured through impregnation of monomer and in situ thermal-catalytic polymerization have been investigated as plain and reinforced members. Various strengths, elasticity, creep, volume stability and durability of plain members are described using concrete, mortar, lightweight concrete and asbestos-cement as the impregnation bases. As a reinforced member, bonding strength with steel reinforcement, restraint of shrinkage caused by polymerization, shear strength and bending capacity tested by a beam are discussed in comparison with untreated members. It has been suggested that remarkably durable high strength members can be manufactured with less variations in properties through the impregnation treatment.

- B33 Wallace, G. B., "Polymer Impregnated Concrete Pipe," Paper for Presentation at the 1971 Annual Meeting of the Agriculture Division of the American Concrete Pipe Association, Denver, Colo.

The developmental program for polymer-impregnated concrete has demonstrated that significant improvements in the properties of concrete are readily achieved by polymer impregnation. One of the important new applications of this new material is polymer-impregnation of concrete pipe, which promises to extend the usefulness of this already proven product. The program is continuing with the goals of developing design data, preparation of specifications and development of economical fabrication methods.

#### 1972

- B34 Auskern, A., "Review of Properties of Polymer Impregnated Concrete," BNL-16578, p 48, Jan 1972, Brookhaven National Laboratory, Upton, N. Y.

Incorporating a relatively small amount of a polymer in cured concrete or mortar alters the nature of the original material dramatically. A new and different structural material results with properties only remotely related to the starting materials. The properties reported were developed from a very limited number of concretes. As work progresses on understanding the basic interactions between the cement, aggregate, and polymer phases, it should be possible to formulate polymer impregnated concretes with specific properties, just as it is now possible to formulate normal concretes with specific properties. It

is doubtful that the ultimate properties of PIC have been achieved. If, as seems likely, there are further improvements in the mechanical properties of PIC, a material will have been derived from concrete without concrete's poor tensile strength. Attempts to develop techniques for incorporating the monomer or polymer in the concrete mix rather than the cast concrete have been unsuccessful. Also, there has been little work done in impregnating existing concrete structures. So for the present, PIC is limited to precast concrete shapes. In the decision of a concrete manufacturer to produce PIC, he must carefully evaluate the additional expense of installing the necessary monomer handling, impregnation, and polymerization equipment against the potential market for a new material derived from concrete with unique structural and durability properties.

**B35** Auskern, A., "A Model for the Elastic Constants of Polymer Impregnated Composites," BNL-16731, Mar 1972, Brookhaven National Laboratory, Upton, N. Y.

A simple model is developed which predicts the relative improvement to the elastic modulus when a porous solid is filled with a rigid polymer. The only material parameter required is the initial porosity of the solid. The agreement between the model and existing data is good.

**B36** Bezler, P., Hendrie, J. N., et al., "Report of Polymer Concrete Applications for the Office of Saline Water," Report No. 16645, Feb 1972, Brookhaven National Laboratory, Upton, N. Y.

Report describes an evaluation of concrete-polymer materials of construction for multistage flash distillation vessels, culminating with the development of five conceptual vessel designs. The polymer impregnation technique and the method of vessel fabrication were common to all construction methods. Each vessel would consist of precast, factory-impregnated cylindrical sections, which would be field assembled and the joints filled with a polymer-sand grout seal.

**B37** Cowan, W. C., et al., "Polymer-Impregnated Concrete Tunnel Support and Lining System," Proceedings, North American Rapid Excavation and Tunneling Conference, Vol 1, 1972.

Present trends in tunneling technology are towards increased use of precast concrete segmental support systems. This trend can be expected to continue as the cost of conventional temporary support increases. The compatibility of modern, sophisticated, mechanized excavation machines, and segmental support systems is now established. However, handling and erecting segments can be greatly simplified by using thin, lightweight, high-strength segments made of polymer-impregnated concrete. Use of such segments will permit more rapid installation of supports, thereby allowing use where immediate ground support is desired. Again, the thin, flexible, segmented support-lining system can better accommodate the inevitable ground-movement-induced

distortions without developing failure stresses.

Recent technological developments have produced a polymer-impregnated concrete having four times the strength and a great beneficiation of other engineering properties over conventional concrete. Individual tests on single segments indicate that polymer-impregnated concrete segments have an ultimate strength of 2.25 times that of conventional concrete segments. Full-scale tests performed on an 8-ft-diameter tunnel support and lining system showed that a system comprised of 2-in.-thick polymer-impregnated segments and 3-1/2 in. of conventional backfill concrete can support 60 percent more load than a similar system comprised entirely of conventional concrete.

The question of feasibility for the use of concrete polymer materials for tunnel support-lining systems can be answered only by continued investigations. Results to date as to strength, durability, and economics are favorable.

B38 *Dikeou, J. T., et al., "Concrete Polymer Materials - Fourth Topical Report," USBR No. REC-ERC-72-10, Jan 1972, U. S. Bureau of Reclamation and BNL-50328, Jan 1972, Brookhaven National Laboratory.*

This report covers work carried out in the period 1 July 1970 through June 1971.

The development of three distinct types of material is being continued in the Concrete-Polymer Materials Program:

1. Polymer-impregnated concrete (PIC), precast portland cement concrete impregnated by a monomer system which is subsequently polymerized in situ;
2. Polymer-cement concrete (PCC), a premixed material in which monomer is added to a water-portland cement-aggregate mix and subsequently polymerized in place; and
3. Polymer-concrete (PC), a composite material formed by polymerizing a monomer and aggregate mixture.

Concrete-polymer materials offer potential advantages of high strength and improved durability, as compared with conventional concrete. Investigations to date indicate that the most advanced concrete-polymer material for construction is PIC, which is now receiving the major emphasis in the program. Investigations are continuing with PC and PCC because these materials have many potential cast-in-place applications.

To date little success has been obtained with PCC. Several monomer systems were used to prepare samples and only epoxy resin showed limited promise of producing an improved concrete when considered on an increased compressive strength basis. However, high concentrations of epoxy are required.

Considerable progress has been made in the development of PC. Specimens produced by using methyl methacrylate (MMA) containing a silane coupling agent for improved bonding had polymer loadings of 5 to 6 percent and compressive strengths of 16,000 psi compared with strengths of 11,000 psi for samples without the silane. The monomer content of this material has been reduced to approximately that used in PIC.

A series of 10 different concrete mixes was produced to investigate the effect of concrete mix design on the compressive strength and polymer loading of PIC. The controls averaged between 4,220 and 7,280 psi, in compressive strength, while all the impregnated specimens except those containing 25 percent fly ash exhibited essentially the same strength, 21,000 psi plus or minus 1,800 psi. Polymer loadings were found to increase with decreased concrete density. This work is being expanded to include a wider range of mix variables.

The impregnation of high-pressure steam-cured concrete with MMA has produced PIC specimens with the highest compressive strengths obtained to date in the concrete-polymer program. Specimens impregnated by the standard vacuum-soak procedure described above, in which specimens are wrapped in aluminum foil prior to polymerization, and radiation polymerized exhibited strengths up to 25,250 psi. Samples impregnated in glass forms and radiation polymerized had strengths up to 27,200 psi.

Three encapsulation methods for reducing monomer evaporation and drainage losses from concrete specimens prior to polymerization have been evaluated. The methods are: (1) encapsulation of the specimen in a form during impregnation and polymerization; (2) polymerization with the monomer-saturated specimens in contact with water; and (3) impregnation with monomer followed by a prepolymer dip, wrapping, and rotation during polymerization. Polymerization under water yields good results and appears to be the most practical. Test data indicate that underwater polymerization of MMA has no detrimental effects on the properties and may even produce benefits because of increased monomer content. It thus seems feasible to consider underwater polymerization as a processing technique in the production of PIC. Improvements in properties and the cost reduction associated with the elimination of the wrapping requirements and the need to use a massive radiation cell make the processing technique attractive. The use of heated water as a means of initiating the thermal-catalytic polymerization of MMA has also been tested in the laboratory and appears to be an alternative processing method.

The trends observed in creep tests of PIC under a compressive load of 800 psi, discussed in previous Topical Reports, continued to be evident. Low positive creep was obtained with specimens impregnated with chlorostyrene, acrylonitrile, and MMA-TMPTMA. Negative creep, which was observed as soon after initial loading of MMA-impregnated specimens, has persisted after 3 years under load. High-stress creep tests on MMA and chlorostyrene-impregnated specimens show low positive creep after 261 days under sustained compressive loadings of 690, 2313, and 7000 psi. Unit deformation is essentially the same at all three compressive loadings and is approximately 1/10 that of the unimpregnated controls. Tensile creep tests indicate negative creep after 261 days at sustained loads of 178 and 345 psi.

Compressive strength, Poisson's ratio, and modulus of elasticity measurements have been made at minus 12° and 20°C on samples impregnated with MMA and (10-90) polyester-styrene. No significant effect due to temperature was observed.

Compressive strength measurements made on MMA-impregnated specimens indicate that the strength is not affected by age for periods of up to 1 year.

- B39 Gebauer, J., et al., "Effect of Temperature on the Strength of a Polymer-Impregnated Porous Ceramic," American Ceramic Society Journal, Vol 55, No. 3, Mar 1972, pp 175-176.

Polymer-impregnation of the porous ceramic approximately doubled its strength at room temperature. The strengths of the nonimpregnated specimens appear to be independent of temperature, but those of the impregnated specimens decrease rapidly near the  $T_g$  of the polymer to values only slightly above the corresponding strengths of the nonimpregnated control specimens. As expected from the difference in the glass transition temperatures, the specimens impregnated with the poly(tert-butyl styrene) retained their strength to a higher temperature than those impregnated with polystyrene. The room-temperature and high-temperature strengths of specimens impregnated with cross-linked polystyrene were slightly higher than those which resulted from normal polystyrene impregnation, consistent with the small increases in modulus expected; however, little effect of the increase in  $T_g$  was evident.

These results substantially support the hypothesis that strengthening of the porous ceramic tile by polymer impregnation can be attributed largely to mechanical reinforcement. Therefore, impregnation of porous ceramics will be most effective when polymers with the highest possible Young's moduli and glass transition temperatures are used.

- B40 Gebauer, J., et al., "Effect of Polymer Impregnation on Physical and Mechanical Behavior of Ceramic Tile Bodies," American Ceramic Society Journal, Vol 51, No. 5, 1972, pp 471-473.

Polymer impregnation of ceramic tile bodies significantly increased the tensile strength, compressive strength, impact resistance, Young's modulus of elasticity, indentation resistance and tile breaking strength. A decrease in water absorption was also observed.

It is concluded that polymer impregnation can lead to major improvements in the mechanical properties of porous ceramic products.

- B41 Hasselman, D. P., et al., "Elastic Behavior of Polymer-Impregnated Porous Ceramics," American Ceramic Society Journal, Vol 55, No. 12, Dec 1972, pp 588-591.

The effect of polymer impregnation on the elastic behavior of porous ceramics was investigated. Large increases in the Young's, shear, and bulk moduli and Poisson's ratio were observed. On the basis of a two-dimensional model containing elliptical inclusions, it was shown that the primary role of the polymer on impregnation is to significantly offset the original reduction in elastic moduli caused by the pore phase. The relative effect of polymer impregnation on elastic behavior increases with increasing pore volume fraction and pore ellipticity. These conclusions are also expected to explain the elastic behavior of polymer-modified cements and concretes.



**B42** Hinze, J. W., Investigation of Monomer Systems, Methods of Application and Curing for Polymer-Impregnated Concrete Surface Treatments, N.S. Thesis, The University of Texas at Austin, Austin, Tex., Dec 1972.

One of the major problems encountered with concrete is that the surface is often not sufficiently durable. This is particularly true of concrete bridge decks. This research was conducted with the goal of improving the durability of concrete surfaces by polymer impregnation. The impregnation is intended to render the concrete tougher, stronger, and essentially impervious to liquids. Tests were performed on polymer impregnated concrete specimens which revealed considerable strength increases over untreated specimens. Surface treatment tests were primarily concerned with determining the most ideal monomer system for practical application. The process was essentially one in which a monomer was allowed to penetrate into the concrete surface; subsequently, a heat source was applied to induce polymerization. The depth of the monomer penetration was highly dependent on the soaking time and monomer viscosity. The rate of polymerization was highly dependent on the volume of monomer used. Additional external heat had to be supplied to the monomer to induce polymerization before excessive monomer evaporation occurred. The monomers most successful for surface treatments were methyl methacrylate, isobutyl methacrylate, isodecyl methacrylate and tertiary-butyl styrene. The most feasible means of supplying external heat are heating blankets, reactive second treatments, steam and hot water.

**B44** Kukacka, L. E., et al., "Concrete-Polymer Materials for Highway Applications," Progress Report No. 2, BNL-50348, and FHWA-RD-73-7, Apr 1972.

Investigations of polymer-impregnated concrete for highway applications made at Brookhaven National Laboratory during the period July 1970 to December 1971 are reported. Samples of normal weight and structural lightweight concretes containing several high-quality aggregates were impregnated with methyl methacrylate and radiation polymerized in situ. All the materials produced high-strength (15,000-psi) durable composites, and the results indicate that concretes prepared from locally available materials can be used in the preparation of polymer-impregnated concrete. Comparable results have been modified with thermal-catalytically polymerized specimens.

**B45** Kukacka, L. E., and DePuy, G. W., "Concrete-Polymer Materials. Fourth Topical Report," p 126, Jan 1972, Bureau of Reclamation, Denver, Colo.

The development of three distinct types of concrete-polymer materials is described including polymer-impregnated concrete (PIC), precast portland cement concrete impregnated by a monomer system which is subsequently polymerized in situ; polymer-cement concrete (PCC), a

premixed material in which monomer is added to a water-portland cement-aggregate mix and subsequently polymerized in place; and polymer-concrete (PC), a composite material formed by polymerizing a monomer and aggregate mixture. Concrete-polymer materials offer potential advantages of high strength and improved durability, as compared with conventional concrete. Results of investigations indicate that the most advanced concrete-polymer material for construction is PIC, which is now receiving the major emphasis in the program. Investigations are continuing with PC and PCC because these materials have many potential cast-in-place applications. Little success has been obtained with PCC. Several monomer systems were used to prepare samples and only epoxy resin showed limited promise of producing an improved concrete when considered on an increased compressive strength basis. However, high concentrations of epoxy are required. Progress has been made in the development of PC. Specimens produced by using methyl methacrylate (MMA) containing a silane coupling agent for improved bonding had polymer loadings of 5 to 6 percent and compressive strengths of 16,000 psi compared with strengths of 11,000 psi for samples without the silane. The monomer content of this material has been reduced to approximately that used in PIC. Survey experiments are being performed to select monomers for high-temperature applications such as would be encountered in desalting plants. Six monomer systems were screened and three-diallyl isophthalate (DAIP), MMA plus trimethylolpropane trimethacrylic (TMPTMA), and MMA plus ethyl-glycol dimethacrylate (EGDM) were selected for further evaluation.

B46 Kusane, H. M., "Buoyant Concrete for Ocean Construction and Flotation," *Technical Note N-1232*, Jun 1972, Naval Civil Engineering Laboratory.

Buoyant concrete material has been envisioned for ocean construction systems. This report summarizes an investigation of buoyant concretes containing lightweight, nonabsorbent glass nodules as the major aggregate constituent.

Specimens (3- by 6-in. cylinders) from 35 different batches of concrete were tested for workability, strength, density, and absorption. The glass nodules were tested to implosion. Mix design curves and cost estimates were determined. The strength and wet density of this concrete ranged from 130 psi to 1760 psi and 42 pcf to 77 pcf, respectively; the hydrostatic strength of the nodules was approximately 60 psi. Impregnating this concrete with polymer produced strengths of 1670 psi to 5040 psi and densities of 60 pcf to 75 pcf. The results indicate that this concrete can be used as a low-cost (\$0.10 to 0.20 per pound of buoyancy) buoyant filler material for ocean applications in which low-strength (150 psi) is permissible.

B47 Levitt, M., McGahan, D. J., and Hills, P. R., "A Comparison of Concrete-Polymer Composites Produced by High Energy Radiation," *Precast Concrete*, Oct 1972, pp 605-608.

Experiments have been conducted to determine the feasibility and

techniques for impregnation and in situ polymerization of liquid monomers in preformed concrete, and the inclusion of monomers directly into the fresh concrete mix, followed by polymerization. Polymerization by both gamma radiation and chemical reaction in the presence of heat is being studied. Studies include monomer screening tests, development of process technology, and development of applications. It appears that the cost of the treatment will be reasonable. Improvements in properties resulting from the impregnation of concrete with methyl methacrylate followed by irradiation include the following: Compressive and tensile strength and modulus of rupture have been increased from between 256 percent to 290 percent; water permeability has been decreased to negligible values; water absorption has been decreased by as much as 95 percent; and resistance to abrasion, cavitation, freeze-thaw attack, and to distilled water, soluble sulfates, and acid corrosion has shown significant improvements.

**B48** Sorensen, E. V., and Radjy, F., "Monomer Impregnation of Hardened Cement Paste (HCP)," Cement and Concrete Research, Vol 2, No. 4, Jul 1972.

The production of preformed concrete-polymer composites involves three stages: (1) drying of the hardened concrete specimen; (2) impregnation of the dried specimen with monomer; (3) polymerization of the monomer.

The impregnation process was studied for both as-cast cylinders and powdered specimens using styrene and methyl methacrylate (MMA). The cylinders were subjected to both gas phase and liquid phase impregnation, while the powdered specimens were impregnated from the gas phase only.

The maximum amount of impregnation increases in the order, styrene, MMA, and water. Furthermore, results show that the maximum amount of impregnation for the cylinders from the liquid phase is about the same as the corresponding gas phase impregnation for the powders.

Results demonstrate that liquid phase impregnation of the MMA and styrene monomers, without applying pressures higher than one atm., are very rapid. In comparison, the gas phase impregnation is apparently three orders of magnitude slower than liquid phase impregnation.

**B49** Steinberg, M., "Concrete-Polymer Composite Materials Development," Department of Applied Science, Informal Report, BNL-16609, Feb 1972.

A wide range of concrete-polymer composite materials are under investigation. The old technology of hydraulic cement concrete is combined with the new technology of polymers. Polymer impregnated precast concrete (PIC) is the more developed of the composites and exhibits the highest degree of strength and durability. Polymer concrete (PC), an aggregate bound with polymer is potentially a most promising material for cast-in-place applications. PC with solid waste aggregate holds out some interesting possibilities of converting a waste material into a valuable material of commerce.

B50 Steinberg, M., "Concrete-Polymer Materials Development, A Goal-Oriented Program," Nuclear Science Abstracts, Vol 26, No. 12, Jun 1972.

The principles of applied research are briefly reviewed, and the concrete-polymer materials development program is described in detail as an example of goal-oriented research. In this program the ancient technology of concrete is mated with the recent technology of polymers. The composites are classified as polymer-impregnated concrete (PIC), polymer-cement concrete (PCC), cementless polymer-concrete (PC), and concrete with coating in depth (CID). The tasks in the program include monomer survey, process technology, measurement of properties, applications development, economic evaluation, and administration. The materials obtained and their characteristics are described. The durability and structural strength of concrete-polymer are much improved over those of conventional concrete. A number of government agencies, industrial associations, universities, and foreign firms have taken up this research, and preliminary marketing evaluations are in progress. Major potential applications include piping, building panels, bridge decking, distillation vessels, and mine supports. Costs versus product value are briefly discussed.

B51 Steinberg, M., Fontana, J., and Colombo, P., "Thermal Polymerization of Radiation Conditioned Monomers for the Production of Concrete-Polymer Materials," BNL-16989, p 18, Feb 1972, Brookhaven National Laboratory, Upton, N. Y.

For the purpose of reducing the hazard of handling excess monomer containing a chemical initiator in the production of polymer impregnated concrete and to reduce the radiation dose requirements for the polymerization of monomer in concrete, a system is proposed to remove the inhibitor in the bulk monomer prior to impregnation gamma radiation reactions. The radiation conditioned monomer is then allowed to impregnate the concrete after which the monomer is thermally polymerized in situ with no further addition of chemical catalyst. Data are presented for the removal of inhibitor by 60 Co gamma radiation from the bulk monomers, methyl methacrylate (MMA), styrene, t-butyl styrene, and trimethylolpropane trimethacrylate (TMPTMA). The subsequent thermal polymerization of the radiation conditioned monomers is indicated. The in situ polymerization of radiation conditioned styrene-TMPTMA comonomers and t-butylstyrene has been shown and compressive strength of the polymer-concretes has been measured. In the case of MMA further work is needed to determine the reason for incomplete polymerization of the monomer in the center part of the concrete. A process based on this system is discussed.

B51(1) Kukacka, L. E., et al., "Concrete-Polymer Materials for Highway Applications." Report No. FHWA-RD-73-7, Progress Report No. 2, Apr 1972, Federal Highway Administration.

A research program to determine the properties of concrete-polymer materials and to find and develop potential highway applications is being performed by the Radiation Division of the Department of Applied Science, Brookhaven National Laboratory (BNL) and the Materials Division, Office of Research, Federal Highway Administration (FHWA). The program is sponsored by the U. S. Department of Transportation, Federal Highway Administration.

The work to date has indicated that great improvements in the structural and durability properties of highway-quality concrete can be obtained by monomer impregnation and *in situ* polymerization by either radiation or thermal-catalytic means.

After impregnation with methyl methacrylate (MMA) and radiation polymerization, all the materials produced high-strength (>15,000 psi) composites. Comparable strengths have also been obtained with thermal-catalytically polymerized specimens. The data indicate that concretes prepared from locally available materials can be used in the production of polymer-impregnated concrete (PIC).

In conjunction with this effort, encapsulation methods were evaluated following the vacuum-soak impregnation operation to determine the effectiveness in minimizing monomer drainage and evaporation losses.

The choice of encapsulation method appears to depend upon the initial density of the concrete. Polymerization under water yields results that are at least comparable with those obtained by using forms when high-density (>140 lb/ft<sup>3</sup>) materials containing limestone, quartzite gravel, or diorite are impregnated. Forms are more effective for lower density materials such as Solite or slag, probably because their use reduces the drainage losses to which low-density materials are more susceptible to negligible values. However, the differences in strength are not large (<15 percent).

1973

B52 Albertsen, N. D., and Haynes, H. H., "Polymer Impregnated Concrete Spherical Hulls for Seafloor Structures," *Polymers in Concrete*, SP 40-6, pp 119-148, 1973, American Concrete Institute, Detroit, Mich.

Eight polymer-impregnated concrete (PIC) spherical model hulls with outside diameters of 16 in. (40.6 cm) and wall thicknesses of 1 or 2 in. (2.5 or 5.1 cm) were tested under external hydrostatic loading. The test results show that the PIC spheres respond to hydrostatic loading with elastic behavior. Implosion pressures for the PIC spheres with a uniaxial compressive strength ( $f'_c$ ) of approximately 21,000 psi (145 N/mm<sup>2</sup>) are greater by approximately 40 percent than those for similar regular concrete spheres whose  $f'_c$  is approximately 10,000 psi (69 N/mm<sup>2</sup>). Under short-term loading the PIC hulls with 1- and 2-in. (2.5- or 5.1-cm)-thick walls imploded at average hydrostatic pressures of 4810 and 8475 psi (32.2 and 58.4 N/mm<sup>2</sup>), respectively, while 1-in.

(2.5-cm) thick spheres subjected to long-term and cyclic loading conditions imploded at 4000 psi (27.6 N/mm<sup>2</sup>). Classical thick wall theory predicts the strain behavior and implosion pressures for the PIC spherical hulls within engineering accuracy. It is projected that the maximum operating depth for buoyant spherical PIC hulls will be approximately 4000 ft (1220 m) in the ocean.

B53 Auskern, A., and Horn, W., "Polymers Impregnated Concrete As A Composite Material," *Polymers in Concrete*, SP 40-11, pp 223-247, 1973, American Concrete Institute, Detroit, Mich.

The incorporation of a relatively small volume of a rigid polymer in the pore structure of concrete results in a significant increase in the elastic and mechanical properties of the material. The role that polymer plays in improving these properties is reviewed. It is concluded that the main effects of the polymer are to (1) improve the strength and increase the modulus of the cement phase, and (2) to improve the bonding between the cement and aggregate phases.

Composite theory is applied to various model concrete systems both with and without polymer. It is shown that with polymer the systems behave in better accord with composite theory. It is further demonstrated that the presence of the polymer permits extensive changes to the failure mode of concrete without sacrificing the improved properties of the material.

B54 Bhargava, J. K., "Radiographic Studies of the Structure of Polymer Impregnated Concrete," *Polymers in Concrete*, SP 40-10, pp 205-223, 1973, American Concrete Institute, Detroit, Mich.

The structure of polymer impregnated concrete and its cracking behaviour under load was studied by radiographic technique. It was observed that polymer impregnation not only reduced the porosity of the mortar but also of the interface. No microcracks were observed at the polymer-impregnated contact phase, on loading, in contradistinction to ordinary concrete. Cracks, which were first detected around 70 to 80 percent of the ultimate load, propagated usually through the aggregate, instead of following its boundary. Dispersion and orientation of fibers had a significant influence on the cracking behavior. Distortion and kinking of fibers indicated very good adhesion between the fibers and the polymer-impregnated matrix.

B55 Carpenter, L. R., Cowan, W. C., and Spencer, R. W., "Polymer-Impregnated Concrete Tunnel Support and Lining," REC-ERC-73-23, Dec 1973, Bureau of Reclamation.

The development of precast polymer-impregnated concrete (PIC) tunnel support-liner systems is reported. Investigations included: (1) Full-scale tests of conventional concrete and PIC segments with concrete backfill as well as PIC segments with sand backfill;

(2) economic studies to compare precast conventional concrete and PIC systems; (3) the effects of joint configuration, elastomeric joint sealer, and segment material on the support-lining system strength determined by laboratory tests and statistical inference; (4) heat transfer analysis employing finite differences to determine temperature distribution in the PIC lining caused by transportation tunnel fires; (5) effects of elevated temperature on the compressive strength and the heat transmission characteristics of PIC; and (6) determination of flame spread, fuel contribution, smoke developed, the combustion gases, and visual damage of PIC resulting from exposure.

B56 Dahl-Jorgensen, E., and Chen, W.-F., "Polymer-Impregnated Concrete as a Structural Material," p 20, May 1973, Lehigh University, Fritz Engineering Laboratory, Bethlehem, Pa.

Polymer impregnated concrete (PIC) impregnated with the most common polymers, polymethyl methacrylate and polystyrene shows little ductility. The ultimate strength of these materials are found to be 3 to 4 times higher than that of ordinary concrete, but when the ultimate load of the PIC is reached, the failure comes without warning in a brittle, almost explosive manner. This investigation was designed to increase the ductility of the PIC so that some plastic yielding may take place before and after the ultimate load is reached. By various percentages of monomer combinations of the methyl methacrylate with an elastomer, n-butylacrylate, this increase in ductility was demonstrated herein by the determination of the entire stress-strain relationship of such co-polymer composite material through the split-tensile and simple compression tests.

B57 DePuy, G. W., and Kukacka, L. E., "Concrete Polymer Materials. Fifth Topical Report," BNL-50390, p 114, Dec 1973, Brookhaven National Laboratory, Denver, Colo.

The development, properties, and uses of polymer-impregnated concrete, polymer-concrete, and polymer-cement concrete are summarized. This report covers work performed from 1 July 1971 to 30 June 1972.

The development program for concrete-polymer materials covers three distinct types of material: polymer-impregnated concrete (PIC), polymer-concrete (PC), and polymer-cement concrete (PCC).

Progress in the development of PC as a practical construction material has continued with the development of an economical fabrication process. The new process uses conventional concrete mixing and placing equipment and produces a product which, on the basis of initial tests, has about the same polymer content and compressive strength as standard PIC. The product may be polymerized at room temperature by promoter-catalyst methods. PC should be more economical to produce than PIC since it does not require special process equipment and it can be field-installed using the techniques used for conventional concrete. Studies were continued on increasing the compressive strength of PC

through the use of silane coupling agents. An investigation was started to determine whether the plasticity of PC could be increased by copolymerizing methyl methacrylate (MMA) and butyl acrylate.

Investigation of PCC continued on a limited basis with a preliminary study of furfuryl alcohol PCC. Studies to date have shown strength improvements with furfuryl alcohol similar to those found previously with epoxy resins. However, large amounts of epoxy resins were required to increase compressive strengths. Furfuryl alcohol appears promising since it can be polymerized in an alkaline environment, does not appear to interfere with the hydration of portland cement, and is much lower in cost than epoxy resins. Increases in compressive strength of up to 24 percent were obtained with relatively small amounts of furfuryl alcohol.

Several plasticizers were tested as additives for monomer systems to increase the flexibility or plasticity of PIC. Stress-strain curves showed that using 35 wt percent butyl acrylate - 65 wt percent MMA produced the most pronounced effect in PIC. However, it appears that the concrete itself has an overriding effect and that for a wider change in mechanical properties, energy-absorbing materials should be incorporated into the concrete.

Studies were continued on the effects of composition of the concrete and concrete curing conditions on compressive strength and polymer loading of PIC. Compressive strengths of PIC specimens ranged from about 17,000 psi for PIC made with a poor-quality high-porosity limestone aggregate to 32,400 psi for a high-strength, high-pressure steam-cured specimen; this is the highest compressive strength obtained to date. These tests indicate that good-quality PIC can be produced from concrete containing very-poor-quality aggregates. The primary factors in producing good-quality high-strength PIC appear to be achievement of a high degree of impregnation and complete polymerization. For production of very-high-strength PIC, a high-strength concrete mix with high-pressure steam curing is advantageous.

Experiments are in progress to determine the vacuum time, soaking time, and pressure requirements for full impregnation of various types of concrete. Impregnation rates depend on the porosity of the portland cement matrix and to a certain extent on the porosity of the aggregate. For impregnation of standard-weight, high-pressure steam-cured concrete specimens up to 12 in. thick, the recommended process consists of oven-drying the specimens to constant weight, evacuation at 30 in. Hg for 30 min, soaking in monomer for 60 min at 10 psig, and polymerization under water by radiation or thermal-catalytic methods.

Partial impregnation and coating techniques were developed for protective treatment of concrete linings in desalting plants. The concrete liner of a flash distillation chamber and various sections of mortar-lined steel pipe were treated and are being field-tested at the OSW Water Desalting Facility in Freeport, Texas. Two monomer systems were used: 60 wt percent styrene - 40 wt percent TMPTMA followed by a seal coat of 53 wt percent polyester - 28 wt percent styrene - 19 wt percent TMPTMA; and 70 wt percent MMA - 30 wt percent TMPTMA followed by



a seal coat prepared by dissolving 20 percent MMA prepolymer and a small amount of paraffin wax in some of this mixture. Polymerization of both systems was accomplished at ambient temperatures by promoter-catalyst methods. Preliminary inspection after 6 weeks of normal operation indicated no deterioration in the treated areas.

Studies of polymerization techniques have included experiments to remove the inhibitor in a monomer by radiation and then thermally polymerize the uninhibited and uncatalyzed monomer. A process flow sheet was developed for impregnating concrete and other porous materials and polymerizing by the thermal method. Other polymerization techniques studied were promoter-catalyst methods for ambient-temperature polymerization, polymerization of impregnated specimens immersed in water to reduce monomer drainage and evaporation, and thermal-catalytic polymerization of specimens in the impregnation tank with use of steam heat.

The testing program on PIC for ambient-temperature applications is continuing. Structural properties of MMA, styrene, acrylonitrile, MMA - 10 wt percent TMPTMA, chlorostyrene-impregnated concrete, and MMA-impregnated concrete polymerized under water, are given in previous topical reports. Results for 10 wt percent polyester - 90 wt percent styrene-impregnated concrete are given in this report. The polyester and styrene specimens were polymerized by radiation and had an average compressive strength of 20,500 psi, modulus of elasticity of  $6.5 \times 10^6$  psi, direct tensile strength of 1530 psi, and modulus of rupture of 3300 psi.

Structural properties tests during the year included direct tension tests at  $-12^\circ\text{C}$  and  $20^\circ\text{C}$ , single- and double-shear test, continuation of long-term creep tests under several compressive and tensile loadings, flexural strength tests of beams impregnated from one and two sides, and flexure and shear tests of steel-reinforced PIC beams. Preliminary design values were obtained for tensile strength at  $-12^\circ\text{C}$  and  $20^\circ\text{C}$  of MMA and of 10 wt percent polyester - 90 wt percent styrene PIC. Shear tests indicated that single-shear or double-shear test methods have little effect on results with PIC. The shear strength of MMA-impregnated concrete is  $\approx 3700$  psi, two to three times greater than that of unimpregnated concrete.

Durability tests include resistance to freezing and thawing, acids, sulfates, sodium hydroxide, and weathering. Freeze-thaw tests of PIC show all specimens to have greatly improved durability when compared with unimpregnated concrete. An MMA-impregnated and radiation-polymerized specimen that has been in test for the longest time has shown only 0.5 percent weight loss after 12,010 cycles, an improvement of  $>1523$  percent over unimpregnated concrete. Unimpregnated concrete generally fails the test at about 740 cycles with a 25 percent weight loss. PIC specimens still under test include MMA - 10 wt percent TMPTMA with no weight loss at 9450 cycles, acrylonitrile with 11 percent weight loss at 8910 cycles, MMA radiation-polymerized under water with 2 percent weight loss at 2780 cycles, and 10 wt percent polyester - 90 wt percent styrene with 1 percent weight loss at 1530 cycles. Testing has been concluded on MMA, styrene, chlorostyrene, and the bulk of the MMA - 10 wt percent TMPTMA and acrylonitrile specimens.

In the accelerated sulfate attack test, PIC specimens have shown moderately to greatly improved resistance as compared with unimpregnated concrete. MMA-impregnated concrete has been under test longer than other CP test series specimens and has shown from 0.016 to 0.032 percent expansion after 1436 cycles. Unimpregnated concrete failed the test at 480 cycles with 0.5 percent expansion.

Unimpregnated concrete and MMA, 10 wt percent polyester - 90 wt percent styrene, and 60 wt percent styrene - 40 wt percent TMPTMA PIC specimens were continuously exposed to a 5 percent solution of sodium hydroxide for >1 year. All specimens showed no loss in weight and no visible signs of deterioration. After removal from test, specimens had compressive strengths ranging from 16,000 to 19,000 psi for PIC specimens and 6,500 psi for unimpregnated concrete.

Acid-resistance tests were conducted with PIC specimens immersed in 15 percent HCl and 5 percent H<sub>2</sub>SO<sub>4</sub>. Weight losses from exposure to 15 percent HCl ranged from 10 to 12 percent for MMA specimens after 1395 days of exposure to about 12 percent for chlorostyrene specimens after 882 days. Unimpregnated concrete specimens failed with 25 percent weight loss after 105 days. In the 5 percent H<sub>2</sub>SO<sub>4</sub> test, which is still in progress, 10 wt percent polyester - 90 wt percent styrene and MMA specimens polymerized under water show a weight loss of about 17 percent after 252 days. Unimpregnated concrete failed the test with a 32 percent weight loss after 210 days. Sewer pipe impregnated with MMA and coated with polyester-styrene has shown no attack after exposure for 150 days to 5 percent H<sub>2</sub>SO<sub>4</sub>.

Flammability tests patterned after ASTM D 635-68, Flammability of Self-Supporting Plastics, were performed on PIC and PC specimens and on the polymers themselves. Most of the polymers support combustion according to this test, but when incorporated in PIC or PC, the composite materials are either self-extinguishing or do not burn at all.

Development of partially impregnated concrete as a less costly alternative to fully impregnated concrete continued during the year. Durability tests (freeze-thaw, sulfate attack, and resistance to acid) show generally beneficial but somewhat erratic improvement in durability as compared with unimpregnated concrete. A new series of tests was started to evaluate partially impregnated concrete prepared from a concrete mix with a high entrained air content, and high-pressure steam-cured concrete.

Development of PIC for desalting plant applications continued with testing of 60 wt percent styrene - 40 wt percent TMPTMA and 70 wt percent MMA - 30 wt percent TMPTMA impregnated concrete for compressive strength, tensile strength, flexural strength, shear strength, thermal properties, creep deformation, and long-term exposure to distilled water, brine, vapor, and the brine-vapor interface. Tests were conducted at temperatures ranging from -23° to 177°C.

Preliminary design values have been calculated for compressive strength, Poisson's ratio, and modulus of elasticity for 70 wt percent MMA - 30 wt percent TMPTMA and 60 wt percent styrene - 40 wt percent TMPTMA impregnated concrete at various temperatures. The values were

obtained from compressive strength tests and are for short-term exposures at the various temperatures. A trend toward lower values with increasing temperature was observed. The lowest values for compressive strength, found at 143°C, are 13,700 psi for the styrene - TMPTMA and 12,000 psi for the MMA - TMPTMA impregnated concrete.

OSW-type concrete impregnated with 60 wt percent styrene - 40 wt percent TMPTMA has been exposed for 2 years to brine at 121° and 143°C. CP-type concrete impregnated with the same monomer system has been exposed for 1 year to brine, vapor, and the brine-vapor interface at 121° and 143°C. The PIC specimens show a trend toward lower compressive strengths with increases in exposure time and temperature. Compressive strengths ranged from 16,200 psi for specimens exposed for 215 days in 121°C brine to 10,300 psi for specimens exposed for 2 years in 143°C brine. The specimens also show minor increases in weight, due to moisture absorption, and a small progressive expansion with increase in exposure time and temperature. Specimens of 70 wt percent MMA - 30 wt percent TMPTMA impregnated concrete are being tested, but results are not yet available. In pressure vessel tests of PIC specimens exposed to brine and distilled water, 70 wt percent MMA - 30 wt percent TMPTMA PIC specimens were observed to undergo failure after 270 days of exposure at 143°C and 83 days at 177°C. Analysis of these results will determine whether continued testing of this system is desirable.

In the area of fundamental studies, composite materials theory was used to calculate the modulus of elasticity of concrete-polymer materials, porosimetry studies of high-pressure steam-cured cement paste were made, and the stability of 60 wt percent styrene - 40 wt percent TMPTMA polymer exposed to brine at high temperatures was determined. The high modulus of elasticity of PIC appears to result from the stiffening produced by incorporation of a rigid polymer into the pores of the cement paste.

High-pressure mercury porosimetry studies showed that cement paste with a high water-to-cement ratio has a group of large pores that are not present in cement paste with a low water-to-cement ratio. Studies were also conducted to determine whether steam-cured and water-cured polymer-impregnated cement pastes undergo changes in porosity when exposed to a high-pressure steam environment. Results indicate that steam-cured cement is more stable than water-cured cements in a high-pressure steam environment, and that polymer impregnation does not completely seal either water-cured or steam-cured cement.

The studies of 60 wt percent styrene - 40 wt percent TMPTMA indicate that this polymer is stable in sealed exposure to brine, air,  $\text{Ca(OH)}_2$  slurry, and distilled water at 150°C. In preliminary studies of 70 wt percent MMA - 30 wt percent TMPTMA PIC, several specimens have failed in exposure to hot brine. Differential thermal analysis has revealed changes in the MMA-TMPTMA polymer after exposure to hot brine, which indicates that the failure of PIC is due to degradation of the polymer rather than of the concrete.

Fundamental studies were conducted of the reaction between MMA and  $\text{Ca(OH)}_2$ . One study indicated that MMA reacts with  $\text{Ca(OH)}_2$  during thermal polymerization. The other showed that MMA reacts rapidly with  $\text{Ca(OH)}_2$

in the presence of water to form calcium methacrylate and methyl alcohol. The significance of these findings is not understood.

In the search for nondestructive test methods for quality control of PIC, the acoustic impact and the dielectric methods were investigated. The acoustic method appeared more suitable for measuring resonant frequency than dampening of transmitted signals. Further work on dielectric and electrical resistivity measurements indicated that the dielectric method was not feasible for PIC.

The use of PIC as a construction material is under investigation in such diverse areas of application as desalting plants, concrete pipe, bridge decks, piling, housing construction, marine applications, and tunnel lining and support systems.

PIC draintile has been under test for 3 years in the laboratory and in the field at the Westlands Experimental Drainage Plot, Tranquility, California. This area has a high concentration of sulfates in the soil. A field inspection last year revealed no indication of sulfur attack; further inspection is planned.

In a cooperative program with the American Concrete Pipe Association, 3-ft-i.d. by 6-ft-long lengths of concrete pipe are being impregnated and polymerized at the USBR and BNL. Steel-fiber-reinforced concrete pipe has also been included in the program. The PIC pipes will be tested at the USBR next year. The testing program includes three-edge bearing and hydrostatic pressure tests and tests for resistance to attack by sulfate and sulfuric acid. The performance of the unreinforced PIC pipe will be compared with that of conventional steel-reinforced precast concrete pipe. The goal of the program is to provide design information, determine service requirements and manufacturing techniques, and make an evaluation of economic benefits.

Field tests of PIC sewer pipe are in progress in the San Diego sewage system in a cooperative program with the city of San Diego. In laboratory tests, PIC pipe specimens treated with a polyester-styrene seal coat and exposed to 5 percent sulfuric acid show no deterioration. PIC pipe installed in the San Diego sewage system is scheduled for inspection after 18 months in service.

A low-cost high-strength PIC tunnel lining and support system is under development. A full-scale laboratory test was conducted on an 8-ft-i.d. tunnel test chamber. Tunnel liner segments of PIC and unimpregnated concrete were assembled in the test chamber, backfilled with concrete, and loaded until failure. Single segments were also tested for arch deflection and failure and analysis of the joint. The test showed that 2-in.-thick PIC segments with 3.5 in. of concrete backfill can support 60 percent more load than a similar system composed of unimpregnated concrete segments. Further full-scale tests are planned for next year.

The Federal Highway Administration is interested in the potential of concrete-polymer materials for use in a number of highway applications. These include bridge decks, pilings, and culverts.

Programs have started on design of a precast, prestressed PIC bridge-deck system, repair of deteriorated bridge decks, and treatment of new concrete bridge decks to improve durability.

B58 DePuy, G. W., and Dikeou, J. T., "Development of Polymer-Impregnated Concrete As A Construction Material for Engineering Projects," *Polymers in Concrete*, SP 40-3, pp 33-56, 1973, American Concrete Institute, Detroit, Mich.

The developmental program for polymer-impregnated concrete (PIC) has shown that a material of greatly improved properties, as compared with conventional concrete, can be routinely produced. Applications of this remarkable new material are now under active investigation. Typical structural properties at ambient and elevated temperatures are presented and results of durability tests are reviewed. The program has advanced from the stage of determining the basic characteristics and engineering properties of PIC to the gathering of statistically significant data for preliminary design purposes. Tests have shown that good quality PIC can be produced from precast concrete of widely varying quality and composition, and cured by different methods although some differences in the resultant properties can be expected due to porosity, composition of mix, curing conditions, and other factors affecting concrete properties. The main factor in producing high quality PIC is achieving a high degree of impregnation and complete polymerization. Potential applications currently under study for PIC include saline water distillation plants, precast tunnel liners and supports, concrete pipe, bridge decks, wall panels and beams, and marine structures. Field tests are in progress for polymer-impregnated draitile and sewer pipe and are being planned for precast PIC tunnel liners.

B59 Fowler, D. W., Houston, J. T., and Paul, D. R., "Polymer-Impregnated Concrete for Highway Applications," Report 114-1, Feb 1973, The University of Texas at Austin, Center for Highway Research, Austin, Tex.

Polymer-impregnated surface treatments have been developed to improve durability of bridge decks. Several monomer systems have been identified that, after soaking into concrete, can be polymerized at temperatures of 125°F or higher. The strength and stiffness of the polymer-impregnated concrete are increased by several times.

Surface treatment evaluations were performed to determine the effectiveness of the treatments. Freeze-thaw tests indicated that field treated slabs were more durable than nonair-entrained control slabs. Air-entrained control slabs were quite durable but were less resistant to scaling than treated slabs. Treated slabs resulted in improved watertightness in all cases. After undergoing freeze-thaw tests, many impregnated slabs maintained a relatively watertight concrete surface.

In wear track tests, eight of nine polymer treatments provided significantly higher skid resistance than control slabs. After grit and water were applied, the skid resistance of all treated specimens decreased; however, at the termination of the test all treated specimens had a skid resistance equal to or slightly higher than the control specimens had. Surface wear was about equal for treated and untreated

slabs. Wear measured by sandblast tests showed a higher abrasion resistance for treated slabs.

Tests on surface-treated reinforced beams indicated a 22 percent higher strength than for untreated beams. Under cyclic loading, no spalling of the surface has been observed to date. Unreinforced beams broken in flexure have been repaired successfully with monomer systems that yield approximately the original flexural strength.

Significant savings are likely if the surface treatment procedures are implemented.

B60 Fowler, D. W., Houston, J. T., and Paul, D. R., "Polymer-Impregnated Concrete Surface Treatments for Highway Bridge Decks," *Polymers in Concrete*, SP 40-5, pp 93-118, 1973, American Concrete Institute, Detroit, Mich.

The significant increases in strength and durability of polymer-impregnated concrete suggest the use of this material as a surface treatment for highway bridge decks. Several monomers have been used successfully to obtain treatments that can be field applied. The concrete slab surface is kept wetted with the monomer for several hours. External heat is supplied by one of several methods to polymerize the monomer to a depth of 0.5 to 1.5 in. (1.37 to 3.8 cm). Evaluation tests on the treated specimens indicate excellent resistance to freeze-thaw deterioration, water penetration, abrasion, and wear. Skid resistance has generally been found to be equal to or superior to nontreated slabs. The treatments appear to be practical and economically feasible for applications to highway bridge decks.

B62 Hasselman, D. P., and Penty, R. A., "Stress Concentrations in Polymer-Impregnated Porous Brittle Materials," *American Ceramic Society Journal*, Vol 56, Feb 1973, p 105.

Data suggest that strengthening of a porous brittle material by polymer impregnation can be attributed largely to major decreases in stress concentrations in the matrix combined with a major contribution by the load-bearing ability of the polymer. The effect is particularly pronounced for very flat pores.

B63 Heins, C. F., "Ambient Pressure Impregnation of Concrete by Low Viscosity Monomers," *Polymer Preprints*, Vol 14, No. 2, Aug 1973, p 1130.

When precast portland cement concrete is saturated with a monomer such as methyl methacrylate and the monomer polymerized, a new composite material, dubbed polymer impregnated concrete (PIC) is formed. Properly prepared PIC is an exceptional engineering material. It possesses roughly four times the compressive and tensile strength of concrete, twice the elastic modulus, one-tenth the creep, and is extremely durable in environments that rapidly destroy ordinary concrete. However, PIC is

relatively expensive. Materials costs alone are more than twice those of ordinary concrete. Processing requirements add even more to the cost and limit the possible applications of this material.

Current technology involves placing a dried precast structure in a vessel which is evacuated, filled with monomer, pressurized and drained. The saturated specimens are then polymerized by gamma radiation or by thermocatalytic means. Many situations exist in which an in situ process would be desirable. In these cases the pressure cycles and total immersion of the specimen in monomer are either impractical or impossible, and impregnation from only one side of the structure would be a necessity. The partial impregnation of a concrete pier to make it resistant to salt water spray is a good example of such an application.

This paper reports the results of a study of the effects of different variables on the rate of surface impregnation by low viscosity monomers at ambient pressure.

1. The addition of surfactants to methyl methacrylate and styrene did not improve their rate of uptake by concrete.
2. Predrying of concrete decreased by at least a factor of two the time required to obtain a given loading of monomer.
3. Uptake of monomers appears to proceed by way of a capillary diffusion process. Increasingly slower rates of impregnation by monomers containing carboxylic acid functional groups may result from reactions of the acids with basic compounds in the concrete.

B64 Kukacka, L. E., and Romano, A. J., "Process Techniques for Producing Polymer-Impregnated Concrete," Polymers in Concrete, SP 40-2, pp 15-32, 1973, American Concrete Institute, Detroit, Mich.

Techniques for producing polymer-impregnated concrete (PIC) are evaluated and a processing cycle recommended. A study of concrete mix variation indicates that this parameter has only a small effect on the final strength of the composite. The impregnation of high-pressure steam-cured concrete produces PIC with strengths greater than those obtained from fog-cured material.

Impregnation parameters such as vacuum, pressure, soaking time, and methods of encapsulation all have an effect on the strength of PIC. The degree of sample evacuation is one of the most important parameters. Complete saturation and therefore maximum improvement in strength and durability is accomplished only after prior evacuation to  $\approx 30$  in. Hg (760 mm).

The feasibility of using water as a means of reducing monomer losses due to evaporation and drainage has been demonstrated. Test data indicate that the underwater polymerization of methyl methacrylate has no detrimental effects on the properties of the composite and may even produce benefits due to the increased polymer content.

B65 Levitt, M., et al., "Comparison of Concrete Polymer Composites Produced by High Energy Radiation," Journal, Prestressed Concrete Institute, May-Jun 1973, pp 35-41.

The radiation polymerization of four different concretes impregnated with either methyl methacrylate, or a proprietary system developed at Harwell, England, has shown that substantial improvements in properties can be obtained. The modulus of elasticity was increased by as much as 40 percent and the initial surface absorption, an indication of durability, was improved in all cases. Although the presence of moisture reduced the polymer loadings obtained, the initial surface absorption results reached their best values when water was present in the concrete at the time of impregnation.

B66 Lott, J., and Birkimer, D., "Polymerized Lightweight Structural Elements," p 11, May 1973, Army Construction Engineering Research Laboratory, Champaign, Ill.

Impregnation of concrete materials with polymers was extended to include the impregnation of lightweight foam concretes. Filling approximately 90 percent of the extensive void system of the foam concrete with a polymer increased the compressive strength from 202 psi to 3,250 psi, the splitting tensile strength from 30 psi to 1,008 psi, and the modulus of elasticity from 100,000 psi to 425,000 psi. Beam structural elements were partially impregnated to produce a 'sandwich panel' element which can use the foam concrete core to act as an insulator and as a spacer to separate the polymer impregnated surface regions; and can use the polymer impregnated surface regions to resist loadings. The sandwich element produced thus uses materials efficiently to satisfy the multiple functional requirements of load and of environment.

B67 Manning, D. G., and Hope, B. B., "The Influence of Porosity and Partial Drying on Properties of Polymer Impregnated Mortar," *Polymers in Concrete*, SP 40-9, pp 191-205, 1973, American Concrete Institute, Detroit, Mich.

Three mortar mixes of widely differing porosities were impregnated with three vinyl monomers and methanol. The monomers were polymerised thermally using a free radical initiator. Specimens of one of the mortar mixes were dried to different relative water vapor pressures prior to impregnation with either methyl methacrylate or styrene. The compressive strength was determined in all cases and the strains in the partially dried specimens were recorded throughout the processing cycle. The compressive strength of the impregnated mortars was found to be a function of both porosity and the properties of the matrix and polymer. Length changes during processing were dependent on the degree of drying. Maximum swelling in monomer occurred in specimens stabilised at intermediate relative humidities.

B68 Manson, J. A., Chen, W.-F., Vanderhoff, J. W., Liu, Y.-N., Dahl-Jorgensen, E., "Stress-Strain Behavior of Polymer-Impregnated Concrete," *Polymer Preprints*, Vol 14, No. 2, Aug 1973, pp 1203-1208.



A study was begun to determine the effect of polymer state (i.e., glassy or rubbery) on the stress-strain behavior and fracture morphology of PIC and the extent to which the mode of failure can be controlled. Various mixtures of methyl methacrylate (MMA) and butyl acrylate (BA) were polymerized in porous mortar and concrete substrates, to give examples of polymer behavior ranging from glass to rubbery, and the stress-strain behavior of the PIC specimens was determined.

B69 McNeil, M. L., "An Investigation of the Durability Properties of Polymer-Impregnated Concrete Surface Treatments," M.S. Thesis, The University of Texas at Austin, Austin, Tex., May 1973.

This research was conducted to investigate the durability properties of polymer-impregnated concrete surfaces. The investigation was primarily directed toward improving the durability of highway bridge decks. The monomer system that achieved the most success was methyl methacrylate; 1 percent of the catalyst, benzoyl peroxide; and 10 percent of the cross-linking agent, trimethylolpropane trimethacrylate.

The specimens were exposed to a 24-hr water penetration test, usually resulting in a penetrated depth of 2 to 3 in. for untreated slabs and essentially zero penetration for polymer-impregnated slabs. Treated concrete proved to be more resistant than control slabs when subjected to sandblast abrasion, especially for relatively low quality, untreated concrete. Exposure to freeze-thaw cycling with water ponded on the slab surface was considered to simulate a mechanism of deterioration for concrete bridge decks. It was found that nonair-entrained control slabs usually fail by severe scaling and cracking after 25 to 55 cycles whereas several polymer treatments remained in relatively good condition through 100 to 120 cycles at which point the testing was stopped. It was found that air-entrained control slabs proved to be volumetrically stable through 100 to 120 cycles of freeze-thaw testing with light to moderate scaling. Treated slabs of the same concrete exhibited similar behavior with only negligible to light scaling. Slabs tested in the wear track facility were subjected to 420,000 wheel passes of a rotating, weighted tire. Generally, the wear and skid resistance of both the control and treated slabs were about the same. Crack repair tests were performed on small, broken, unreinforced, concrete beams by securing the broken specimens with polymerization. It was found that certain treatments gave strengths approaching or equal to the original strength when the beams were retested in flexure.

B70 Price, E., and Lott, J., "Polymer Impregnated Fibrous Cellular Concrete for BMD Facilities," p 23, Jul 1973, Army Construction Engineering Research Laboratory, Champaign, Ill.

The objective of the study was to evaluate the structural behavior of polymer-impregnated, fibrous cellular concrete (PFCC) elements to see if further consideration of the use of such material systems is warranted for BMD facilities. A fibrous cellular concrete was impregnated with

polyester resin to obtain polymer-impregnated, fibrous cellular concrete (PFCC) test specimens. Structural behavior was examined by testing simply supported beams; material behavior was determined by compression cylinder tests. Flexural behavior was evaluated based on the observed behavior of PFCC and steel reinforcing bars.

- B71 Ramachandran, V. S., and Sereda, P. J., "Differential Thermal Studies of Polymethyl Methacrylate-Impregnated Cement Pastes," *Thermochemica Acta*, Vol 5, No. 4, 1973, pp 443-50.

Differential thermal curves have been obtained for two polymethyl methacrylate-impregnated cement pastes prepared at a water/cement ratio of 0.37 and 0.70. Complex thermal effects, including a substantial decrease in the endothermal peak for  $\text{Ca}(\text{OH})_2$  decomposition, were observed in samples heated in air. These effects originate in the portland cement paste, in the polymer, and from interactions between the polymer and the hydrated cement during heating. Less complex effects resulted when DTA was carried out in  $\text{N}_2$ . There was no evidence of a reaction between the hydrated cement and PMMA during impregnation.

- B72 Reich, M., and Koplik, B., "Analysis of Bridge Decks Using Polymer Impregnated Concrete," *Polymers in Concrete*, SP 40-12, pp 247-283, 1973, American Concrete Institute, Detroit, Mich.

During the last few years extensive research has been carried out with the aim of developing polymer-impregnated-concrete (PIC) composites for improved materials of construction. Remarkable improvements in permeability and strength have been observed and reported in the literature. The materials, however, fail in a brittle manner and are substantially more expensive than regular concrete. One of the most frequently encountered structural problems on the interstate highway system is the cracked and deteriorated bridge deck. The use of polymer-impregnated-concrete with its low permeability and high strength may offer a solution to the bridge deck problem. In view of the brittle behavior and higher cost of these materials, the importance of a thorough in-depth stress analysis for the PIC designs cannot be over-emphasized. Three different finite element techniques applicable for most designs anticipated for these materials are demonstrated by several sample solutions. A design of a small overpass that can be manufactured in a facility recently completed at Brookhaven National Laboratory as well as future bridge deck designs are discussed in detail.

- B73 Sople, B., Fiorato, A. E., and Lenschow, R., "A Study of Partially Impregnated Polymerized Concrete Specimens," *Polymers in Concrete*, SP 40-7, pp 149-173, 1973, American Concrete Institute, Detroit, Mich.

An experimental program to study the preparation and properties of partially impregnated polymerized concrete specimens is described.

Preparation consisted of the impregnation of hardened and dried concrete with methyl methacrylate monomer followed by polymerization. Combining the sealing and polymerization stages of production by polymerizing the specimens in warm water gave uniform results. Variations in the original concrete quality and its treatment prior to soaking did not radically alter the compressive strengths obtained for the polymer-impregnated specimens, but did influence the speed of the drying and soaking stages of production, as well as the total monomer loading. A controlled, uniform depth of polymer penetration was obtained by varying the duration of soaking. The stress-strain curve for the partially-impregnated polymerized specimens was essentially linear up to from 70 to 75 percent of failure and deviated from linearity by only 10 to 15 percent at failure. No significant shrinkage or creep was measured on polymer-impregnated specimens or on corresponding dried and sealed concrete control specimens. The limiting sustained load capacity for polymer-impregnated concrete prisms was between 70 and 75 percent of their ultimate short-term strength.

B74 Tazawa, E., and Kobayashi, S., "Properties and Applications of Polymer Impregnated Cementitious Materials," Polymers in Concrete, SP 40-4, pp 57-92, 1973, American Concrete Institute, Detroit, Mich.

Basic problems related to manufacturing of polymer impregnated cementitious materials are discussed. Experimental studies on drying, impregnation and polymerization are presented. In addition to these conditions of the treatment, mix proportion of the base material should be carefully selected so as to optimize a property aimed at. Mechanical strength of PIC is influenced by self stress generated in the material possibly due to shrinkage caused by polymerization and the difference in thermal coefficients of expansion of polymer and concrete. Annealing and addition of a plasticizer are useful methods in reducing this self stress. Improvement of strength is analysed by Griffith theory, and uniformity of PIC is evaluated by Weibull's theory. Both of these analyses indicate that the impregnation is a reasonable method to improve mechanical properties of cementitious material, though shrinkage caused by this treatment should be deliberately taken into account when the material is further reinforced with steel or other fibers. Products manufactured by the process studied in this report have shown good performance in actual service to date.

B75 Thurman, A. G., "Polymer Impregnated Precast Concrete Bridge Deck," In partial fulfillment of Contract No. 14-06-D-7369 to the Bureau of Reclamation, Aug 1973, Prestressed Concrete of Colorado, Inc. and Allen G. Thurman, Chicago, Ill.

This report is part of an overall research program on polymer impregnated precast concrete bridge deck panels being conducted jointly by the Federal Highway Administration, the Bureau of Reclamation and the

Prestressed Concrete Institute. It is specifically intended to define panels suitable for use in the physical testing portion of the research program. In addition to serving the planned research program, the design, fabrication and erection criteria necessary for the incorporation of such panels into a future full-service prototype bridge is considered.

The calculations and explanatory comments lead to the following recommendations for the test panels: panel size should be 4 ft by 16 ft by 6 in.; the panels are to be transverse to traffic flow and continuous over two concrete bridge girders spaced not over 8 ft center to center; reinforcement should be limited to pretensioning longitudinal to the panel and nominal posttensioning longitudinal to the bridge; product cement and natural aggregates should be used to provide 4,000 psi minimum release strength and 15,500 psi minimum 28-day strength; the panels should be fully impregnated to provide 16,000 psi minimum compressive strength; and the panel connections are to develop panel to panel shear transfer and panel to girder composite action.

B76 Toyer, M., "Plastic Concrete: Development and Potential Applications," *Commission of the European Communities, Brussels, Bureau Euristop, May 1973, p 35.*

Plastic concrete is a new construction material perfected in the nuclear research laboratories of the United States. This booklet gives a brief summary that will serve as an introduction to the specialized literature and possibly will permit the resolution of some problems of construction or of industrial technology that remain unsolved.

B77 Vanderhoff, J. W., Hoffman, J. D., and Manson, J. A., "Polymer-Impregnated Concrete: Rate of Penetration of Monomer," *Polymer Preprints*, Vol 14, No. 2, Aug 1973, pp 1136-1141.

The practical objective of this study is to develop a functional relationship to predict penetration behavior in large slabs from small laboratory specimens. The fundamental objective is to better understand the physical chemistry of penetration of liquids into porous substrates. The purpose of this paper is to present preliminary results of rate-of-penetration experiments using standard portland cement mortar specimens as substrate.

B77(1) Ohama, Y., "Basic Study on Manufacturing Process of Polystyrene-Impregnated Concrete by Heat-Polymerization-in-Hot-Water Method," *Journal of the Society of Material Science, Japan*, Vol 22, No. 232, 1973, pp 57-61.

In the experiments reported here, styrene monomer having about 1/3 of the cost of methyl methacrylate monomer was selected for impregnation and the basic conditions for manufacturing polystyrene-impregnated concretes were examined by using the heat-polymerization-in-hot-water method, which enables impregnated monomer to polymerize, but prevents

the evaporation of monomer from the base material by hydrostatic pressure. In this case, the polystyrene-impregnated mortar or concrete was specially prepared by the heat-polymerization-in-hot-water method after impregnating a dried mortar or concrete with styrene monomer (with addition of trimethylolpropane trimethacrylate (TMPTMA) as a crosslinking agent and benzoyl peroxide as a catalyst), and the basic conditions of its process, that is, the composition of impregnating monomer, the temperature of hot water, the immersion time and the polymer-impregnating thickness (or polymer-penetrating depth), were examined.

The conclusions obtained from these experiments are summarized as follows:

(1) The composition of suitable impregnating monomer is: styrene 90, TMPTMA (crosslinking agent) 10, 50 percent DOP solution of benzoyl peroxide (catalyst) 4~6 (by weight).

(2) The heat-polymerization-in-hot water can be attained by immersing the mortar or concrete impregnated with the monomer in hot water at temperature of 70°C to 90°C for 2 hr or more.

(3) The polymer-impregnating thickness can be controlled by varying the evacuation time as well as the soaking time (in the monomer) of the base materials.

B78 Waide, C. H., et al., "Mine Safety and Underground Support Structures Rock Impregnation and Pumpable Rockbolt Development," BNL-50402, Jun 1973, Brookhaven National Laboratory, Upton, N. Y.

A pumpable roofbolt system was developed based on the installation of a reinforcement consisting of flexible bundles of continuous glass roving fibers delivered from reels into a drill hole simultaneously with the pumping in of a high-flashpoint fire-retardant polymer resin filled with milled glass fiber. Polymerization of the resin with a promoter-catalyst system fixes the bundles and produces a rigid bolt having a tensile strength >20,000 psi bonded to the wall of the hole along its entire length. Incorporation of an expansion agent and a bonding agent in the polyester resin ensures maximum contact with the wall during and after polymerization.

The process was demonstrated by three field tests at the White Pine Copper Company mine in Michigan. In the last test, a roof support test involving 150 bolts placed in a mine intersection, after 5 months the roof condition compared favorably with that of an adjacent intersection bolted with resin-grouted bolts.

In the rock impregnation work, several monomers and resins and a variety of impregnation techniques were used with coal-mine shale and coal. Although monomer loadings were low, in the range of 0.5 wt percent, improvement in the tensile strength of cores (the most sensitive test found) ranged up to a factor of eight times that of control samples, tending to be greatest where shale quality was poorest.

B78(1) Vanderhoff, J. W., Hoffman, J. D., and Manson, J. A., "Polymer-Impregnated Concrete: Rate of Penetration of Monomer," Polymer Preprints, Vol 14, No. 2, Aug 1973, pp 1136-1142.

Because PIC effectively resists penetration by water and salt solutions, several research programs have been initiated to apply PIC technology to highways, in particular, to bridge decks, in which the corrosion of steel reinforcing rods by deicing salts is a pressing problem. The practical application of PIC technology in the field requires the development of monomer-impregnation techniques. In the laboratory, PIC is prepared by placing cured concrete specimens in a chamber, which is then evacuated; monomer is then introduced and allowed to infuse the concrete specimen; after sufficient time has elapsed, the impregnated specimen is removed and the monomer is polymerized by high-energy radiation or free-radical initiators. This method produces completely-impregnated specimens limited in size only by the size of the evacuation chamber. In the field (e.g., highway or bridge deck), however, the impregnation must be carried out either at atmospheric pressure or by using a yet-to-be-developed pressure applicator.

To date, laboratory impregnations at atmospheric pressure of freshly-cured, uncontaminated concrete slabs have shown that the maximum depth of penetration is less than 1 in. in most cases and up to 2.5 in. in a few cases. Preliminary tests of the latter specimens have shown that they are particularly resistant to corrosion. In the field, however, the highways and bridge decks are likely to be contaminated with deicing salts, which reduce the porosity of the concrete. Moreover, penetration to a depth of 4 in. is necessary if the PIC layer is to encompass the top layer of reinforcing rods.

Since the few available data show that monomers penetrate rather slowly into concrete at atmospheric pressure, the rate of penetration was investigated as a function of the monomer structure and properties, as well as the experimental conditions of impregnation. The practical objective of this study is to develop a functional relationship to predict penetration behavior in large slabs from small laboratory specimens. The fundamental objective is to better understand the physical chemistry of penetration of liquids into porous substrates. The purpose of this paper is to present preliminary results of rate-of-penetration experiments using standard portland cement mortar specimens as substrate.

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B79 Auskern, A., and Horn, W., "Fracture Energy and Strength of Polymer Impregnated Cement," BNL-18661, p 16, Feb 1974, Brookhaven National Laboratory, Upton, N. Y.

The fracture energy, or effective surface energy of hardened cement paste and polymer-impregnated hardened cement paste, was measured by an analytical method. The fracture energy of polymer-impregnated hardened cement paste is considerably higher than the unimpregnated paste ( $7.5 \times 10^4$  to  $0.91 \times 10^4$  ergs/cm<sup>2</sup>). The increase appears to be entirely due to the polymer contribution. The results predict a factor of 5 improvement in the fracture strength of hardened cement paste upon polymer impregnation.

B80 Blankenhorn, P. R., Weyers, R. D., Kline, D. E., and Cady, P. D., "Enclosed Soak System for Deep Polymer Impregnation of Concrete Bridge Decks," Transportation Engineering Journal, 15-19 Jul 1974.

Steinberg and his associates at the Brookhaven National Laboratory (BNL), Upton, N. Y., and elsewhere have been active in impregnating monomers into concrete with subsequent polymerization to improve the physical properties of the concrete. Most of that work centered around low viscosity monomers, e.g., methyl methacrylate (MMA). Steinberg, et al. also have reported that polymer-impregnated concrete (PIC) displays significant increases in compressive strength, elastic modulus, freeze-thaw durability, etc. In addition to research in PIC with low viscosity monomers, some work has been reported using high viscosity monomers, e.g., epoxy resin.

Presently research is being conducted at the BNL, United States Bureau of Reclamation, University of Texas, California Department of Transportation, Lehigh University/Pennsylvania State University, and elsewhere, in efforts to apply laboratory knowledge to the impregnation of concrete in the field. A large portion of the emphasis is in the area of impregnation of existing bridge decks, with the goal of prolonging the serviceability of the bridge.

In general, the problems encountered in impregnating a bridge deck center around drying, impregnation, and polymerization. Specific areas include method of drying (infrared, hot air, microwave, etc.), time required to dry the deck to a specific depth, depth of penetration required, monomer system, impregnation method (soak, vacuum, pressure, etc.), rate of monomer penetration, polymerization method, and time necessary for polymerization. The depth of penetration required is important because it governs the time needed to dry, impregnate, and polymerize the concrete.

Different methods for achieving the drying, impregnation, and polymerization of bridge decks have been proposed. It is the purpose of this paper to present infrared drying data, a soak impregnation method, and subsequent polymerization data needed to achieve 4-in. penetration of large slabs and a bridge deck.

B81 Chen, W.-F., and Jorgensen, B. D., "Polymer-Impregnated Concrete as a Structural Material," Magazine of Concrete Research, Vol 26, No. 86, Mar 1974, pp 16-21.

Polymer-impregnated concrete (PIC) impregnated with the most often used polymers, polymethyl methacrylate and polystyrene, shows little ductility. The ultimate strength is often three to four times higher than that of ordinary concrete, but failure comes without warning in a brittle, almost explosive manner. This paper reports an investigation designed to increase the ductility of PIC so that some plastic yielding can take place before and after the ultimate load is reached. Various percentages of monomer combinations of the methyl methacrylate were used

with an elastomer, n-butyl-acrylate. The entire stress-strain relationship of the materials was determined by means of the splitting tensile and axial compression tests. The investigation shows that PIC can be modified to give either a material with high strength and little ductility or one with a somewhat lower strength and large ductility. Thus, potentially material properties can be tailored to particular structural service requirements.

B82 Cowan, W. C., and Riffle, H. C., "Investigation of Polymer-Impregnated Concrete Pipe," p 55, Sep 1974, Bureau of Reclamation, Engineering and Research Center, Denver, Colo.

The evaluation of structural and durability properties of polymer-impregnated concrete (PIC) pipe as compared with those of commercially manufactured concrete pipe is presented in three separate studies: (1) 4-in.-diameter concrete draintile, (2) 12- and 24-in.-diameter concrete sewer and culvert pipe, and (3) 36-in.-diameter concrete culvert pipe. Impregnation and polymerization of concrete pipe result in significant improvement in strength and durability. Polymer impregnation of concrete draintile increase the three-edge bearing strength from about 70 to 280 percent above that of the untreated pipe. The three-edge bearing strength of 12- and 24-in. unreinforced concrete sewer and culvert pipe was increased from about 110 to 150 percent by polymer impregnation. Unreinforced 36-in.-diameter PIC pipe exceeded the ASTM: C 76 requirements for ultimate three-edge bearing load by 50 to 90 percent. Polymer-impregnated 36-in.-diameter concrete pipe subjected to 5 percent sulfuric acid showed increases in resistance to sulfuric acid attack of from 2.8 to 7.8 times that of the untreated concrete pipe.

B83 Dahl-Jorgensen, E., Chen, W.-F., Manson, J. A., and Vanderhoff, J. W., "Polymer-Impregnated Concrete: Laboratory Studies," p 31, May 1974, Lehigh University, Fritz Engineering Laboratory, Bethlehem, Pa.

To aid in the development of polymer-impregnated portland cement (PIC) for highway bridge deck and other structural applications, a laboratory study of several process and material parameters was conducted. It was shown that (1) stress-strain behavior could be varied over a wide range, from ductile to brittle, by using combinations of a plasticizing and/or crosslinking comonomer with methyl methacrylate; (2) the presence of a realistic level of salt (up to 1 percent) in concrete has little effect on polymer loading and mechanical properties, but requires more rigorous drying; (3) while high temperatures (750 F) accelerate drying but decrease strength, subsequent polymer impregnation essentially yields a PIC with properties similar to a conventionally dried material; and (4) salt penetration (short-time, static) in mortars is reduced in order of magnitude by polymer impregnation, regardless of whether the polymer is glassy or rubbery. Thus, strong PICs can be



prepared under a variety of drying and salt contamination conditions, and the mechanical behavior of PIC can be tailored to various specifications by varying polymer composition, without diminishing PIC's improved resistance to salt penetration.

B84 Datta, R. K., and Dass, K., "Studies on Polystyrene Impregnated Cement Mortar and Concrete," The Indian Concrete Journal, Jul 1974, pp 231-234.

The concept of improving the strength and other properties of cement concrete by impregnating organic monomers in the preformed elements, and polymerising them in situ is relatively new. It has been shown that hardened cement concrete can be fully or partly impregnated with a suitable monomer and the monomer polymerised in situ either by radiation or by thermal-catalytic methods. The most suitable monomers for this purpose are methyl methacrylate (MMA), styrene, and a few others. Enormous improvements in strength and durability of concrete by this technique have been reported by several investigators. In most of the investigations dense concretes were used and the impregnation of monomer into the concrete was carried out using vacuum and pressure techniques for maximum polymer loading and strength. The present investigation was carried out using leaner mixes of mortar and concrete including lightweight concrete, and the impregnation was done simply by immersing the dry specimens in the monomer, avoiding the other complicated techniques. Only one monomer, namely, styrene, was used because of its indigenous availability. The thermal-catalytic method of polymerisation was adopted in view of its simplicity. The results of tests for compressive strength, flexural strength, tensile strength, water absorption, and chemical resistance are reported in this paper.

B85 Dutruel, F., "Concrete Impregnation Techniques," Precast Concrete, Vol 5, No. 4, Apr 1974, pp 197-200.

This article presents two methods of impregnation of concrete; case of total impregnation and case of partial impregnation.

#### Case of total impregnation

This technique aims at obtaining the maximum filling of the pores, thus reaching an impregnation ratio near unity. To attain this result, it is first necessary to empty the pores of their contents, particularly air and water, otherwise the amount of absorbed monomer and the rate of impregnation will be considerably reduced.

#### Case of partial impregnation

The technology of partial impregnation is related to that of total impregnation, while being considerably simplified.

In this case, it is not necessary to degas the concrete and only a partial drying out is necessary provided that the zone to be submitted to impregnation be thoroughly prepared. The nitrogen pressure which is intended to assist the penetration of the monomer is also not essential, and the entire operation can therefore be limited to drying, immersion,

and polymerisation. This technique, which is far more in line with economical considerations, seems to be of more practical interest to the precaster than the technique of total impregnation.

B86 Fowler, D. W., and Fraley, T. J., "Investigation of Polymer-Impregnated Brick Masonry," Journal of the Structural Division, American Society of Civil Engineers, Vol 100, No. ST1, Proc. Paper 10278, Jan 1974, pp 1-10.

Brick, brick prisms, and mortar specimens were impregnated with methyl methacrylate and polymerized by either a thermal-catalytic process or irradiation. Common brick and high-strength brick were used in the investigation. Compressive strength of polymer-impregnated common brick prisms increased 200 percent to 300 percent over the strength with a maximum of 18,088 psi, apparently the highest ever reported. Brick compressive strength and moduli of rupture, and mortar compressive and tensile strength also showed significant increases due to polymerization. The mortar-brick bond strength increased by more than 10 times. Thermal-catalytic polymerization produced higher strengths for common brick prisms and mortar specimens while polymerization achieved by irradiation produced higher strengths in the high-strength brick prisms. No significant differences were observed in the strengths of the brick polymerized by the two methods.

B87 Fowler, D. W., et al., "Corrosion Protection of Reinforcing Steel Provided by Polymer-Impregnated Concrete," Research Report 114-2, Dec 1974, Center for Highway Research, The University of Texas at Austin, Austin, Tex.

The protection against corrosion provided reinforcing bars by polymer-impregnated concrete was investigated. Partially-impregnated slabs and fully-impregnated piling specimens were used in the investigation. The slabs were sprayed with salt water for 20 months and the pilings were immersed in sea water for 12 and 28 months.

The bars from the control slabs had about 24 times more surface area corrosion than bars from the treated slabs. The chloride content in the treated slabs ranged from 4.6 percent to 38.2 percent of that in the control slabs.

The bars from the control piles had corrosion ranging from 10 percent to 39 percent over the surface area while the PIC specimens had corrosion over 0.5 percent or less of the bar area. The chloride content of the PIC slabs ranged from 3.4 percent to 8.5 percent of the chloride in the controls.

B88 Godard, P., and Mercier, J. P., "Impregnation and Polymerization of Vinylic Monomers in Porous Media. II. Polymerization In Situ," Journal of Applied Polymer Science, Vol 18, No. 5, 1974, pp 1493-1504.

In this work, we have studied the kinetics of polymerization of styrene and of methyl methacrylate in a porous asbestos cement medium initiated by the thermal decomposition of a radical initiator. Our results show that the presence of the porous medium appreciably modifies the rate of polymerization. Two factors have been proposed to explain this effect: a variation of the constant of decomposition of the initiator resulting from the alkalinity of the surface, and a modification of the rate constant of chain propagation related to the electron-releasing or attracting capacity of the double bond of the monomer.

B89 Godard, P., Delmon, B., and Mercier, J. P., "Impregnation and Polymerization of Vinyllic Monomers in Porous Media. I. Kinetics of Impregnation," Journal of Applied Polymer Science, Vol 18, No. 5, 1974, pp 1477-1491.

In this work, we have studied the mechanism and kinetics of penetration of monomers and of liquids of low molecular weight into porous media such as asbestos cements. Although the phenomenon is physically different from a molecular diffusion, the kinetics of impregnation are well represented by Fick's laws of diffusion. We observe an excellent agreement between the experiment and the theoretical equation as long as the degree of impregnation does not exceed 80 percent. If, in order to represent this, we use a simplified model introducing a flow governed by Poiseuille's law through a bundle of capillaries of the same diameter, we obtain a parabolic law which is verified up to only 55 percent. We have demonstrated the physicochemical parameters which influence the kinetics of impregnation.

B90 Godard, P., Delvaux, P., Faille, M. D., and Mercier, J. P., "Mechanical Properties of Impregnated Asbestos-Cement," Polymer. Eng. Sci., Vol 14, No. 61, 1974, pp 429-434.

This study is devoted to the mechanical properties of impregnated asbestos-cements. We studied the influence of the degree of impregnation and of the nature of the resin on modulus of elasticity and on the strength of the materials. The impregnation of asbestos-cement by polymeric resins produces composites of outstanding mechanical properties. The relative increase in flexural and tensile strength is much higher for mortar and concrete but the improvement produced by the polymer on asbestos-cement is especially significant if one takes into consideration the already high absolute strengths of the materials.

B91 Gunasekaran, M., Ichikawa, Y., and Dunlap, A. B., "On The Properties and Behavior of High Early Strength Light Weight Polymer Impregnated Concrete Reinforced with Alkali Resistant Glass Fibers," Fiber Reinforced Concrete, SP-44-15, pp 265-285, 1974, American Concrete Institute, Detroit, Mich.

Some of the principal structural properties of lightweight, sintered fly-ash aggregate concrete made with Regulated Set cement and reinforced with alkali-resistant glass fibers are presented. The influence of fiber quantity, fiber length, and surface treatment of the fibers, and also of polymer impregnation on the properties of the concrete are discussed. Within the limits of the experimental program it was found that (1) the addition of glass fibers improves the tensile strength of lightweight aggregate concrete significantly, (2) for a water-cement ratio of 0.4, and a fiber length of 0.5 in. or 1 in., the tensile strength of nonpolymer impregnated concrete appears to be enhanced more by the addition of about 1 percent of fibers (Owens-Corning No. 885, by weight) than by the addition of twice or even thrice this amount, (3) the tensile strength of polymer-impregnated concrete increases with an increase in its fiber content, (4) the shrinkage of laboratory specimens under varying conditions of temperature and humidity is influenced by the amount and length of the fibers used in the concrete, and (5) the flexural strength of 2-in. by 2-in. by 7-in. glass fiber reinforced polymer impregnated beams, tested as per ASTM C 293-68, was about 2000 psi.

B92 *Idorn, G. M., and Fordos, Z., "Cement-Polymer Materials," The VI International Congress on the Chemistry of Cement, Moscow, USSR, Sep 1974.*

The invention of polymer impregnated concrete as an application spin-off of recent atomic energy research in the USA is emphasized in the introduction to the paper, whereafter the broader field of cement polymer materials is surveyed. Polymer impregnated concrete is chosen to be dealt with in more detail. At first is described some important features of the porosity strength and the bond strength relationships in ordinary concrete. Next follow descriptions of the preparation technique for and the properties of polymer impregnated concrete, and some unsolved problems are discussed.

The potential applications of polymer impregnated concrete are discussed with a view to where excessive functional requirements to concrete can be expected to occur, and also considering economic parameters.

The possible future development of polymer based/cement based composite materials is outlined in some prospective comments which emphasize the need for basic research and for more communication between conventional cement and concrete research and polymer science and research.

The economic aspects and the need to integrate research and technological development are stressed in the concluding remarks.

B93 *Kasperkiewicz, J., and Skarendahl, A., "Bibliography on Fiber Reinforced and Polymer Impregnated Cement Based Composites," 1974, Swedish Cement and Concrete Research Institute, Stockholm.*

This bibliography contains 312 titles on fiber-reinforced cement based composites and 70 titles on polymer-impregnated cement based composites. Seven titles concern both subjects. The information was collected before July 1974.

- B94 Kosi, V., "Some Properties of Poly(Methyl Methacrylate) Impregnated Asbestos-Cement Materials," Cement and Concrete Research, Vol 4, No. 1, Jan 1974, pp 57-68.

After previous study of conditions in impregnating asbestos-cement samples with methyl methacrylate and its thermal-catalytically initiated polymerization "in situ," a series of informative experiments to improve asbestos-cement was carried out. Incorporating about 14 percent of poly(methyl methacrylate) into thin (6-mm), asbestos-cement panels, having a porosity of about 0.20 cm<sup>3</sup>/g, some of their properties have been improved similarly to those reported for the concrete (e.g., water absorption); some of them, however, to a much lesser extent (e.g., particular mechanical strengths). The following best results have been achieved:

- average flexural strength of dry samples increased for a factor of 1.37;
- average flexural strength of wet samples increased for a factor of 1.53;
- tensile strength (tension in the fibers' direction) increased for a factor of 1.20;
- resistance to 0.5 N hydrochloric acid increased for a factor of 1.74;
- water absorption decreased for a factor of nearly 20.

- B96 Mehta, H. C., Chen, W.-F., Manson, J. A., and Vanderhoff, J. W., "Use of Polymers in Highway Bridge Slabs," Report No. 390.10, Oct 1974, Lehigh University, Office of Research, Fritz Engineering Laboratory, Materials Research Center, Center for Surface and Coatings Research, Bethlehem, Pa.; Prepared for Presentation at Inter-Associations Colloquium, Behavior in Service of Concrete Structures, Liege, 4-6 Jun 1975.

The field experience with large-scale impregnations shows that it is just as easy to impregnate a larger area as a smaller one, with further savings in heat losses, pressure, impregnation and polymerization time. The stated objective of impregnating beneath the top reinforcing rebar has been achieved. The experience gained will make further trials successful enough to give promise not only of long range improvements in deck durability but also indicate its potential to become one of the key treatment procedure for the future. Future plans include additional testing on the impregnated deck area and impregnation trials on an actual bridge deck in service.

- B97 Mehta, H. C., Chen, W.-F., Manson, J. A., and Vanderhoff, J. W., "Innovations in Impregnation Techniques for Highway Concrete,"

Report No. 390.8, Jul 1974, Lehigh University Office of Research, Fritz Engineering Laboratory, Materials Research Center, Center for Surface and Coatings Research, Bethlehem, Pa.; Prepared for Presentation at the Annual Meeting of the Transportation Research Board, Washington, D. C., Jan 1975.

Preliminary experiments with two new approaches to the impregnation of bridge decks consisting of rubber-pressure mat impregnation (with MMA) and sulfur impregnation of moist concrete show excellent promise for economizing, simplifying and rationalizing the laboratory field techniques developed so far. Further work is continued in this area as they show promise of easy adaption for the large-scale impregnation of bridge decks, highways, and airfield runways.

B98 Mehta, H. C., Manson, J. A., Chen, W.-F., and Vanderhoff, J. W., "Polymer Impregnated Concrete: Field Studies," p 34, May 1974, Lehigh University, Fritz Engineering Laboratory, Bethlehem, Pa.

The principles developed in the laboratory for polymer impregnation of concrete to depths below the top layer of steel reinforcing rods were applied to the impregnation of large concrete slabs and a bridge deck. These principles include drying of the concrete to the desired depth of impregnation, allowing sufficient time for complete impregnation with monomer (e.g., using pressure to increase the rate of penetration), and selecting the monomer, not only for its cost and the properties of its polymer, but also for its rate and uniformity of penetration. The polymer-impregnated slabs show increased compressive and split-tensile strengths, decreased water absorption, and improved resistance to corrosion, freeze-thaw cycling, abrasion, and acid-etching. The polymer-impregnated bridge deck shows decreased water absorption and improved resistance to acid-etching. These improvements give promise of exceptional durability in practice.

B99 Ohama, Y., "Creep of Resin Concrete and Polymer-Impregnated Concrete," Proceedings of the Seventeenth Japan Congress on Materials Research, Society of Materials Science, Japan, 1974, pp 140-143.

In this paper, the compressive creep tests of the resin concrete using unsaturated polyester resin and polymer-impregnated concrete using methyl methacrylate are carried out and their creep behavior is discussed.

B100 Ohama, Y., "Relation Between Pulse Velocity and Compressive Strength of Polystyrene Impregnated Concrete," Proceedings of the Seventeenth Japan Congress on Materials Research, Society of Materials Science, Japan, 1974, pp 140-143.

The purpose of this study is to help developing a method of estimating its quality by establishing a relation between the pulse velocity

and the compressive strength of polymer-impregnated concrete. In this paper, the polystyrene-impregnated concrete, in which the concrete having various mix proportions is used as a base material, is prepared by a heat-polymerization-in-hot-water-method. Its compressive strength and pulse velocity are determined and the correlation between them is discussed.

*B102 Ohgishi, S., and Ono, H., "Chemical Attack Resistance Characteristics of Polymer Impregnated Concrete," Journal of the Society of Material Science, Japan, Vol 23, No. 247, 1974, pp 286-291.*

In this paper, the losses in weight and strength of a plain mortar, a mortar (PIC) impregnated with poly-methyl-methacrylate polymerized by thermal-catalyzer with BPO = 5 percent, and a mortar impregnated with polypropylene fiber reinforced polymer were examined in order to obtain their resistance to chemical attack by 10 percent-HCl, 10 percent-MgSO<sub>4</sub>, 10 percent-CH<sub>3</sub>COOH and pure C<sub>6</sub>H<sub>6</sub>.

The results showed that the weight loss of PIC (18.6 percent) was less than that of the plain mortar (24 percent), when attacked by 10 percent-HCl for 28 days. The losses in compressive strength of PIC and plain mortar after attacked by HCl were 67 percent and 97 percent, respectively; and after attacked by CH<sub>3</sub>COOH the losses were 26 percent and 57 percent, respectively. So, it can be said from the viewpoint of compressive strength that the chemical resistance of PIC is 23 times that of the plain mortar against HCl and 3.6 times against CH<sub>3</sub>COOH.

*B103 "Polymer-Impregnated Concrete: First Applications," Civil Engineering, American Society of Civil Engineers, Jan 1974.*

Bridge decks are the major area of PIC application today, because of the seriousness of the deck deterioration problem and lack of sure solution. But the BuRec Denver research center and the Atomic Energy Commission's Brookhaven National Laboratory on Long Island, New York, are studying other applications. Here are four:

1. Agricultural drain tile. At BuRec's Westlands Irrigation Project, Tranquility, California, near Fresno, the salt content of the soil was high, lessening its usefulness for farming, so underdrains were needed to flush out the salt. The water drained from the soil is high in sulfate, which is hard on concrete drain tile. But PIC has exceptionally good sulfate resistance. Several PIC drain tile were installed. About 2 years later a borehole TV camera was run through the pipe, and showed no deterioration in either the PIC tile or the conventional concrete drain tile. The demonstration installation will be observed again.

2. Sanitary sewer. About 2 years ago, 40 ft (12 m) of 8-in. (200-mm) PIC was installed in San Diego, in a hydrogen sulfide sewage environment. This chemical attacks conventional concrete, but PIC shows exceptional resistance to it.

3. Concrete pipe. Three-edge bearing tests of 24-in. (670-mm)

diameter unreinforced PIC pipe showed that it is 20 percent stronger than conventional reinforced concrete pipe. This great strength, plus the durability of PIC pipe, suggests that significant field installations may not be long in coming.

4. Tunnel linings. BuRec, a water resources agency that has built several major water tunnels, was impressed by PIC's potential - in precast tunnel linings it would allow use of thinner segments, provide improved abrasion resistance, and a 95 percent reduction in water permeability. BuRec constructed a full-scale tunnel section 8 ft (2.4 m) ID by 8 ft long. Lining and ground support system consists of 2-in. (50-mm) thick precast PIC segments backed by 3-1/2 in. (89 mm) of conventional concrete backfill. Tests show this system can support 60 percent more load than a comparable conventional concrete system. Of course, the PIC is more costly; economic studies suggest the PIC system would be competitive in tunnels of 20-ft (6.1-m) and larger diameter. This is the size range of highway and rail transit tunnels.

B104 Pu, D. C., Moisture Control and Monomer Impregnation of Cement Mortar and Concrete Without Pressurization, Ph. D. Dissertation, Pennsylvania State University, University Park, Pa., 1974.

The recent experiments regarding property improvements of concrete when impregnated with the polymer reported by several university and governmental research units have led highway research people to new approaches for improving durability of bridge decks. Theoretically, a long-lasting bridge deck highly resistant to freeze-thaw attack and deicing salt corrosion can be obtained by allowing an adequate monomer system to penetrate into it and be polymerized there *in situ*. However, the field drying, impregnation and polymerization processes cannot be easily carried out in the same way as handling small test specimens in the laboratory with ovens and pressure vessels only. New techniques and equipment are, therefore, needed to suit the field working conditions on bridge decks, and they have to be efficient, economical, safe and reasonably easy to apply. The work described here is a beginning in the direction of development of suitable prototype field apparatus and techniques.

The proposed and tested simple impregnation-polymerization pool exhibited excellent performance on nine small concrete blocks and one large concrete slab. The Dow Corning "silastic" and silicone rubber sealers showed good resistance to the MMA solution and hot water. Impregnation and polymerization were done with these convenient, inexpensive pieces of equipment very easily and effectively. The technique based on this pool is, therefore, highly recommendable for future bridge deck application. Specifications regarding the size, shape and material of this pool, detailed application procedure and time, temperature and duration of hot water, etc., are premature at this moment, pending field tests.

The major conclusion of this research is that deep penetration by the MMA-TMPTMA-AZO (100:10:0.3 or 0.5 by weight) system into concrete



can be obtained with pressurization provided that the concrete is properly dried. In order to obtain a given penetration by surface ponding, drying may be considered sufficient if the concrete temperature at that depth has achieved a value around 250°F. The poor impregnation reported by other researchers was mainly caused by insufficient drying.

**B105** Rio, A., and Cernin, E. M., "Polyblends of Cement Concrete and Organic Polymers," J. Polymer Sci., Macromolecular Reviews, Vol 9, 1974, pp 127-162.

This paper reviews the compound materials composed of cement concrete and organic polymers wherein the action of the polymer is essential, even representing, as a limit case, in the place of concrete the only binding phase of the system. The paper reviews the properties of all three types of concrete polymer materials and points out the advantages and the disadvantages of each. After this short review of the principal properties of the different compound materials that can be obtained when mixing cement concrete with organic polymers, we will examine more particularly the class of materials made of concrete fill with polymers after hardening.

**B106** Rio, A., Cerrone, M., and Colleferro, A. S., "Method for Preparing Polymer Impregnated Cement Articles," U. S. Patent 3,826,680 (Cl 117-119.6), 30 Jul 1974.

A method for preparing polymer impregnated cement articles wherein a preformed cement article is impregnated with a liquid polymerizable composition, then immersed in water, heated at a temperature required for the polymerization of said polymerizable composition maintaining the impregnated cement article at such a temperature until polymerization in situ of the monomer has been completed.

**B107** Steinberg, M., "Concrete-Polymer Materials and Its Potential for Construction, Urban Waste Utilization and Nuclear Waste Storage," Polymer Preprints, Vol 15, No. 1, 1974, pp 737-742.

This article discusses concrete-polymer materials and reports on their properties and advantages. Included in the discussion are: polymer impregnated concrete, polymer cement concrete, polymer concrete. It also mentions urban waste utilization and storage of nuclear waste materials in respect to polymer-concrete materials.

**B108** Steinberg, M., and Farber, G., "Refuse and Sewage Polymer Impregnated Concrete," p 3, Apr 1974, Atomic Energy Commission, Washington, D. C.

The patent concerns a load bearing composite and a method of producing such a product comprising sewage and refuse bound in a cement and penetrated with a polymer for strength and water impermeability of the resulting concrete blocks.

B109 Weyers, R. W., The Effects of Road Contaminants on the Impregnation of Bridge Deck Type Concrete with Polymethyl Methacrylate, M.S. Thesis, Pennsylvania State University, University Park, Pa., 1974.

The conclusions reached in this thesis indicate to the highway engineer that effects of deicer salts and road dirt can be tolerated in relation to the impregnation of a concrete bridge deck. However, the organic contaminants effects on the contact angle (which implies a decrease in impregnation rate) and polymerization time were more pronounced than the deicer salts. Therefore, if possible heavy accumulations of these contaminants should be removed before the impregnation begins.

B110 Whiting, D., et al., "Effect of Hydration on the Mechanical Properties of Epoxy Impregnated Concrete," Cement and Concrete Research, Vol 4, May 1974.

Following various hydration times (1 to 28 days) concrete was impregnated with an epoxy resin system. For a given impregnation condition (vacuum, pressure and time), it was found that higher polymer loadings were achieved in specimens having shorter hydration times. Compressive modulus and compressive strength values for impregnated specimens were higher than their corresponding control values. Compressive modulus values appear to be a function of hydration time (up to 14 days) for impregnated specimens, but the modulus of 1 day impregnated specimens is considerably higher than that of all the controls (1 to 28 days). Compressive strength values appear to be primarily a function of volume loading, and 1-day impregnated specimens displayed compressive values of greater than 10,000 psi.

B111 Whiting, D., Dynamic Mechanical Response of Polymer Impregnated Hardened Cement Pastes and Mortars, Ph. D. Thesis, Pennsylvania State University, University Park, Pa., Aug 1974.

Polymer impregnated cement paste (PICP) and polymer impregnated mortar (PIM) over the temperature range from 80 K to about 500 K are discussed. A number of different monomers have been used as impregnants, hence a comparison can be made between the relative efficiency of impregnation between monomers having widely differing chemical structures and viscosities. Impregnation was carried out at various stages in the hydration of the cement, thus it is possible to observe the effect of the cement maturity on the dynamic mechanical behavior of the composites. In addition, data obtained herein on elastic moduli have been applied to test the applicability of various composite materials theories to PICP and PIM.

B112 Whiting, D., Blankenhorn, P. R., and Kline, D. E., "Mechanical Properties of Epoxy Impregnated Concrete," Journal of Testing and Evaluation, American Society of Testing and Materials, Vol 2, No. 1, 1974.

Concrete has been impregnated with a particular epoxy system using a combined vacuum-pressure technique. Compressive modulus and compressive strength of these concretes were determined and found to be a function of total porosity. Results are compared with data previously reported for polymer concretes based on other monomer systems.

1975

B113 Aleszka, J. C., and Beaumont, P. W. R., "The Work of Fracture of Concrete and Polymer Impregnated Concrete Composites," Polymers in Concrete, pp 269-275, May 1975, The Concrete Society, London.

Authors attempt to characterise the fracture behaviour of (1) "plain" concrete; (2) polymer (polymethylmethacrylate)-concrete; (3) steel-wire-reinforced concrete; and (4) steel-wire-reinforced polymer-concrete, in terms of the fracture stress, fracture toughness, and fracture surface energy. The micro-failure models are then used to explain the experimental values of fracture-surface energy.

The stress for the onset of cracking in concrete which determines the ultimate strength can be increased by nearly an order of magnitude by impregnating the concrete with polymethylmethacrylate. This has the effect of reducing the amount of porosity in the material and the tendency for crack initiation. The improvement in fracture strength is similar to the benefits gained by incorporating short strong steel wires into the concrete. But the most dramatic improvements are found in steel-wire-reinforced polymer-concrete where the ultimate strength is a factor of 2 greater than a similar reinforced "plain" concrete, and the work of fracture is raised by a factor of 3 or 4. This latter phenomenon can be explained in terms of the work done at the crack tip to overcome the frictional drag that exists at the wire-matrix interface during the extraction of the wire. In reinforced "plain" concrete, the energy of plastic deformation of the fibre is of the same order of magnitude as the fibre pull-out energy term; in reinforced polymer-concrete, the improvements in interfacial shear strength by 3 times make the fibre pull-out term the dominant one.

B114 Arredondo, F., et al., "Characterisation of Vinyl Polymers Prepared in Concrete Matrices," Polymers in Concrete, pp 137-143, May 1975, The Concrete Society, London.

While a great number of publications have dealt with improvements in PIC properties, the ones which describe the properties of polymers used in concrete-impregnation are somewhat scarce. The work deals with the properties obtained in the PIC using a 95:5 MAM-MAA system: the factors influencing the copolymerisation of MAM with MAA as well as some properties of these copolymers at complete conversion are analysed; and, finally the molecular weight of the PMAM prepared within concrete matrices is studied in comparison with that of the PMAM obtained by conventional methods.

B115 Blankenhorn, P. R., et al., "Enclosed Soak System for Deep Polymer Impregnation of Concrete Bridge Decks," Transportation Engineering Journal, American Society of Civil Engineers, Vol 101, No. TE1, Feb 1975.

Results of polymer impregnation of concrete slabs and a bridge deck to a depth of 4 in. are presented and examined. The criteria developed for drying the slabs and bridge decks to a depth of 4 in. using gas-fired infrared heaters (applied on one surface only) is either to measure the temperature at 4 in. and cease applying heat when it reaches  $>230^{\circ}\text{F}$  or stop applying heat when the rate of temperature rise on the surface is less than  $10^{\circ}\text{F/hr}$ . Impregnation by ponding of the monomer system (100 parts methyl methacrylate, 10 parts trimethylol propane trimethacrylate, and 0.5 parts azobisisobutyrl nitrile) to achieve a depth of 4 in. required 4 days or longer. Polymerization of the monomer system in the concrete can be achieved at 4 in. by using a hot water bath and by maintaining a temperature at 4 in. of  $>130^{\circ}\text{F}$ .

B116 Brown, J. H., and Pomeroy, C. D., "Mechanical Properties of Some Micro-Concretes and Mortars Modified by Polymethylmethacrylate," TR No. 42.507, Mar 1975, Cement and Concrete Association, London.

Measurements were made of the mechanical properties of micro-concretes and mortars modified by the inclusion of polymethylmethacrylate. The polymer was introduced either as an aqueous emulsion admixture or to the hardened concrete as a monomer that was converted to the polymer form by gamma radiation or by a thermal-catalytic process. The enhanced compressive strengths and elastic moduli observed are associated with a reduction in porosity of the cement paste matrix; thus the potential strength improvement is greatest for high water/cement ratio concretes. It follows that polymer-modified concretes are unlikely to be much stronger than the strongest conventional concretes.

Polymer inclusion increases flexural strength to a far greater extent than would be predicted from a simple change in the matrix porosity, particularly with the system based on a polymer emulsion admixture. Another effect is to make the material more brittle, but inclusion of steel fibres in the formulation can restore ductility to the product.

The improvements in strength on their own are not likely to be economically worthwhile, but the polymer treatments substantially improve the resistance of concrete to chloride and sulphate attack and also provide greater resistance to damage from freezing and thawing. The most promising use of polymer-modified concretes is in applications where these advantages can be exploited.

B117 Clifton, J. R., and Frohnsdorff, G., "Polymer-Impregnated Concretes," Special Review in Cements Research Progress, 1975, pp 173-196.

Developments in the science and technology of polymer-impregnated concretes (PIC's), up to December 1975, are covered in this review. PIC's are important members of the group of concrete-polymer systems. PIC has been defined as 'a precast portland cement concrete impregnated with a monomer system that is subsequently polymerized in situ'. The term PIC is applicable to precast concretes and mortars which are fully-impregnated and those which are partially-impregnated to a finite depth. Sulfur-impregnated concretes are also included in this review, but other concrete-polymer systems, such as polymer-concrete and polymer-concrete, are not.

B118 Cooke, A. M., "An Evaluation of Some Practical Aspects of Concrete Structural Members Partially Impregnated With Polymers," Polymers in Concrete, pp 312-322, May 1975, The Concrete Society, London.

This paper examines the feasibility of partial impregnation of structural members and analyzes their potential performance by means of a simple model. On this basis, partial impregnation of concretes has been demonstrated in part to be the most cost-effective method of using polymer impregnation. Practical difficulties of impregnating and ensuring complete polymerisation of monomer deep inside large members contribute to this conclusion. Additionally for at least two factors, viz. durability and buckling stability, it has been found that a law of diminishing returns exists which reduces the relative effects of each additional polymer addition to the member. A simple mathematical model has been used to describe the mechanical properties of impregnated concretes which adequately describes experimentally derived data. These data show (as does the model) that significant improvement to the mechanical properties of concrete is available at low polymer loadings although linear improvements of mechanical properties with increasing loadings are found. This model is believed to be applicable directly to structural design, and has the advantage of simplicity. Furthermore, it has been shown that large members tend to benefit more than small members for a given degree of impregnation.

In conclusion it is believed that greater efforts should be made to develop practical techniques of partial impregnation of concrete suitable for field use. In addition, work should be carried out to evaluate anionic catalysts of polymerisation, as it is possible that "outside-in" polymerisation routes may be feasible, thus reducing the dangers associated with thermal or radiation polymerisation techniques.

B119 Cowan, W. C., et al., "Introduction to Concrete Polymer Materials," Report No. FHWA-RD-75-527, Supplement No. 1, 1975, Federal Highway Administration.

The purpose of this report is to provide a summary of selected applications for concrete-polymers under development at the Bureau of Reclamation. Discussions are presented on the structural properties of polymer impregnated concrete and its application in prestressed bridge deck panels, polymer impregnation as a bridge deck sealant, polymer concrete, polymer-shotcrete and penetrating protective coatings.

B120 Dahl-Jorgensen, E., et al., "Polymer-Impregnated Concrete: Laboratory Studies," Transportation Engineering Journal, American Society of Civil Engineers, Vol 101, No. TE1, Feb 1975.

It was shown that: (1) stress-strain behavior could be varied over a wide range, from ductile to brittle, by using combinations of a plasticizing or crosslinking comonomer with methyl methacrylate, or both; (2) the presence of a realistic level of salt (up to 1 percent) in concrete has little effect on polymer loading and mechanical properties, but requires more rigorous drying; (3) while high temperatures (750°F) accelerate drying but decrease strength, subsequent polymer impregnation essentially yields a PIC with properties similar to a conventionally dried material; and (4) salt penetration (short-time, static) in mortars is reduced an order of magnitude by polymer impregnation, regardless of whether the polymer is glassy or rubbery. Thus, a strong PIC can be prepared under a variety of drying and salt contamination conditions and the mechanical behavior of PIC can be tailored to various specifications.

B121 DePuy, G. W., "Process Technology Developments with Concrete-Polymer Materials: A Summary Report," GR-4-75, Jun 1975, Bureau of Reclamation, Division of General Research, Engineering and Research Center, Denver, Colo.

This report summarizes developments in process technology for concrete-polymer materials as reported in detail in five referenced topical reports issued during the progress of a Bureau of Reclamation-Brookhaven National Laboratory joint program. The preparation of three different types of concrete-polymer materials is covered. These are polymer-impregnated concrete, polymer concrete, and polymer-cement concrete. Further developments with these materials include partial and surface impregnation techniques, and penetrating polymer coatings for protection of concrete. Safe handling of monomers is also covered.

B122 DePuy, G. W., "Freeze-Thaw and Acid Resistance of Polymer-Impregnated Concrete," Durability of Concrete, SP-47, pp 233-257, 1975, American Concrete Institute, Detroit, Mich.

The developmental program for concrete-polymer materials has shown polymer-impregnated concrete to have significantly improved durability and structural properties as compared with conventional concrete. Laboratory tests show PIC outlasts conventional air-entrained concrete more than 10 times as long in the Bureau's freeze-thaw test and two or more times as long in exposure to acid. Acid resistance can be further increased by doubly coating the specimen with polymer to improve surface sealing. The Bureau tests are customarily evaluated on a weight loss basis and other criteria would be helpful to evaluate durability and to shorten test times. A series of tests were performed to measure compressive and tensile strength, dynamic modulus of elasticity, length change, ultrasonic pulse velocity, and weight loss of specimens during the course of the tests.

B123 DePuy, G. W., "Monomer and Polymers for Concrete-Polymer Materials: A Summary Report," GR-5-75, Jun 1975, Bureau of Reclamation, Division of General Research, Engineering and Research Center, Denver, Colo.

This report summarizes monomer and polymer studies conducted during the first 5 years of a joint Bureau of Reclamation-Brookhaven National Laboratory program for development of concrete-polymer materials. It is one of five summary reports on the joint program; the other four reports are on process technology, structural properties, applications, and the total development program. This report covers the properties of monomers and polymers, polymerization, monomer systems for polymer-impregnated concrete (PIC) and polymer concrete (PC), potential hazards and safety practices, and reactions of monomers and polymers in concrete. The most promising monomer systems developed under the joint program are MMA (methyl methacrylate) and MMA-TMPTMA (trimethylolpropane trimethacrylate) for PIC for normal-temperature applications, styrene-TMPTMA for PIC for high-temperature applications, and MMA-TMPTMA for PC for normal-temperature applications.

B124 DePuy, G. W., "Full-Scale Fabrication and Testing of Polymer-Impregnated Concrete," Polymers in Concrete, pp 262-268, May 1975, The Concrete Society, London.

The Bureau of Reclamation's facilities and procedures for producing fully impregnated PIC are described with particular emphasis on process safety. Studies related to applications of PIC in prestressed bridge decks, tunnel support and lining system, concrete pipe, and surface impregnation of bridge decks are discussed.

B125 DePuy, G. W., "Highway Application of Concrete-Polymer Materials," Polymer Concrete, Transportation Research Record 542, pp 60-66, 1975, Washington, D. C.

The deterioration of concrete bridge decks and pavements presents many highway organizations with major problems of providing safe and satisfactory riding surfaces. Concrete polymer materials, with their excellent durability and strength properties, have potential application to highway construction and maintenance and offer potential benefits of an increase in service life and a reduction in the costs, safety hazards, and inconveniences in performing maintenance and repair work. Polymer-impregnated concrete is highly resistant to freeze-thaw damage and water penetration and provides protection from deicing salt penetration and corrosion of reinforcing steel. A precast, prestressed polymer-impregnated concrete bridge deck system is being developed that incorporates the advantages of a precast, prestressed system for rapid construction and strength; and a surface-impregnation technique is being developed for field treatment of newly constructed concrete bridge decks to provide protection of reinforcing steel from deicing salts. Polymer concrete is a versatile new material with properties comparable to polymer-impregnated concrete and appears to be suitable for both precast

and field applications, such as curbstones, pavements overlays, shotcrete, and rapid-curing patching and repair materials.

B127 Fowler, D. W., and Paul, D. R., "Polymer Impregnation of Concrete Walls," Research Report to U. S. Army Engineer District, Walla Walla, Washington, May 1975, The University of Texas at Austin, Austin, Tex.

The laboratory investigation indicates that polymer-impregnation of vertical surfaces, initially saturated with water can be obtained for depths of one-half inch. Drying times of 6 to 10 hr, at temperatures of 260°F to 280°F and soak times of 4 to 6 hr were used to produce the half-inch polymer depths. Dry pack-filled cavities of up to 1-in. depths were impregnated with additional impregnation of up to 0.25-in. depths obtained in the concrete at the back surface of the dry pack. Sealing cracks in concrete was only partially successful, although very fine cracks (0.05 mm or less) away from the surface were filled.

Porosity reduction of up to 71 percent were obtained in the impregnated concrete. The porosity reduction was generally found to be a function of the drying time and soaking time.

Recommendations were made for the impregnation of the outlet walls and stilling basin of Dworshak Dam.

B128 Fowler, D. W., and Paul, D. R., "Partial Polymer Impregnation of Highway Bridge Decks," *Polymer Concrete*, Transportation Research Record 542, pp 9-19, 1975, Washington, D. C.

Polymer-impregnated concrete is being considered as a means of increasing the durability of bridge decks. For application to existing bridges, the process includes drying the bridge deck to remove the free moisture in the pores, soaking a low viscosity monomer solution into the concrete, and applying heat to polymerize the monomer. Drying, soaking, and curing requirements are discussed. A limited area of a bridge deck has been successfully polymerized to a depth of approximately 1 in. (2.5 cm). Evaluation studies were conducted to determine the freeze-thaw resistance, skid and wear resistance, and protection against corrosion of the reinforcement in relation to polymer-impregnated concrete. Freeze-thaw resistance was significantly increased, and skid resistance improved significantly for the partially impregnated slabs when the tests were performed when the surfaces were dry. Skid resistance was slightly higher when the surfaces were covered with abrasive grit and kept wet. Wear measurements generally indicated little difference between treated and untreated specimens. Corrosion resistance for slabs with a low-quality polymer impregnation is about 25 times greater than that for unimpregnated slabs.

B129 Gunasekaran, M., and Van Antwerp, E. H., "The Creep of Polymer-Impregnated Lightweight Concrete," *Polymers in Concrete*, pp 54-59, May 1975, The Concrete Society, London.



Lightweight polymer-impregnated concrete (PIC) will exhibit creep, which can be substantial, if the polymer loading is high. It is suggested that the creep of PIC depends predominantly on the amount of polymer in the specimen.

B130 Harshavardhan, C. N., Nanson, J. A., Chen, W.-F., and Vanderhoff, J. W., "Polymer Impregnated Concrete: Field Studies," Transportation Engineering Journal, American Society of Civil Engineers, Vol 101, No. TE1, Feb 1975, pp 1-28.

The principles developed in the laboratory for polymer impregnation of concrete to depths below the top layer of steel reinforcing rods were applied to the impregnation of large concrete slabs and a bridge deck. The concrete slabs and bridge deck were dried thoroughly using a propane torch assembly (temperature at surface 700°F or 372°C, at a 4-in. (100-mm) depth 250°F or 121°C) impregnated with a 16-in. (410-mm) ethylene film, and polymerized for a 16-in. (410-mm) pressure impregnator at 15 psi to 80 psi (104 kN/m<sup>2</sup> to 552 kN/m<sup>2</sup>), wrapped or covered with a polyethylene film, and polymerized for 5 hr to 8 hr using steam from a pressure cooker. The monomer was a 90:10 methyl methacrylate-trimethylolpropane trimethacrylate mixture containing 0.5 percent azobisisobutyronitrile initiator. The slabs were impregnated to their full 6-in. (150-mm) thickness, the bridge deck to a depth of at least 5 in. (125 mm). The polymer-impregnated slabs show increased compressive and split-tensile strengths, decreased water absorption, and improved resistance to corrosion, freeze-thaw cycling, abrasion, and acid-etching.

B131 Hastrup, K., et al., "Pore Structure, Mechanical Properties and Polymer Characteristics of Porous Materials Impregnated with MMA," Polymers in Concrete, pp 43-53, May 1975, The Concrete Society, London.

The main objective of this investigation was to examine polymer impregnation in relation to pore structure. Two important building materials, wood and hardened cement paste, and a third model material, porous vycor glass, were investigated. The mechanical properties measured, dynamic modulus of elasticity, the damping factor, and the modulus of rupture, all increased significantly as the degree of pore filling increased.

B132 Holden, F. W., "Evaluation of Bridge Patching Materials (Polymer Concrete) Operational Planning," Report No. R763-75, Mar 1975, Massachusetts Department of Public Works.

Preparatory operational procedures are outlined which involve laboratory control and field personnel organization. Details are given of the budget and the rental of the laboratory trailer. The basic trailer specifications are set forth and the special chemicals used are listed. Step by step operations are described of four sites selected for field testing of various types and uses of the polymers. The first project involved patching a hole (2 ft by 2 ft) full depth of the

reinforced concrete deck of the subject bridge with polymer concrete and to impregnate the existing concrete around the hole with polymer. An 11-step procedure is outlined for the (second project) patching of a section of a bay along the curblin by removing the deteriorated concrete, full depth, from the center of beam No. 2 to the center of beam No. 3, using both polyester styrene and MMA (promoted chemically by heat). Similar projects are described involving patching of shallow surface holes, and the patching of a section bridge deck.

B133 Iwasaki, H., "Durability of Resin Concretes and Polymer-Impregnated Concretes as Ocean Structural Materials," Zairyo, Vol 24, No. 260, 1975, pp 411-17 (Japan); Chemical Abstracts, 102440, Vol 83.

In the future, a large-scale application of resin concrete and polymer-impregnated concrete is expected in the field of ocean engineering structures (offshore buildings, floating structures, etc.). The ocean engineering structures are exposed under more severe external forces than land structures as permanent structures, and so in such an application of resin concrete and polymer-impregnated concrete it is most important to know whether they can be used safely as materials for ocean engineering structures.

In this paper, the marine exposure tests of polyester resin concrete (abbrev. REC), polystyrene-impregnated concrete (abbrev. PIC) and cement concrete (abbrev. CC) are conducted in the Inland Sea of Seto, where high needs for ocean engineering structures are expected in the future. Furthermore, for the design consideration of ocean engineering structures, the change of mechanical properties, the shape change needed for wave force estimation, the weight change needed for dead load estimation, etc., are discussed.

The test results indicate no mechanical deterioration for all specimens. However, when compared with cement concrete, the degree of fouling with living sea creatures on polyester-resin concrete and polystyrene-impregnated concrete is remarkably large.

B134 Kato, K., Iwasaki, H., Ohama, Y., and Kondo, T., "The Structural Behavior of Polymer-Impregnated Mortar Hemisphere and Cement Mortar Hemisphere under Hydrostatic Loadings," Proceedings of the Eighteenth Japan Congress on Materials Research, The Society of Materials Science, Kyoto, Japan, 1975, pp 148-150.

Our research aims to study polymer-impregnated mortar (abbreviated as PIM) for underwater structures such as oil-tank, storage and so on. This material has a high strength, high waterproof performance, high durability and high anticorrosion characteristics. Thus the polymer-impregnated mortar is the best material for marine structures. In this study the structural behavior of polymer-impregnated mortar hemispheres and cement mortar hemispheres subjected to various hydrostatic loadings was experimentally investigated, and the comparison was made between the polymer-impregnated mortar and the cement mortar as a structural material for marine structure.

B135 Kukacka, L. E., et al., "Concrete-Polymer Materials for Highway Applications," BNL-50462, Jun 1975, Brookhaven National Laboratory and FHWA-RD-75-86, Jun 1975, Federal Highway Administration; Prepared under contract for Federal Highway Administration by Brookhaven National Laboratory.

The structural and durability properties of impregnated normal and structural lightweight concretes have been measured. Effects of temperature and cyclic loading were investigated and bond pull-out strength of reinforcement was measured. Process variables studied include monomer type, methods of polymerization, aggregate type, and air content of the concrete. Use of polymer-impregnated concrete to prevent chloride penetration into bridge decks has been demonstrated, and prototype deck panels have been evaluated. Impregnation offers a potential solution to the bridge deck deterioration problem. Field evaluation of use of polymer concrete as a means of rapidly filling holes in major arterial highway bridges has been in progress in New York City for 18 months. No signs of deterioration are apparent. Polymer impregnation of concrete bridge deck surfaces has proven effective in preventing intrusion of deicing salts into the decks.

B136 Kukacka, L. E., et al., "Introduction to Concrete-Polymer Materials," FHWA-RD-75-507, Apr 1975, Federal Highway Administration.

The purpose of this text is to provide highway personnel with a working knowledge of concrete polymer developments and application. Basic information necessary to begin experimental application of these materials is presented.

The text presents discussions on the following: (1) a review of concrete-polymer materials development, (2) knowledge of polymer chemistry as applied to concrete-polymer materials, (3) knowledge of the technology required to produce concrete-polymer materials, (4) a description of the fundamental characteristics and properties of the composites, and (5) an in-depth study of the applications of concrete-polymer materials.

B137 Kukacka, L. E., "Polymer-Impregnated Concrete Development in the USA," Polymers in Concrete, pp 26-30, May 1975, The Concrete Society, London.

The development of PIC in the USA has advanced from the stage of determining the basic material characteristics and methods for producing the composite to the design and testing of prototypes and full-size sections for specific applications.

At present there are no known commercial applications of PIC. Several potential applications have been identified and tests performed. Pipe, tunnel liners, beams, underwater habitats, and prototype bridge deck panels have been impregnated. With the exception of PIC sewer and culvert pipe, which did not exhibit the required resistance to sulphuric acid, and beams, for underground support systems, all the applications appear cost effective. In addition, preliminary design studies and cost

estimates have been made for prestressed PIC pilings and for barges. Both applications show promise.

The use of PIC for a variety of highway structures appears to be the area in which commercialisation will first occur. Specifications have been issued and a contractor has been selected for the installation of PIC curbing in the spring of 1975. Consideration is also being given to the installation of a PIC bridge deck. In addition, the use of monomer impregnation to prevent chloride penetration into cast-in-place bridge decks and for the repair of highly deteriorated decks is being developed and plans to repair a bridge in 1975 are being formulated. PIC may soon become a commercial reality.

*B138 Lockman, W. T., and Cowan, W. C., "Polymer-Impregnated Precast Structural Concrete Bridge Deck Panels," FHWA-RD-75-121, Oct 1975, Federal Highway Administration.*

This report contains the results of a research program that shows how the inherent structural and durability properties of polymer-impregnated concrete (PIC) can be incorporated into a precast panel system to provide an excellent bridge deck. Panels were designed and tested under both static and fatigue loading. The tests verified the design procedures and load carrying capabilities. Extensive physical property testing in compression, tension, flexure, and fatigue was performed on specimens to verify the quality of the initial concrete and PIC used in the panels. An investigation into prestress losses was performed. Also, various nondestructive tests were evaluated to determine a method for quality control for PIC.

*B139 Malinowski, R., Ossowiecka, L., and Srebnik, M., "Påskyndad Härdning Och Samtidig Impregnering AV Betong Med Hjälp av Varm Olja Och Varm Asfalt," Rapport 75:3, Jan 1975, Chalmers Tekniska Hogskola, Institutionen for Byggnadsteknik, Byggnadsakustik och Byggnadskonstruktion, Göteborg.*

Some possibilities to utilize oil of vaseline type and asphalt solution for additional curing combined with impregnation of high-strength concrete has been studied. Concrete of quality K600 with the cement content  $608 \text{ kg/m}^3$  and fluid consistency was tested. Aggregate was graded to 8-mm maximum size. The fineness modulus was  $M = 2.98$ . Total aggregates weight was  $1970 \text{ kg/m}^3$  with coarse aggregate contents of 62 percent. Water/cement ratio was 0.42. Before the oil resp. asphalt treatment, the specimens were steam cured in closed forms for 6 hr at  $90^\circ\text{C}$ . The size of the specimens was 4- by 4- by 16-cm prisms.

The impregnation was carried out merely by soaking without the use of vacuum and pressure. Temperature of the oil impregnation was  $95^\circ\text{C}$  and of asphalt impregnation  $150^\circ\text{C}$ . The oil of vaseline type with viscosity of 10-15 cSt at  $50^\circ\text{C}$  and three types of asphalt solution: RAO, A 140/20 and OA 80-90 with viscosity of 5-7 cSt, 10-15 cSt and 10-18 cSt at  $100^\circ\text{C}$ , respectively, were chosen for investigations. As it was intended to load concrete by capillary action, investigations were started to modify the structure of the concrete by changing its

conditions of curing. In various test series different conditions of curing and varied agents of impregnation were studied. Studies on penetrating ability, soaking time, impregnating agent loadings, depth of penetrations, strength properties, water absorption, resistance to chemical attack by hydrochloric and sulphuric acid as well as resistance to boiled water and hot air treatments are being made.

The following conclusions are drawn from the strength and the durability results:

Both the early and 28-days compressive and flexural strength were always lower for oil-impregnated steam-cured concrete than those obtained for the unimpregnated concrete alone.

Oil was not resistant to boiling in distilled water, to hot air treatment or to attack by hydrochloric and sulphuric acids.

The early compressive strength and both the early and 28-days flexural strengths were higher for asphalt impregnated steam-cured concrete, than those found for unimpregnated steam-cured concrete at the same age. The 28-days compressive strength after asphalt impregnation was, however, equal to that obtained for steam-cured concrete after 28 days.

Asphalt on the contrary to the oil was not suitable only to the sulphuric acid attack.

*B140 Manning, D. G., "The Role of the Polymer in Polymer-Impregnated Paste and Mortar," Polymers in Concrete, pp 37-42, May 1975, The Concrete Society, London.*

The monomers used in this investigation are capable of penetrating the micropores in the cement paste and fill the available pore space to approximately the same degree as methanol.

In general, the effect of polymer impregnation on the stress-strain curve of mortar and cement paste is fourfold: to increase the strength, the elastic modulus, the linear portion of the curve, and the strain at failure.

The influence of the polymer on the properties of the composite is determined primarily by the change in properties of the cement paste phase and not by changes at the paste-aggregate interface. The polymer increases the amount of solid per unit volume in the cement paste and simultaneously reduces the effect of stress concentrations from pores and microcracks. The properties of the polymer in the pores of the cement paste are likely to be the most important factors in determining the effectiveness of any particular polymer. These properties are not always a reflection of the bulk polymer properties.

*B141 Manowitz, B., Steinberg, M., and Kukacka, L. E., "Polymer-Concrete Composites for Energy Related Systems," Progress Report No. 4 (Department of Applied Science), BNL-19970, Mar 1975, Brookhaven National Laboratory, Upton, N. Y.*

Research is reported in programs on polymer-concrete materials for geothermal applications, incorporation of combustion products of solid waste in composites, and development of polymer-impregnated concrete.

B142 Manson, J. A., et al., "Polymer Impregnated Concrete for Highway and Structural Applications," Polymers in Concrete, pp 403-408, May 1975, The Concrete Society, London.

The purpose of this paper is to describe a collaborative research and development programme conducted by an interdisciplinary team to solve two practical problems: the deep impregnation of highway bridge decks below the top layer of reinforcing steel and control of ductility by variation of the polymer properties.

(1) By applying principles developed in the laboratory, it has been possible to achieve polymer impregnation of bridge deck sections to a depth below the level of the reinforcing steel. Based on laboratory experience, it is expected that such impregnation will both effectively seal the pores against permeation by water and salt, and immobilise salt already present in the deck. (2) By varying the physical state of the polymer in PIC (in turn, by changing the composition), it has been possible to vary stress-strain behaviour all the way from brittle to completely ductile - a range of behaviour surely of interest to the design engineer.

B143 Mehta, H. C., et al., "Innovations in Impregnation Techniques for Highway Concrete," Polymer Concrete, Transportation Research Record 542, pp 29-40, 1975, Washington, D. C.

Corrosion of reinforcing steel due to the penetration of deicing salts poses a considerable problem in bridge decks. One approach that has received much attention has been impregnation of the bridge deck with a liquid monomer followed by polymerization to effectively seal the capillary pores against salt intrusion. This approach is technically feasible in the field. The present impregnation techniques, however, are costly in terms of energy, materials, and time, and simplifications and improvement would be desirable. In this paper, results are described of preliminary experiments with sulfur, tar, and mixtures of the two as surface impregnants and with a pressure-mat technique for mechanically assisting monomer or sealant penetration. It is shown that the impregnation of portland cement concrete and mortar by molten sulfur, tar, and an 80:20 mixture of the two yields significant reductions in moisture absorption and increases in strength and that, in the case of concrete slabs, predrying may not be necessary. It is also shown that pressure mechanically applied to patterned rubber mats can effect uniform impregnation with a monomer such as methyl methacrylate or with a sealant such as tar or linseed oil. Such an impregnation could conceivably be effected by using rollers. Thus, initial feasibility of two potential improvements in concrete impregnation processes have been demonstrated.

B144 Mehta, H. C., et al., "Polymer-Impregnated Concrete: Field Studies," Transportation Engineering Journal, American Society of Civil Engineers, Vol 101, No. TE1, Feb 1975.

The principles developed in the laboratory for polymer impregnation of concrete to depths below the top layer of steel reinforcing rods were applied to the impregnation of large concrete slabs and a bridge deck. The concrete slabs and bridge deck were dried thoroughly using a propane torch assembly (temperature at surface 700°F or 372°C, at a 4-in. (100-mm) depth 250°F or 121°C) impregnated with a 16-in. (410-mm) ethylene film, and polymerized for a 16-in. (410-mm) pressure impregnator at 15 psi to 80 psi (104 kN/m<sup>2</sup> to 551 kN/m<sup>2</sup>), wrapped or covered with a polyethylene film, and polymerized for 5 hr to 8 hr using steam from a pressure cooker. The monomer was a 90:10 methyl methacrylate-trimethylolpropane trimethacrylate mixture containing 0.5 percent azobisisobutyronitrile initiator. The slabs were impregnated to their full 6-in. (150-mm) thickness, the bridge deck to a depth of at least 5 in. (125 mm). The polymer-impregnated slabs show increased compressive and split-tensile strengths, decreased water absorption, and improved resistance to corrosion, freeze-thaw cycling, abrasion, and acid-etching.

*B145 Meyer, A. J., "Rate Processes of Polymer Impregnation of Concrete Bridge Decks," M.S. Thesis, The University of Texas at Austin, Austin, Tex., May 1975.*

Polymer-impregnated concrete has proven to be a strong and environmentally resistant material with many potential uses. One such application is to impregnate the surface of highway bridge decks to improve their durability. This paper reports on various aspects of research directed toward the objective of developing a practical and economical process for the surface impregnation of bridge decks with a liquid monomer that is subsequently polymerized.

A correlation for predicting the curing time needed for various levels of a crosslinking agent during polymerization of methyl methacrylate is presented at two temperatures as a function of initiator characteristics. Use of this correlation with a heat transfer model enables one to estimate ultimate polymer depth for a given set of curing conditions.

The mechanism of monomer penetration into the concrete pores was found to be based upon capillary forces modeled by the Washburn equation for meniscus velocity. In addition, it was found that sandblasting the concrete to remove road film did not greatly affect monomer penetration.

*B146 Moore, K. L., and McNeill, R. A., "Terminal Ballistics of Concrete-Polymer Systems," Report No. AFWL-TR-75-167, Sep 1975, Air Force Weapons Laboratory.*

The terminal ballistic properties of certain concrete-polymer systems have been evaluated. Penetration and cratering measurements were made on three different types of materials: (1) polymer concrete consisting of rock and sand bound by a cured polymer; (2) cured portland cement concrete into which liquid monomers were injected and then cured to varying degrees of polymerization; (3) latex modified concrete which differed from portland cement concrete only in the substitution of latex

emulsion for portions of the mix water. Data obtained from impact of 0.30-caliber projectiles indicates that all three systems can produce structural concrete with superior terminal ballistics behavior. Penetration was reduced by up to 30 percent, and cratering by up to 100 percent, with virtual elimination of cracking in the target material.

For new construction latex modified concrete (LMC) offers new possibilities in design where flexibility, impact resistance, and projectile damage are to be considered. The greatest advantage for LMC is its reduction of cratering almost to zero, and its ease of fabrication with existing equipment. The prospect of anti-spall and anti-fragmentation concrete is especially promising for this class of materials.

B147 Ohama, Y., et al., "Design of Polymer-Impregnated Concrete Plant for Mass Production," Polymers in Concrete, pp 300-305, May 1975, The Concrete Society, London.

The authors describe the design of an automatic thermal polymerisation plant for mass production of polystyrene-impregnated concrete products. The productivity of the plant is 4 m<sup>3</sup>/hour or 9,600 m<sup>3</sup>/year (23,000 t/year). The unit cost of polystyrene-impregnated concrete products manufactured by the plant, is 1.48 × 10<sup>5</sup> yen/m<sup>3</sup> or 62,000 yen/t (≅U. S. \$500/m<sup>3</sup> or U. S. \$200/t).

B148 Ohama, Y., "Molecular Weight of Polymer Formed in Polymer-Impregnated Concrete," Polymers in Concrete, pp 60-63, May 1975, The Concrete Society, London.

In this paper, the molecular weight of polymer formed in polymethyl methacrylate-impregnated concrete is determined, and the relationship between the molecular weight and the polymerisation temperature and that between the molecular weight and the polymer-impregnating depth (cross-sectional location) of the polymer-impregnated concrete are discussed.

The conclusions obtained are summarised as follows:

(1) The polymer extract from PMMA-impregnated concrete tends to increase with a rise in polymerisation temperature, and decrease with additional polymer-impregnating depth. All the polymer extracts do not exceed 70 percent of the polymer content calculated from the polymer loading.

(2) The number-average molecular weight of polymer in PMMA-impregnated concrete decreases with a rise in polymerisation temperature, but hardly changes with an increase in polymer-impregnating depth. The weight-average molecular weight generally tends to decrease with a rise in polymerisation temperature and polymer-impregnation depth.

(3) The un-uniformity of polymer in PMMA-impregnated concrete generally becomes smaller with an increase in polymer-impregnating depth, but almost no change is observed with a rise in polymerisation temperature.



B149 Paul, D. R., and Fowler, D. W., "Surface Impregnation of Concrete Bridge Decks with Polymers," Journal of Applied Polymer Science, Vol 19, 1975, pp 281-301.

Polymer-impregnated concrete has proven to be a strong and environmentally resistant material with many potential uses. One such application is to impregnate the surface of highway bridge decks to improve their durability. This paper reports on various aspects of research directed toward the objective of developing a practical and economical process for surface treating bridge decks with liquid monomers which subsequently are polymerized. This work has included (1) selection and tailoring the monomer-initiator system, (2) development of application and curing systems, and (3) evaluation of the resulting treatments by many different testing procedures. Considerable progress has been made toward increasing the durability of concrete slabs as shown by laboratory and small-scale field tests and toward developing a practical method of application. Selected aspects of the fundamentals of surface treatments of highway bridge decks and details of the process and product as they have been developed to date will be presented here.

B150 Poad, M. E., et al., "Engineering Properties of Fiber-Reinforced and Polymer-Impregnated Shotcrete," RI 8001, 1975, U. S. Bureau of Mines.

Structural properties of steel-fiber-reinforced shotcrete and polymer-impregnated shotcrete, both plain and fiber-reinforced, were investigated by the Federal Bureau of Mines, Spokane Mining Research Center. The research center has found that flexural strengths can be increased by as much as 106 percent, and splitting-tensile strength by 50 percent, by introducing randomly oriented steel fibers. A slight decrease of compressive strength was found in the fiber-reinforced shotcrete. Polymer-impregnated shotcrete exhibited a threefold to fourfold increase in compressive and splitting-tensile strength.

The techniques of preparing shotcrete with the dry process, using both fast-set agents and regulated-set cement, are described, along with the results of physical-property testing. Physical properties include compressive and splitting-tensile strengths, tangent and secant moduli, and stress-strain curves for plain shotcrete, fiber-reinforced shotcrete, and polymer-impregnated plain and fiber-reinforced shotcrete. Flexural strengths for plain and fiber-reinforced shotcrete are also reported.

Steel-fiber shotcrete is the more promising of the new structural materials for ground support, and additional research is recommended.

B151 "Polymer Impregnated Concretes," Precast Concrete, Nov 1975, pp 595-597.

Research in the development of economic and practical applications for polymer impregnated concretes was the subject of papers at the BIBM Congress in Italy. The three countries that were interested were Italy, Spain, and France. Summaries of the papers are as follows:

#### Research in France

F. Dutruel of the Centre d'Etudes et Recherches de l'Industrie du Béton Manufacturé, Epernon, France, gave a paper on the partial impregnation of concrete with polymerizable resins.

The resins used in concrete impregnation have a minimum tensile strength of 500 bar when polymerized, and enable micro-reinforcement to be obtained in all directions within the concrete itself. Mechanical performance is thus improved considerably and capillary phenomena greatly limited.

#### Research in Spain

The Eduardo Torroja Institute and the Spanish Institute for Plastics Materials - both belonging to the Consejo Superior de Investigaciones Científicas (National Scientific Research Council) - started a cooperative research effort in 1971 to investigate polymer impregnated concretes (PIC). The investigation was not limited to products of high mechanical properties, but also aimed at developing concretes that could withstand the attack of very aggressive agents, like sulphates, in which the Spanish soil is particularly rich.

The results reported concern PIC where the polymer addition consists of a mixture of 95 percent methyl methacrylate and 5 percent allyl methacrylate plus 3 percent of 2-2' azodiisobutyronitril as initiator.

The treatment cycle used lasts 5 hr (2 hr of 5-mm Hg vacuum and 3 hr of impregnation). Figures 1, 2, and 3 show the comparative results.

#### Research in Italy

In their paper on the performance of polymer impregnated concrete, Arturo Rio (Institute of Applied Chemistry, Engineering Faculty, University of Rome) and Stefano Biagini (Italcementi Laboratory, Colleferro, Rome) said that research showed that the presence of polymer exerts positive influence in a cement concrete through three different mechanisms:

1. The first consists in improving the adherence of the cement paste (the matrix of the system) to the "Stony skeleton" represented by the aggregates, and so reducing the risk of possible microcracks;
2. The second consists in increasing the specific mechanical characteristic of the matrix as a result of the reduced porosity;
3. The third consists in the stabilization of the optimum condition reached by the concrete as the result of the thermal treatment and the impregnation process.

B153 Rio, A., and Biagini, S., "Recent Progress in the Field of Polymer Impregnated Concretes," Polymers in Concrete, pp 14-21, May 1975, The Concrete Society, London.

Following a review of progress in the area of PIC the paper concludes that cement concrete impregnated with polymers, given the characteristics that can be reached today, is a true alternative to the use of more expensive materials for those uses that normal concrete, even of high quality, cannot satisfy.

Impregnated concrete must be considered a new compound material with specific characteristics, which place it in a position, from the

viewpoint of quality and cost, between traditional concrete and metallic and ceramic materials.

An evaluation of the technical-economic convenience of its use has to be carried out, keeping in mind all the particular properties presented, among them the possibility of a notable decrease in dimensions and sections of products.

*B154 Sadler, J., "Polymer and Sulphur Impregnation of Concrete Farm Silos and Liquid Manure Tanks," Paper Presented at the 1975 Winter Meeting of American Society of Agricultural Engineers, Chicago, Ill., 15-18 Dec 1975. (Copies of the paper may be obtained from ASAE, P. O. Box 229, St. Joseph, Mich. 49085.)*

Both polymer impregnation and sulphur infiltration decreases the permeability of concrete making precast concrete almost completely resistant to attack from acids within silage or from liquid manure. Possible methods for impregnation are presented along with advantages and disadvantages of alternative techniques.

*B155 Sakmanalit, S., "The Monomer Absorption and Polymerized Strengths of Two Concrete Mixes," M.S. Thesis, University of Florida, Gainesville, Fla., Aug 1975.*

The structural properties of polymer-impregnated concrete tubes as a cover for pretensioned strands to prevent corrosion, is now under separate investigation. This report evaluates the feasibility of using no-slump extruded concrete of the type being used by the prestressed concrete industry instead of the specially designed laboratory concrete used up to now for the tubes. Compressive and split tensile tests were performed to compare the strengths of both concretes in both their unpolymerized state and their polymer-impregnated state. The depth of polymer penetration was also determined for both concretes.

*B156 Schorn, H., "Limits in the Modification of Characteristics by the Transformation of Cement Concrete into Polymer Impregnated Concrete," Polymers in Concrete, pp 31-36, May 1975, The Concrete Society, London.*

Principal material limits, as well as manufacturing operations, disclose that economic considerations indicate that the use of polymer-impregnated concrete should preferably be directed only to small prefabricated members for special requirements - for instance, the use of precast members for road construction (kerbs etc.), whereby resistance to deicing agents in connection with high mechanical strengths may be most promising.

*B157 Selander, C. E., et al., Introductory Course on Concrete-Polymer Materials, Bureau of Reclamation, Engineering and Research Center, Denver, Colo., Feb 1975.*

The purpose of this report is to provide a summary of concrete-polymer materials. Discussions are presented on: partial impregnation of concrete, prestressed PIC bridge deck panel systems, material properties, and design method for PIC.

*B158 Selander, C. E., "Development of Concrete-Polymer Materials by the Bureau of Reclamation." Report No. BR-1-75, Jun 1975, Bureau of Reclamation.*

This report summarizes the total concrete-polymer development program, as reported in detail in five referenced topical reports. It is one of five summary reports; the other four report on monomer and polymer studies, process technology, structural properties, and applications. The program was initiated in 1967 as a cooperative research and development program between the Atomic Energy Commission through Brookhaven National Laboratory and the Bureau of Reclamation. Shortly thereafter, the Office of Saline Water (now the Office of Water Research and Technology) joined the program as a major sponsor, followed by other Government agencies interested in these new materials. Primarily, three types of materials were studied: polymer-impregnated concrete (PIC), polymer concrete (PC), and polymer-cement concrete (PCC). Polymer-impregnated concrete (PIC) and polymer concrete (PC) both have improved properties which will enable them to be considered for use in many structural applications in the water resource development field. Polymer-cement concrete (PCC) may someday prove to be a good construction material, but considerable research work remains to be done.

*B159 Smoak, W. G., "Polymer Impregnation of New Concrete Bridge Deck Surfaces, Interim Users' Manual of Procedures and Specifications," Report No. FHWA-RD-75-72, Jun 1975, Federal Highway Administration.*

A technique of impregnating new concrete bridge deck surfaces with an acrylic polymer to a depth of 1 in. (25 mm) or more for protection against chloride ion intrusion and freeze-thaw deterioration is reported. The process technology, materials, equipment, and safety provisions used in the technique are discussed, with the objective of informing potential users of the various steps necessary to insure successful field application of the process. An appended materials and performance specification is included.

*B160 Sople, B., "Polymer Impregnated Concrete Process Techniques and Applications," Polymers in Concrete, pp 254-261, May 1975, The Concrete Society, London.*

In this paper emphasis has been placed on a general discussion of the PIC production process, together with a presentation of the field test programme.

Impregnation of a total number of 870 concrete plates showed that a reliable process technique for a plant production of polymer-impregnated concrete is at hand.

High-quality impregnated concrete can be made from concrete varying

widely in composition and curing. A complete drying is essential. Since the drying process's duration is the most critical step in production a high drying temperature in the range 150 to 200°C is recommended.

By cooling the specimens to room temperature before soaking, a continuous process with catalysed monomer can be run without any other arrangements than refilling.

Polymerisation in warm water 75 to 80°C gives a uniform result. A continuous process pollutes the water and the water has to be cleaned or circulated regularly.

Experience from a 3-year field test of polymer-impregnated kerb stones shows excellent performance. No reduction in bending tensile strength or changes in the absorption properties are registered after 3 years of outdoor storage.

Polymer-impregnated concrete has a potential market in connection with bridge and road surface structures. A major testing field with polymer impregnated wear surface was opened to traffic in August 1974.

*B161 Spellman, D. L., Woodstrom, J. H., Bailey, S. N., Nakao, D. I., and Spring, R. J., "Field Application of Polymer Impregnation of Concrete," CA-DOT-TL-5299-1-75-34, (PB-252327), Oct 1975, Office of Transportation Laboratory, California Department of Transportation, Sacramento, Calif.*

Oven dried concrete specimens were impregnated with a methyl methacrylate monomer system and polymerized by thermal-catalytic means. This treatment produced concrete having significant improvement in compressive strength, surface abrasion resistance, and reduction in permeability as measured by electrical resistance.

A technique for the impregnation and polymerization of concrete with a monomer system was developed and successfully applied under field conditions to obtain 1/2- to 3/4-in. penetration. This application was made on a 10- by 90-ft section of a bridge deck.

*B162 Steinberg, M., et al., "Method of Making Corrosion Resistant Concrete Articles," Report No. PAT-Appl-303 753, Jan 1975, Atomic Energy Commission, Washington, D. C.*

The patent describes concrete pipes rendered resistant to corrosion by a process in which the pipe is first impregnated with a liquid monomer which is then polymerized in situ followed by an application of a coating of a liquid monomer which is polymerized in situ followed by a second coating application which is polymerized in situ. Preferably, the coating material has a higher viscosity than the impregnating material. The monomers disclosed are styrene, acrylonitrile, methyl methacrylate, isobornyl methacrylate and trimethylolpropane trimethacrylate. Mixtures of styrene and polyester are also disclosed. Polymerization may be carried out by thermal process using a catalyst or by the use of radiation.

- B163 Steinberg, M., "Concrete-Polymer Composite Materials and Their Potential for Construction, Urban Waste Utilization, and Nuclear Waste Storage," Copolymers, Polyblends, and Composites, Adv. Chem. Series 142, Chapter 37, pp 431-441, 1975, American Chemical Society, Washington, D. C.

Results of a test program are presented in which a range of concrete-polymer composite materials is under investigation. The old technology of hydraulic cement concrete is combined with the new technology of polymers. Polymer-impregnated precast concrete (PIC) is the most highly developed composite, and it exhibits the highest degree of strength and durability. Polymer concrete (PC), an aggregate bound with polymer, is potentially a most promising material for cast-in-place applications. PC with solid waste aggregate offers interesting possibilities for converting urban waste into commercially valuable construction materials. PIC and PC also show potential for immobilizing radioactive waste from the nuclear power industry for long-term engineered storage.

- B164 Swamy, R. N., "Some Engineering Implications of Design in Polymer Concrete," Polymers in Concrete, pp 349-359, May 1975, The Concrete Society, London.

Improving existing materials and developing new materials of construction is a key factor to progress and economics in the construction industry. Concrete-polymer materials and polymer-impregnation in particular, with their increased strength, stiffness and durability properties, appear to provide the answer to the age-old problem of cracking and deterioration of concrete under adverse environmental and loading conditions. An engineering evaluation of their short- and long-term performance is, however, necessary before safe and economic designs can be produced. It is shown that if strength, stiffness, ductility and fire resistance are factors of design, then impregnated concrete may behave no better than other new concrete materials. Its low permeability and high strength can, however, be combined to provide in situ strengthening and long-term protection of cracked and deteriorated concrete, and to transform low-density waste products into a high-strength durable construction material. It is suggested that to evaluate properly the role of materials in structural design, it is unrealistic to treat these new materials as modified forms of conventional concrete.

- B165 Weyers, R. E., et al., "Effects of Deicer Salts and Roadway Contaminants on Polymer Impregnation of Bridge Deck Concrete," Polymer Concrete, Transportation Research Record 542, pp 41-49, 1975, Washington, D. C.

Cores, 4 in. (10 cm) wide, extracted from three 7-year-old concrete bridge decks were impregnated with methyl methacrylate to evaluate the effects of deicer salts and roadway contamination on polymer impregnation. All specimens were impregnated by soaking from the top

(traffic) surface at atmospheric pressure for a sufficient period of time to achieve approximately 5 in. (12.7 cm) of penetration. Deicer salts, in the quantities measured in the three bridge decks, did not reduce the depth of polymer penetration or the volume of voids filled with polymer. However, the rate of penetration decreased as salt concentration increased. The rate of penetration was a linear function of the square root of time. Removal of roadway contaminants by lye, detergent, or sandblasting had no apparent effect on the rate or extent of polymer impregnation.

B166 Whiting, D., and Kline, D. E., "Dynamic Mechanical Response of Polymer-Impregnated Mortars," Polymer. Eng. Sci., Vol 15, No. 2, 1975, pp 65-69.

Dynamic elastic modulus and internal friction of a portland cement (Type I) mortar system impregnated with an epoxy resin system and with methyl methacrylate were measured in the temperature range of 100 to 450° K by use of a free-free resonance technique. Dynamic modulus values were found to increase greatly compared to controls, especially at lower (<300° K) temperatures. Above 320° K the dynamic moduli of polymer-impregnated mortars exhibited a sharp decrease toward control values. Low temperature damping maxima of the composites differed significantly from those of the constituent phases.

B167 Wyman, J., Static and Cyclic Strengths of Polymer Impregnated Surface Treated Reinforced Concrete, M. S. Thesis, University of Texas at Austin, Austin, Tex., Dec 1975.

This research was conducted to investigate the static and cyclic strength of reinforced polymer-impregnated surface treated concrete. The test specimens constructed for this experiment were 4 in. wide, 5-1/2 in. deep, and 60 in. long. The reinforcement consisted of one No. 5 deformed steel bar positioned approximately 1-1/2 in. from the bottom of the beam. These beams were simply supported on a 56-in. span and loaded with equal loads 24.4 in. from each end.

The beams were treated with a monomer solution of methyl methacrylate, 1 percent benzoyl peroxide (catalyst), and 10 percent trimethylpropane trimethacrylate (cross-linking agent), and polymerized through the application of hot water or steam. Some of the beams were treated on the compression side and some were treated on the tension side. The impregnated depth varied from 0.5 in. to 1.5 in.

Static tests were conducted on both treated and untreated beams to determine their ultimate strength. The primary purpose of the cyclic testing was to determine if bridge decks, treated with this monomer solution, could still sustain repeated service load conditions. Therefore, most of the cyclic tests consisted of varying the loading between the service load of the section (determined by AASHTO standards) and a specified minimum load (14.7 percent of the maximum load during the cycle). Several beams were loaded to two and three times the calculated service load. All cyclic tests were concluded after  $2 \times 10^6$  cycles or failure of the specimen, but one beam was allowed to continue until

$5 \times 10^6$  cycles. The beams that did not fail under cyclic loading were later tested statically. Some beams were tested continuously while others were permitted rest periods. The loading rate varied from 60 to 330 cycles per minute.

Despite the presence of anchorage failures and the absence of web reinforcement, conclusions following from this investigation are: (1) compression side treatments increase the flexural capacity and stiffness of the beams while decreasing the cyclic strength; (2) tension side treatments decrease the diagonal tension capacity and stiffness of the beams and also the cyclic strength.

B168 *Yimprasert, P., Durability, Strength, and Method of Application of Polymer Impregnated Concrete for Slabs, Ph. D. Dissertation, University of Texas at Austin, Austin, Tex., Dec 1975.*

The application of polymer-impregnated concrete (PIC) for improving the durability of concrete slabs, especially highway bridge decks, has been widely investigated. For this application, the slab is partially impregnated from the upper surface. Parameters such as drying time and temperature, soaking time, and curing time and temperature, which, of course, can influence the durability of concrete bridge decks after impregnation, were thoroughly investigated.

The monomer system of methyl methacrylate (MMA) with 1 percent (by weight) benzoyl peroxide (BP) and 10 percent (by weight) trimethylpropane trimethacrylate (TMPTMA) was generally used throughout the tests. A drying temperature of more than 212°F at the surface of the concrete was necessary to reduce the drying time to an acceptable level (usually less than 24 hr) for field application. It was found that a drying temperature of 250°F to 300°F was acceptable for the slabs tested.

The durability performances of partially-impregnated slabs were evaluated by freeze-thaw and salt water exposure tests. The freeze-thaw tests were conducted on 10- by 10- by 6-in. concrete slabs. The salt water exposure tests were conducted on 5.5- by 40- by 43-in. concrete slabs. The specimens were sprayed daily with salt water with 3 percent sodium chloride by weight, which simulated sea-water concentration. The freeze-thaw tests were conducted by placing the specimens, which contained approximately 0.25 in. ponded water on the surface, in a 24-hr cycle with the temperature ranging from -20°F to room temperature (~75°F). It was found that the durability performance of concrete was significantly increased by PIC partial impregnation.

Actual field impregnation tests on highway bridge decks were conducted. Polymer depths of approximately 0.75 to 1.0 in. were achieved.

#### 1976

B169 *Bazhenov, Iu. M., Gorchakov, G. I., and Alimov, L. A., "Increasing the Resistance of Hydraulic Engineering Concretes by Monomer Impregnation," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.*



Increasing the service life of hydraulic concrete structures can be done by impregnating the concrete with a low-viscosity liquid monomer which is converted to a polymer after polymerization. Concrete which has been treated in this manner is called polymer-impregnated concrete (PIC).

The large increase in the production of synthetic resins has raised the possibility of "alloying" concretes under production conditions. The goal of the present work is a deeper understanding of PIC properties as functions of technological parameters.

There are two methods of treating the free radicals to initiate polymerization of the monomers in the concrete: the radiation method (using gamma rays), and the thermocatalytic method (using catalysts and heat). The radiation method has a number of disadvantages: the complexity of radiation installations, the need for large capital investments, and radiation hazards. The thermocatalytic method is technologically simpler, safer, and does not require large capital investments. Thermocatalytic polymerization takes place at an elevated temperature, but it must be remembered that the temperature should not exceed the boiling point of the monomer. The structure of the concrete has a big effect on the degree of impregnation.

Impregnation with monomers increases the compressive strength of the concrete (e.g., from 40-60 to 140-150 MPa) and increases the tensile strength by a factor of 3 to 4. Impregnation increases the resistance of concrete to corrosive environmental action. For example, the frost resistance of PIC can be as high as 6000 to 7000 freeze-thaw cycles. The bonding of concrete to reinforcement is increased by a factor of approximately 4.

B170 Chen, W.-F., et al., "Use of Polymers in Highway Bridge Slabs," New Horizons in Construction Materials, Vol 1, 1976, pp 327-344.

This article describes in detail a test that was carried out in response to deterioration of concrete bridge slabs.

The field experience with large-scale impregnations shows that it is just as easy to impregnate a larger area as a smaller one, with further savings in heat losses, pressure, impregnation and polymerization time. The stated objective of impregnating beneath the top reinforcing rebar has been achieved. The experience gained will make further trials successful enough to give promise, not only of long range improvements in deck durability, but also indicate its potential to become one of the key treatment procedures for the future. Future plans include additional testing on the impregnated deck area and impregnation trials on an actual bridge deck in service.

B171 Chen, W.-F. and Dahl-Jorgensen, E., "Stress-strain Behavior of Polymer-Impregnated Concrete," New Horizons in Construction Materials, Vol 1, Nov 1976, pp 303-326.

The paper shows that stress-strain behavior of concrete can be varied over a wide range, from ductile to brittle, by using combinations of plasticizing (n-butyl acrylate) or cross building (TMPTMA) monomers

with methyl methacrylate, or both. It is also shown that a realistic level of salt (up to 1 percent) in concrete prior to impregnation has little effect on polymer loading mechanical properties, but it requires more rigorous drying. While high temperatures accelerate drying out but decrease strength, subsequent polymer impregnation essentially yields a material with properties similar to a conventionally dried material.

B172 Clear, K. C., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs," Performance after 830 Daily Salt Applications, Report No. FHWA-RD-76-70, Vol 3, Apr 1976, Federal Highway Administration, Washington, D. C.

The purpose of this investigation is to provide administrators and designers with factual data on which to base decisions on the type of protection to provide to bridge decks constructed in corrosive environments. Specifically, the objective is to determine the relative time-to-corrosion of reinforcing steel embedded in concrete slabs, fabricated from various mix designs and construction procedures when the slabs are subject to periodic setting with a 3 percent NaCl solution.

One hundred and twenty-four 4-ft by 5-ft by 6-in. reinforced concrete slabs were fabricated, cured, and placed in the outdoor exposure yard on elevated stands. Concrete covering the feasible range of mix designs were investigated. Clear concrete cover over the reinforcing steel was varied from 1 to 3 in. Various finishing methods, curing procedures, admixtures, surface protective treatments, and special new concretes were also included.

Volumes I and II, FHWA-RD-73-32 and 33, issued in April 1973 presented the details of slab fabrication and testing as well as an interim evaluation after 330 daily salt applications. This report, Volume 3, presents the results of evaluations of conventional concretes and those materials and techniques which "looked good" in the initial report. Eight hundred thirty daily saltings were applied prior to this evaluation.

R172(1) Nagaraj, T. S., et al., "Some Studies on Polymer Concrete," Indian Concrete Journal, Vol 50, No. 4, Apr 1976, pp 117-120.

The paper presents the results of a pilot study on polymer concrete. It has been attempted to collect information on the techniques of monomer impregnation and subsequent polymerization, using thermally dissociative initiators. Measured and evaluated mechanical properties and durability aspects of the material reveal that improvements can be achieved by resorting to polymerization of hardened concrete.

B173 Clifton, J. J., Fearn, J. E., and Anderson, E. D., "Polymer Impregnated Hardened Cement Pastes and Mortars," Building Science Series No. 83, 1976, National Bureau of Standards, U. S. Department of Commerce.

Polymer impregnated hardened cement pastes and mortars have been prepared and their properties compared to those of control specimens. Specimens were made by impregnating dried and evacuated precast hardened cement pastes and mortars with methyl methacrylate, under pressure, which was thermally polymerized. The effects of the microstructure of the cement pastes and mortars on the performance of polymer impregnated mortars were determined by preparing specimens with a wide range of porosities by varying the water-cement ratio and the curing times prior to impregnation.

The properties of impregnated and control specimens were investigated by scanning electron microscopy for porosity determinations. The polymer impregnated materials had compressive and flexural strengths, moduli of elasticity, and fracture toughness which were substantially higher than unimpregnated materials.

*B174 "Dam Fights Erosion with Plastic Coat of Armor," Engineering News-Record, Vol 196, No. 11, 11 Mar 1976, pp 18-19.*

Polymer-impregnated concrete now lines an outlet tunnel and part of the stilling basin floor at Dworshak Dam in Idaho, providing protection against erosion and cavitation experienced during the first few years of operating the 717-ft-high gravity structure. Its voids plugged with plastic, the concrete has a compressive strength four to five times that of untreated concrete.

The first large-scale polymerization project in the United States took about nine months to complete. Three types of concrete - fiber reinforced, conventional, and dry-pack - on both vertical and horizontal surfaces, in an enclosed area as well as in the open, were polymerized. The type used depended on the severity of the damage.

*B175 Dansby, J. B., The Shear Behavior of Rectangular Concrete Beams Reinforced with Specifically Developed Precast, Pretensioned, Polymer Impregnated Concrete Tubes, Ph. D. Dissertation, University of Florida, Gainesville, Fla., 1976.*

Analytical and experimental investigations were conducted to determine the influence of seven variables on the strength and modulus of elasticity of polymer impregnated concrete (PIC). A procedure for optimizing PIC strength and modulus of elasticity was developed and resulted in increases with respect to unimpregnated concrete in compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity by factors of 4.07, 5.40, 4.46, and 2.75, respectively.

A procedure was developed for producing precast, pretensioned, PIC tubes (PIC rebars) which could be used as a highly corrosion-resistant form of tensile reinforcement for concrete structural members. This method of production resulted in PIC rebars composed of a 2.40-in. O.D. PIC casing prestressed by a concentrically located, 1/2-in., 270K strand tensioned to approximately 70 percent of its yield strength.

A total of 30 beams were tested in shear. The experimental findings indicated that the shear strength was directly related to the

reinforcement ratio, and inversely related to the shear-span to depth ratio. The ultimate shear strength was adequately predicted by a rational model based on tensile cracking of the PIC rebar, and the inclined cracking shear strength was adequately predicted by a rational model based on maximum principal tensile stress.

B176 DePuy, G. W., et al., "Concrete-Polymer Materials - Final Report," REC-ERC-76-10, Aug 1976, Bureau of Reclamation, Denver, Colo.

The Bureau of Reclamation and Brookhaven National Laboratory conducted a joint research program on development of concrete-polymer materials under the sponsorship of the then U. S. Atomic Energy Commission, the then Office of Saline Water, and the Bureau of Reclamation. The program began in 1967 and continued to June 1973. Five topical reports have been published on the work performed through June 1972. Test results presented were conducted at the Bureau during the final year of the cooperative program, and include: (1) work on monomer and composite surveys, (2) process technology development for PIC (polymer-impregnated concrete), (3) test results on PIC at ambient and elevated temperatures, (4) examination of PIC after exposure to brine at elevated temperatures, (5) nondestructive testing of PIC, and (6) a brief summary of applications development. The purpose of this report is to record final data from the testing program. Detailed analyses of these data are not included.

Some of the important general conclusions from the total program are:

- PIC has greatly improved structural properties compared to unimpregnated concrete.
- The durability of PIC is greatly superior to that of unimpregnated concrete. PIC shows excellent freeze-thaw resistance, potentially excellent sulfate attack resistance, and substantial improvement in acid resistance. It appears that PIC could be made to be virtually immune to acid attack by coating the surface with multiple layers of polymer.
- A feasible thermal-catalytic process has been developed for large-scale production of PIC. The process involves drying the concrete, vacuum/pressure impregnation, and polymerization under water.
- Concrete quality and curing conditions are of relatively minor importance in producing good quality PIC. However, it is likely that the best quality and most economical PIC would be produced from good quality, dense concrete.
- MMA, MMA-TMPTMA, and styrene-polyester monomer systems appear promising for PIC applications at normal temperatures. A styrene-TMPTMA monomer system appears promising for PIC in applications under an exposure to brine and vapor at temperatures up to 290°C (143°C), as may be encountered in saline water distillation plants.
- For applications which require good durability rather than high strength, partially impregnated PIC appears to be a less costly alternative to fully impregnated PIC. Further development is required to refine the process for field applications and to determine properties of the material.
- Very promising results have been obtained in the developmental

studies on PC (polymer concrete). PC made with a MMA monomer system has structural properties generally comparable to that of PIC and should have much better durability. PC should be substantially less costly to prepare than PIC.

The limited studies with PCC have not given the desired results. Further work would be required to develop a satisfactory PCC.

B178 Kukacka, L. E., and Steinberg, M., "Concrete-Polymer Composites, A Material for Use in Corrosive Environments," Materials Performance, Oct 1976, pp 13-15.

Advantages of polymer (methyl methacrylate) impregnated and polymer/concrete materials in corrosive environments are described. Polymer additions to concrete greatly improve resistance to abrasion and cavitation and reduce water absorption over 99 percent. The combination also has better resistance than hydraulic concrete to hot brine, distilled water, acids and freezing and thawing cycles. Principal applications in the U. S. are for bridge decks. Polymer impregnated concrete is being used on bridges in Colorado and Utah. Polymer concrete, which consists of a mixture with 7 to 8 percent of a methacrylate, for example, is widely applied in Europe and Japan for pipe, tunnels, patching concrete, and pump beds. Application to piling and barge construction is under way. A polymer-silica formation has been developed in Russia which is recommended for acid resistant floors among other uses.

B179 Manson, J. A., Stress-Strain Behavior of Polymer-Impregnated Concrete, Lehigh University, College of Engineering, Bethlehem, Pa., 1976.

The polymerization of monor within the pore structure of previously-cured concrete yields a new composite, POLYMER-IMPREGNATED CONCRETE (PIC), which has an unusual combination of mechanical properties and corrosion resistance. Steinberg et al. have demonstrated that PIC composites containing relatively small proportions of polymers (e.g., poly(methyl methacrylate) show several-fold increases in Young's modulus, tensile strength, and compressive strength compared with those of the control. Similar observations were made by other investigators, not only with cement and concrete, but also with ceramic substrates.

In order to properly use PIC in the design of structures, its entire stress-strain relationship and mode of failure must be known as a function of loading conditions. Auskern and Horn showed that the compressive stress-strain curves for cement and concrete specimens impregnated with poly(methyl methacrylate) were dramatically different from those of the unimpregnated control specimens. The PIC specimens responded in a linear (Hookean) elastic manner over most of the experimental range, whereas the control specimens yielded and began to fail progressively at relatively low strains (behavior typical of concrete).

The mechanism by which the polymer strengthens the concrete is of great fundamental interest. One suggestion is that the polymer simply fills the void spaces of the concrete so that the strength of the

composite begins to approach the idealized strength of pore-free cement. Other suggestions attribute the improved strength of PIC to such specific factors as enhanced interphase bonding and better resistance to crack growth.

B180 Mehta, H. C., et al., "High-Temperature Drying of Thick Concrete Slabs," American Society of Civil Engineers Transportation Engineering Journal, Vol 102, No. 2, May 1976, pp 185-200.

The foremost requirement for deep polymer impregnation of thick concrete slabs is thorough drying to remove all evaporable water from the pore system in concrete. To facilitate rapid repair of bridge decks with polymer impregnation, it is desirable to dry the concrete from the surface with surface temperatures not exceeding 700 to 800°F (370 to 420°C). A time-temperature-moisture loss study is presented on six 24- by 24- by 6-in. (610- by 610- by 150-mm) concrete slabs, a 72- by 72- by 8-in. (1800- by 1800- by 200-mm) slab and a small section of 7-1/2-in. (190-mm) bridge deck. The specimens were dried from one surface using an automated propane gas fired torch assembly. The feasibility of high-temperature drying of concrete without cracking problems is demonstrated and a criterion for safe and rapid drying to the depth of 4 to 6 in. (100 to 150 mm) in the field is developed.

B181 Mornson, G. L., et al., "Chloride Removal and Monomer Impregnation of Bridge Deck Concrete by Electro-Osmosis," FHWA-KS-RD.74-1, Interim Report, Apr 1976, Kansas Department of Transportation.

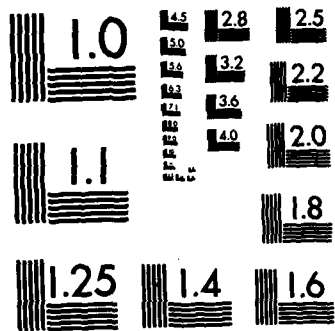
Removal of chloride application of a direct current potential between bridge reinforcing steel and a copper screen conductor on the bridge surface results in a significant increase (about 5 times) in the concrete permeability leaving the deck much more vulnerable to future salt attack. Overlays, membranes, and surface sealants may not be adequate to prevent future corrosion problems due to internal chloride redistribution by an electro-osmotically created battery effect.

Monomers, polymers, or other materials may be moved into the concrete either simultaneously with or subsequent to chloride removal by the same applied potential. A monomer penetration depth of 15 in. within 24 hr has been attained. At least one polymer, furfural-acetone, results in a significant reduction in permeability (to about 1/3 that of untreated concrete and 1/15 that of electrically treated concrete) in the concrete in the vicinity of the reinforcing steel.

B182 Muñoz-Escalona, A., and Ramos, C., "Polymerization Rate and Mechanical Properties of Polymer-Impregnated Mortar," Cement and Concrete Research, Vol 6, No. 2, 1976, pp 273-286.

The influence of different types of monomer on the mechanical properties of mortar impregnated composite were analyzed. Additionally a semi-empirical model developed by Auskern was applied to predict the strength of the composites from the obtained values of porosity before and after impregnation. The velocity of polymerization and the





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catalytic effect of the cement on this reaction were analyzed through the continuous recording of temperature by means of embedded thermocouples. The molecular weight of the polymer inside the specimens was also obtained. Microscopic observation of the fracture surface is presented.

**B183** *Nashid, M., Lacasse, M., and Turcke, D., "Computer Simulation of Polymer Impregnated Concrete," Conference on Computer Simulation for Materials Applications, National Bureau of Standards, Gaithersburg, Md., Apr 1976.*

A study was made of the composite action between the concrete materials and polymer considering the upper and lower bound extreme solutions for a two-phase material, making suitable corrections for voids. A computer simulation of the material response is examined such that properly defined constitutive relations can be procured for various material compositions.

**B184** *"Polymer Concrete Composites," Journal, Concrete Society of Southern Africa, Johannesburg, South Africa, No. 3, Sep 1976, pp 3-4.*

Polymer, monomer, and polymerization are defined while the processes of polymer impregnated concrete and polymer cement concrete are explained with examples of their use in concrete.

**B185** *"Polymers in Concrete," Proceedings, First International Congress on Polymer Concretes, The Concrete Society, London, 5-7 May 1976.*

Contains papers presented at the First International Congress on Polymer Concretes held in London in May 1975. Contributions from over 60 concrete and plastics specialists involved in the use of polymers in concrete discuss: polymer impregnated concrete, concretes with polymers added, with dispersed polymers, and resin bound aggregates. A good portion of the volume is devoted to papers on practical applications of polymer concrete. The existing worldwide state of affairs of polymers in concrete is also discussed.

**B186** *Pu, D. C., and Cady, P. D., "Effect of Moisture Content and Drying Method on the Penetration of Monomers into Concrete," Journal of the American Concrete Institute, Vol 73, No. 8, Aug 1976, pp 447-453.*

Impregnation of methyl methacrylate in hardened bridge deck type concrete was studied in the laboratory using a field applicable technique. Penetration as deep as 8 in. (20.3 cm) was obtained by ponding only. It was found that monomer loading was mainly determined by the amount and distribution of moisture in the concrete, and was slightly affected by ambient temperature. Due possibly to the disturbance of the capillary network, unequal rates of impregnation were noticed with specimens dried by different methods. Simple equipment and operation processes showed satisfactory drying, impregnation, and polymerization.

B187 Rosebashvili, K. I., Tatishvili, T. I., and Tsilosani, V. N., "Sulfate Resistance and Deformability of Polymer-Impregnated Concrete," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

Objects made of concrete can be modified by impregnating them with low-viscosity monomers which are then polymerized within the concrete material by radiation or by thermalcatalytic processes. Concrete objects of this type are quite distinct from traditional building materials because of their improved traditional building materials because of their improved physiochemical and mechanical properties.

This work is an experimental study of the strength, deformability, and sulfate resistance of polymer-impregnated concrete under various environmental conditions.

Our research has shown that: the strength of polymer-impregnated concretes is 3 to 3.5 times that of ordinary concrete, reaching 1300 to 1500 kg/cm<sup>2</sup>; their elastic modulus is increased by a factor of 1.5 to 1.8; their water absorption is reduced by a factor of 6 to 8; their water proofness is increased; their resistance to various corrosive media (in particular, sulfate solutions of various concentrations) is increased.

The results of 2-year tests have shown that, for practical purposes, polymer-impregnated concrete does not creep under various environmental conditions (absolute dryness, normal humidity, immersion in water, immersion in sulfate solutions).

B188 Smoak, W. G., "Development and Field Evaluation of Techniques for Polymer Impregnation of New Bridge Deck Surfaces," FHWA-RD-76-95, Sep 1976, Federal Highway Administration.

The development and field evaluation of a technique of impregnating new concrete bridge decks with an acrylic polymer system to a depth of 1 in. (25 mm) or more for protection against chloride induced corrosion of the reinforcing steel and freeze-thaw deterioration is reported.

The durability of concrete treated with the polymer impregnation technique was determined in chloride intrusion, freeze-thaw and skid and abrasion resistance tests.

The first polymer impregnation of the entire riding surface of a full-size bridge deck was performed as a part of this research and development program in October 1974. A detailed discussion of this first field treatment and a general discussion of two subsequent full-size bridge treatments which resulted in refinements to the treatment technique are included.

B189 Steinberg, M., "Concrete-Polymer Composite Materials," Polymer News, Vol 2, No. 11-12, 1976, pp 3-12.

A wide range of concrete-polymer composite materials is presently under investigation, including polymer impregnated precast concrete (PIC) which is the more developed of the composites and exhibits the highest degree of strength and durability, and polymer concrete (PC), an aggregate bound with polymer which has considerable potential for cast-in-place applications. PC with solid waste aggregate holds out interesting possibilities for converting urban waste into valuable construction materials of commerce. PIC and PC also show potential for immobilising radioactive waste from the nuclear power industry for long-term engineered storage.

B191 Vaschuk, V. Ia., Levchenko, A. I., and Doliuk, V. P., "The Technology and Properties of Polymer-Impregnated Concretes for Hydraulic Engineering Construction," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

The technology for preparing polymer-impregnated concrete consists of impregnating ordinary concrete with a low-viscosity monomer which is then polymerized within the concrete by radiation or thermal-catalytic methods. The result of this treatment is that the pores and capillaries of the concrete are filled by the polymer; this significantly increases the strength and frost resistance of the concrete (3-4 and 10 times, respectively). For practical purposes, the material becomes waterproof and resistant to corrosive environments.

The high values for the physicomechanical properties of polymer-impregnated concretes permit them to be recommended for the production of penstocks in corrosive environments and for revetments in hydraulic structures which are resistant to impact, abrasion, and cavitation.

Preliminary technical and economic calculations have shown that polymer-impregnated-concrete pipes up to 500 mm in diameter are cost-equivalent to ones made of asbestos cement. Protective revetments of spillway dams made with polymer-impregnated concrete are significantly lower in cost than revetments made with cast iron, steel, etc.

B191(1) Bazhenov, Iu., M., and Milkov, S. B., "Silicate Concrete Polymer;" Translated from the Russian by Novye Stroitel'nye materialy, Sbornik trudov, No. 139, 1976, pp 56-68.

1. The impregnation of silicate concrete with MMA with subsequent polymerization leads to a significant improvement in its structural properties and durability:

- compressive strength is increased by 2 to 4.78 times;
- tensile strength is increased by 2.52 to 3.5 times;
- bending strength is increased by 2.60 to 3.3 times;
- modulus of elasticity is increased by 1.5 times;
- frost resistance is increased by several times;
- water absorption decreases from 16 to 20 times;
- the material becomes practically impervious to water.

2. Under otherwise identical conditions, an increase in the quantity of polymer leads to an increase in the strength of silicate concrete polymer. The amount of increase in strength depends on the structure of the concrete, lower grade concretes being strengthened more.

3. To accelerate the process of production of concrete polymer and improve its technical and economic factors, it is desirable to use drying to a residual moisture content of less than 0.2 percent by mass, preliminary short-term evacuation, and polymerization under water.

4. It is desirable to use silicate concrete based on crushed gravel with a binder content of 300 to 400 kg/m<sup>3</sup> for processing, since in this case impregnation of the concrete is accelerated, the consumption of monomer remains the same, with sufficiently high strength of the silicate concrete polymer (over 140 MPa).

5. Silicate concrete polymer can be used in those cases where ordinary silicate concrete cannot be used due to its poor resistance to severe operating conditions.

B192 Webster, R., et al., "Partial Polymer Impregnation of Center Point Road Bridge," Report No. CFHR 3-9-71-114-5, Jan 1976, Center for Highway Research, The University of Texas at Austin, Austin, Tex.

The application of polymer-impregnated concrete to an actual bridge deck is described. A method of determining the need for cleaning the surface is presented which consists of performing monomer penetration tests on sandblasted and nonsandblasted cores. The procedures used for the polymer impregnation of the Center Point Road bridge are described in detail.

B193 Whiting, D., and Kline, D. E., "Internal Friction in Polymer-Impregnated Hardened Cement Paste," Journal of Applied Polymer Science, Vol 20, 1976, pp 3337-3351.

Hardened cement paste specimens were prepared with hydration times of 1, 3, 7, 28, and 180 days. Specimens were oven dried and subsequently impregnated with methyl methacrylate, tert-butylstyrene, polyethylene glycol, and an epoxy resin system via a vacuum-pressure technique. Internal friction ( $Q^{-1}$ ) of in situ polymerized specimens was measured over the temperature range from 100° to 500°K. Results indicate that the internal friction spectra of polymer-impregnated specimens closely parallels the internal friction spectra of the bulk polymers used for impregnation. Magnitudes of the internal friction peaks in the impregnated specimens were found to be less than that expected on the basis of volume fraction of polymer present. These results are attributed to hindered motion at the cement/polymer interface.

B194 Whiting, D., and Kline, D. E., "Theoretical Predictions of the Elastic Moduli of Polymer-Impregnated Hardened Cement Paste and Mortars," Journal of Applied Polymer Science, Vol 20, No. 12, Dec 1976, pp 3353-3363.

Hardened cement pastes with water-to-cement (W/C) ratios of 0.4 and 0.8 and hydration times of 1, 3, 7, and 28 days were oven dried and subsequently impregnated with an epoxy resin formulation which was then polymerized in situ at 75 C. Portland cement mortars containing Ottawa sand and asbestos fibers as filler were also subjected to this impregnation process. Experimental values were compared with moduli calculated using various theoretical approaches based on two-phase composite materials theory. Best agreement between experimental and calculated results occurs when Wu's theory for spherical polymer inclusions was applied to a cement-based matrix. In the case of polymer-impregnated mortars, experimental and theoretical results are in closest agreement at low temperatures and at low volume fraction of filler.

B195 Yimprasert, P., et al., "Durability, Strength, and Method of Application of Polymer-Impregnated Concrete for Slabs," *CFHR 3-9-71-114-4*, Jan 1976, Center for Highway Research, The University of Texas at Austin, Austin, Tex.

The application of polymer-impregnated concrete (PIC) for improving the durability of concrete slabs, especially highway bridge decks, has been widely investigated. For this application, the slab is partially impregnated from the upper surface. Parameters such as drying time and temperature, soaking time, and curing time and temperature, which, of course, can influence the durability of concrete bridge decks after impregnation, were thoroughly investigated.

The monomer system of methyl methacrylate (MMA) with 1 percent (by weight) benzoyl peroxide (BP) and 10 percent (by weight) trimethylolpropane trimethacrylate (TMPTMA) was generally used throughout the tests. A drying temperature of more than 212°F to 300°F was acceptable for the slabs tested.

To obtain at least a 1-in. polymer depth, a soaking time of 4 hr or more was necessary. Steam was found to be an economical, safe and workable curing source for field treatment. With adequate steam, the monomer in concrete can be cured within 30 min. A curing temperature of at least 140°F is necessary to achieve adequate polymer depth.

The durability of partially-impregnated slabs was evaluated by freeze-thaw tests conducted on 10-in. by 10-in. by 6-in. concrete slabs. It was found that the durability performance of concrete was significantly increased by PIC impregnation.

B195(1) Schrader, E. K., and Kaden, R. A., "Outlet Repairs at Dworshak Dam," *The Military Engineer*, Vol 68, No. 443, May-Jun 1976, pp 254-259.

Sluiceways, spillways, outlets, stilling basins, and similar structures subjected to high-velocity water flows are faced with the serious problem of cavitation forces. As a result, concrete surfaces that carry sustained high-velocity water flows have failed from either erosion or cavitation. The outlets of Dworshak Dam have suffered such damage and are being repaired using two new concepts in concrete

construction--fiber-reinforced concrete (FRC) and polymer-impregnated concrete (PIC).

The regulating outlets at Dworshak Dam have not yet been put back into service, so a full evaluation of their performance cannot be made at this time, although the project appears to be quite successful. It has been shown that it is possible and practical to perform polymer-impregnated concrete work and fibrous-concrete work under extremely difficult field conditions using a fixed-price contract. Also, it has been shown that it is possible to impregnate concrete on vertical surfaces. It appears that polymer impregnation of in-place concrete can be performed in an economical and safe manner under typical construction conditions.

B195(2) Schrader, E. K., and Kaden, R. A., "Stilling Basin Repairs at Dworshak Dam," *The Military Engineer*, Vol 68, No. 444, Jul-Aug 1976, pp 282-286.

This paper is a discussion of repairs at Dworshak Dam using fiber-reinforced and polymer-impregnated concrete.

The relative effectiveness of the epoxy mortar, fiber-reinforced concrete impregnated will be evaluated. At this time the project has been successful from the standpoint of showing that polymer impregnation of concrete can safely be accomplished by contract using low bids and standard specification techniques. Fiber-reinforced concrete work has become fairly common and continues to show its field acceptability.

#### 1977

B196 Bazhenov, Iu. M., et al., "Studying the Process of Impregnating Concrete with Polymerizing Monomer;" Translated from Russian by Bureau of Reclamation, No. 1229, Denver, Colo., 1977.

This article is intended to continue the study of the fundamentals of changes in concrete polymer properties as a function of the technical parameters. To systematize the research on the process of impregnation as a function of the structural characteristics, mixes were devised which cover the entire useful range of the constituent parts of the cement system. As a result of analyzing 29 mixes, a relationship was determined between the quantity of monomer absorbed and the total porosity of the concrete as follows.

$$M_o = 0.9P - 2.0$$

where  $M_o$  = Maximum saturation of the concrete

P = Total porosity of the concrete

Thus, only the use of the method of structural characteristics has made a systematic study of the process of impregnation of concrete possible. It has also permitted the definition of the general conditions necessary for a change in impregnation parameters as a function of the type of pores and the total porosity.

B197 Carino, N. J., "Effects of Polymer Impregnation on Mortar-Aggregate Bond Strength," Cement and Concrete Research, Vol 7, No. 4, Jul 1977.

Polymer-impregnated concrete (PIC) is recognized as a superior construction material with higher durability and strength than plain concrete. The increase in strength has been thought to be a result of an increase in bond strength between mortar and aggregate phases and a reduction of the porosity of the mortar. However, there has been no direct evidence to support that an enhanced mortar-aggregate bond is achieved. In this study, modified briquet tension specimens were tested to determine effects of polymer-impregnation on tensile bond strength, and prismatic specimens with inclined aggregates were tested to determine effects on compression-shear bond strength. Plain mortar briquets were also tested. Results indicate that polymer impregnation does not significantly improve interface bond strength in PIC. However, mortar tensile strength is increased. A review of the failure process (microcracking) in plain concrete is presented. It is proposed that if the same microcracking process occurs in PIC, then high compressive strength is a result of high mortar tensile strength.

B198 Chen, W.-F., "Field Impregnation Techniques for Highway Concrete," Transportation Engineering Journal of American Society of Civil Engineers, Vol 103, No. TE3, 1977, pp 355-368.

The corrosion of reinforcing steel due to the penetration of deicing salts poses a considerable problem in bridge decks. One approach which has received much attention has been impregnation with a liquid monomer followed by polymerization to effectively seal the capillary pores against salt intrusion. The feasibility of impregnating a bridge deck to a depth of 4 in. or more under field conditions is demonstrated herein. Since the present deep impregnation techniques are costly in terms of energy, materials, and time, simplifications and improvement would be desirable. Herein, results of preliminary experiments with the use of a pressure-mat technique for mechanically assisting monomer or sealant penetration are described. It is shown that pressure mechanically applied to patterned rubber mats can effect uniform impregnation with a monomer such as methyl methacrylate or a sealant such as tar or linseed oil in reasonable times. Such an impregnation could conceivably be effected using rollers.

B199 Colombo, P., and Neilson, M., "Some Techniques for the Solidification of Radioactive Wastes in Concrete," Nuclear Technology, Vol 32, Jan 1977, pp 30-38.

Techniques are developed for the solidification of radioactive wastes in concrete. Included are the sources, storage, volume reduction, and solidification of liquid wastes at Brookhaven National Laboratory using the cement-vermiculite process, as well as solid waste treatment, shipping containers, and off-site shipments of solid wastes.

The properties of low-heat-generating high-level wastes, simulating

those in storage at the Savannah River Plant, solidified in concrete were determined. Polymer impregnation was found to further decrease the leachability and improve the durability of these concrete waste forms.

B200 Frondistou-Yannas, S. A., and Dietz, G. L., "Economic Feasibility of Polymer-Impregnated Concrete as a Building Material," Pre-stressed Concrete Institute Journal, Vol 22, No. 4, Jul-Aug 1977, pp 62-79.

In this work we have designed a plant that will mass produce polymer-impregnated concrete members for building construction and, for steady-state production, have derived the incremental cost of PIC over the costs of conventional concrete. We conclude the following:

1. When advantage is not taken of the increased strength of PIC members and their thickness is not reduced accordingly, PIC members are more costly than conventionally produced members even when the PIC plant operates at full capacity.

2. The initial investment required in the irradiation process is significant. The cost of the cobalt-60 source is the major component.

3. The thermal-catalytic process for polymerization is economically more attractive than the irradiation process.

4. The cost of polymerization agents is the most significant component of the incremental PIC production cost. The above holds even when the volume of PIC members has been reduced to account for their superior strength. The cost of polymerization agents is followed in importance by the cost of labor.

5. Panels of the same size and carrying capacity can be produced at a lower cost when styrene, rather than methyl methacrylate, is used as the monomer.

6. When the thickness of PIC members is reduced to reflect their superior strength, the farther away the building site is from the PIC plant, the more attractive PIC members become when compared to conventionally precast members; this is a result of the lower weight of PIC units.

7. PIC units are economically most attractive when used as exterior members where full advantage can be taken of their superior durability and esthetic potential.

8. Styrene-impregnated exterior panels of reduced thickness polymerized by the thermal-catalytic method (the economically most attractive combination) are economically more attractive than conventional panels for building sites that are at a distance of more than 28 miles from the plant (when plant utilization factor is 1.0) or more than 100 miles from the plant (when plant utilization factor drops to 0.6). By contrast, interior panels based on PIC become more attractive than conventional panels only at the unrealistically large distances of 190 to 262 miles.

B201 Fukuchi, T., and Ohama, Y., "Chemical Resistance of Autoclaved Concrete With and Without Polymer Impregnation," Journal of Society Materials Science Japan, Vol 26, No. 290, Nov 1977, pp 1117-1123.



Autoclaved concrete (AC), polystyrene-impregnated autoclaved concrete (PIAC), and water-cured concrete (WCC) were prepared and tested for chemical resistance to 10 types of chemical agents such as hydrochloric acid, sulfuric acid, sodium hydroxide, etc. In general, the chemical resistance of various concretes is in the following order: (good) PIAC > AC > WCC (bad). The aggressive chemical agents that attack markedly various concretes are hydrochloric acid, sulfuric acid, ammonium sulfate, etc. It seems that the chemical resistance of various concretes depends on the formation of free  $\text{Ca}(\text{OH})_2$  (highly reactive and susceptible to attack by chemical agents) and tobermorite (chemically resistant and watertight, produced as a result of autoclaving) in them. The superior chemical resistance of PIAC is due to the impregnation of autoclaved concrete with chemically resistant polymer (polystyrene).

*B202 North Pacific Division Materials Laboratory, "Investigation of Cavitation-Erosion Resistance of Conventional Steel Fiber and Polymer Impregnated Concrete for Tarbela Dam," Jan 1977, Corps of Engineers, U. S. Army, Troutdale, Oreg.*

High-head velocity tests were performed on laboratory prepared concrete slabs to determine the relative resistance to cavitation-erosion of plain concrete, steel fiber reinforced concrete, polymer impregnated plain concrete and polymer impregnated steel fiber concrete. The investigation was conducted to provide information for selection of materials for repair of stilling basins and spillway chutes at Tarbela Dam in Pakistan. It is evident from the test results that the good quality, nominal 4000-psi 1-1/2-in. MSA conventional concrete was the least resistant to cavitation-erosion of the four concretes tested. It would appear the steel fiber reinforced 3/4-in. MSA and the polymer impregnated 1-1/2-in. MSA conventional concretes were about equal in overall performance with the steel fibrous concrete showing greater erosion resistance in the earlier stages of the tests. The polymer impregnated steel fiber reinforced concrete was superior to the other three but the degree of superiority cannot be judged at this time because the test was not extended to completion.

*B203 Keeton, J. R., "Concrete Polymer Composite for Military Underseas Facilities," Technical Note N-1230, YF38.535.005.01.010, 1977.*

Precast portland cement concrete specimens were impregnated with monomeric and resinous materials by the brush-on, soak, and vacuum-soak methods. The impregnants were polymerized by the promoted-catalytic or thermal-catalytic methods or with curing agents. Impregnations of specimens with certain epoxies by the vacuum-soak method resulted in reductions in water absorption of over 99 percent. Impregnations of specimens with methyl methacrylate by the vacuum-soak method, polymerized thermal-catalytically, resulted in compressive strengths as high as 23,750 psi.

**B204 Kennedy, T. R., "Polymer Impregnation of New Concrete Bridge Decks," FHWA-RD-78-504, Oct 1977, Texas State Department of Highways and Public Transportation for Federal Highway Administration.**

This report describes in detail the method of polymer impregnating a new 64-ft 8-in. by 751-ft bridge deck at Big Spring, Texas. A drying method using gas fired infrared radiant heaters for drying the deck and polymerizing the monomer system was developed by the contractor. This method did not require an insulated enclosure, provided uniform heat on the deck and was considered to be an efficient economical construction method.

The impregnation depths achieved were generally the 1/2-in. to 5/8-in. range. While some minor cracking of the concrete was observed, it did not appear to be more than normal from aging and weathering and while heating and cooling of the deck may have been a contributing factor, cracking was not directly attributed to the heating process by project personnel.

**B205 "Largest Polymerization Project Aims at Protecting Bridge Deck," Engineering News-Record, Vol 199, No. 10, Sep 1977, p 43.**

Polymer-impregnated concrete (PIC), designed to protect bridge decks from damage caused by deicing chemicals, is getting its largest field application - and the first under competitive bidding - in Texas.

Tests begun in 1970 at the Center for Highway Research at the University of Texas' Austin campus conclude that life of PIC bridge decks may be more than double that of ordinary concrete. Research there also shows that this type of deck has significantly greater durability and freeze-thaw resistance and offers excellent protection against salt intrusion. (Corrosion of rebars in PIC is only 5 percent of that in untreated slabs.) In addition, skid-resistance is no less than for control slabs and wear is about equal.

According to Texas researchers, there have been four previous field applications of PIC involving full bridge decks but on much smaller structures. Also, these were done under a cost-plus arrangement with the Federal Highway Administration. Costs were considerably higher, up to \$50 per sq yd, although in some cases deeper polymerization, as much as 1 in., was attempted.

**B206 Limswan, E., Behavior of Post-Tensioned Polymer-Impregnated Concrete Beams, Ph. D. Dissertation, The University of Texas at Austin, Austin, Tex., May 1977.**

This study was conducted to investigate the behavior of post-tensioned polymer-impregnated concrete (PIC) beams. Three major areas of behavior were studied by experimental and theoretical analyses: flexure, shear, and time-dependent deflections. Test results were compared to values calculated according to ACI Standard 318-71 and to results from numerical analyses for inclined cracking and ultimate shears, moment capacity, and tendon stress increase.

To construct PIC beams, the beams were dried to remove the moisture from the concrete voids, impregnated with the monomer system, and polymerized by thermal-catalytic methods. The tendons were stressed to about 70 percent of the ultimate strength prior to the testing.

Nineteen simply-supported beams with an I-shaped cross section were tested using two symmetrically placed concentrated loads. For flexure, the major variables were the prestressing steel percentage, the monomer system, the impregnation depth of PIC, and tendon bonding. For shear, the number of tendons and the amount of web reinforcement were the major variables. Three control beams were tested, one for flexure and two for shear. For time-dependent deflection tests, the number of tendons and magnitude and duration of sustained loads were selected as the variables. In all beams, bonded reinforcing bars were used to supplement longitudinal reinforcement to prevent cracking from the drying process.

Crack patterns and modes of failure were similar to the ordinary post-tensioned concrete beams. Friction loss and friction coefficients for PIC beams containing unbonded tendons were found to be slightly higher than for the control beam containing the same percentage of steel; the wobble and friction coefficients were determined to be about 0.005 and 0.50, respectively. The equivalent rectangular stress block for 100 percent MMA-PIC was determined. The test results for flexure indicates reserve strength beyond values predicted by the ACI equation. A numerical iteration procedure was developed to predict load-deflection response and yielded good agreement with the test results.

Beams tested for shear strength were found to develop shear-compression failure. Empirical equations to predict inclined cracking shear and ultimate shear for PIC beams were developed from the test results.

B207 Liu, Y.-N., Manson, J. A., Chen, W.-F., and Vanderhoff, J. W., "Polymer-Impregnated Mortars I. Effect of Polymer State on Mechanical Behavior," Polymer Engineering and Science, Vol 17, No. 5, 1977, pp 325-334.

Mortar specimens were impregnated with methyl methacrylate, n-butyl acrylate, styrene, and crosslinking agents in various combinations. After polymerization of the monomers in situ, studies of mechanical properties such as Young's modulus and compressive strength were made. In one experiment, various copolymers of methyl methacrylate and n-butyl acrylate were prepared and tested as a function of temperature. Excellent reinforcement was obtained with any combination of monomers as long as the resulting polymer was at a temperature below its glass transition temperature. This suggests that the modulus of the reinforcing polymer is crucial, glassy behavior being required. The addition of crosslinking agents such as TMPTMA increased the high temperature strength, however.

B208 "Polymer Impregnation, Bridge No. 2583," Project I-IG-77-3(88)95, C-3, Materials Research Report, Feb 1977, Materials Control, Soil and Testing Division, West Virginia Department of Highways.

This report contains construction comments and initial evaluation of a polymer impregnation system placed on the deck of the southbound structure of Bridge No. 2583, Project I-IG-77-3(88)95, C-3. Weather conditions prevailing at the time of treatment apparently interfered with the process, and results obtained were somewhat less than desired. However, with some adjustments in the process, it is believed the 1-in. target penetration could be achieved.

B209 U. S. Army Engineer District, CE, "Polymer Impregnation of Concrete at Dworshak Dam," Apr 1977, Walla Walla, Wash.

A major concrete polymer impregnation project was undertaken at Dworshak Dam, Orofino, Idaho, in 1975. Because it was the first project of its type (the first major field application of PIC, first competitive bid project for PIC, first application of PIC to vertical surfaces, first field application of PIC to fibrous concrete, and first impregnation of dry pack patching), this report has been prepared to identify the technical procedures used in the different phases of work. The lessons learned on this project should provide assistance for future design and construction of polymer-impregnated concrete. The work was performed in an outlet conduit and in the stilling basin of the dam to repair major cavitation/erosion damage.

B210 Whiting, D., and Kline, D. E., "Pore Size Distribution in Epoxy Impregnated Hardened Cement Pastes," Cement and Concrete Research, Vol 7, No. 1, 1977, pp 53-60.

Specimens of hardened portland cement paste (Type 1), hydrated for various periods of time, were oven-dried and subsequently filled with an epoxy resin system via a vacuum-pressure technique. Data obtained from mercury intrusion porosimetry indicate that a significant amount of porosity is left unfilled by polymer in the more mature (28 days hydration) specimens. Calculations indicate that the smallest micropores ( $<0.0044 \mu\text{m}$ ) are essentially inaccessible to the monomer system used in this study.

#### 1978

B211 Bartholomew, J., et al., "Current Status of Bridge Deck Impregnation," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 399-412.

Polymer impregnation procedures have been developed to improve the durability of portland cement concrete. The concrete is dried, monomer is applied to a shallow sand cover and permitted to soak into the concrete, and the monomer is polymerized (or cured) to produce polymer-impregnated concrete to depths of 1 in. (25 mm) or more.

This paper reviews the structures that have most recently been impregnated. The bridges are located in Charleston, West Virginia; Yakima, Washington; Big Spring, Texas; and Lubbock, Texas. Three of the bridge decks were cast-in-place, and one was constructed of precast

prestressed tees which were impregnated prior to erection. Procedures, results, and costs are given for each structure. Recommended procedures for polymer impregnation of bridge decks are summarized.

B212 Bazhenov, Iu. M., Gusev, B. V., and Davidiuk, A. N., "Study of the Possibility of Surface Treatment of Concrete with Various Impregnation Materials," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 89, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The surface treatment of concrete can increase its strength by a factor of 2 to 3 and significantly increase its durability. The cost of the products increases by only 10 to 25 percent.

We used materials which are less volatile and toxic, as well as less expensive in comparison with monomers for our studies of surface treatment. These materials include: carbamide, polyester and epoxy oligomers, fused sulfur, and liquid glass. These materials differ in their chemical nature, viscosity properties, and wettability parameters.

Saturation with carbamide oligomers can be effectively achieved by the use of excess pressure and a saturating material with low viscosity (100 s on the VZ-4 instrument), and also by the introduction of surface-active agents (surfactants). By selecting the proper catalyst, we succeeded in conducting the process of polycondensation at room temperature.

Saturation with epoxy resins was performed using the lowest viscosity resin - ED-22; however, even the use of excess pressure and vibration during saturation did not achieve any significant surface impregnation of the concrete. In this case, impregnation with heated epoxy resin was much more effective, though the behavior of the heated resin required that a careful selection be made of systems for curing of the resin saturating the pores of the concrete.

Surface treatment of concrete with epoxy oligomers according to the technology suggested allows a new type of lining material to be produced, equal in its physical and mechanical characteristics to marble and granite materials.

The surface treatment of concrete with fused sulfur, achieved by simply dipping products into melted sulfur, then allowing them to cool, is also promising; after this treatment, the concrete has an improved combination of physical and mechanical properties and is resistant to the corrosive effects of various corrosive media.

B213 Cady, P. P., et al., "Deep Impregnation of Concrete Bridge Decks with Linseed Oil," Transportation Research Record No. 664, pp 183-188, 1978, Transportation Research Board, Washington, D. C.

The overall objective of the research described in this paper was to evaluate the feasibility of deep (>5 cm) impregnation of concrete bridge decks with boiled linseed oil/diluent mixtures. Impregnation is one of the techniques that is currently receiving considerable attention as a means of improving the longevity of bridge decks by reducing or preventing spalling problems associated with corrosion of reinforcing steel. The choice of linseed oil was based on safety (low volatility and high flash point), cost considerations, and the elimination of the polymerization step required for other polymers. Also, many highway agencies are already familiar with linseed oil, since it is commonly sprayed on bridge deck surfaces periodically to retard surface spalling. The latter procedure results in penetration depths of less than 3 mm and has little or no effect on preventing spalling. Deep impregnation requires a drying step to remove water, followed by sufficient contact with the impregnant to permit penetration to the desired depth. Following a period of preliminary laboratory studies, demonstration impregnations were carried out on 5.6-m<sup>2</sup> areas on two bridge decks. One of the bridges had been subject to three winters of deicer salt application. The other had received no salt. Examination of cores subsequently removed from the test areas revealed that penetration depths ranging from about 5 to 10 cm were obtained.

B214 Chen, W.-F., and Dahl-Jorgensen, E., "Monomer Impregnation Through Cast-In Perforated Pipes," Polymers in Concrete - International Symposium, SP-58, pp 299-312, 1978, American Concrete Institute, Detroit, Mich.

Impregnation with monomer over a large concrete area under field conditions is often a difficult and cumbersome task and must be carried out with special care. When polymer impregnation of a bridge deck can be planned in advance, a network of perforated pipes could be permanently cast in concrete inside the deck. Impregnation can then be carried out through these pipes in an enclosed system using high pressure where both the fire hazard and the exposure of monomer is reduced to a minimum. Such a system of pipes could be placed together with the upper layer of reinforcing steel and even be utilized as part of the reinforcement. To demonstrate such a method, 1/4-in. perforated steel pipes were cast inside 6- by 12-in. (152- by 305-mm) concrete cylinders. To prevent the cement grout from clogging the pipe through the perforation, a steel rod was placed inside the pipe and pulled out when the concrete had started to harden. After curing, the concrete cylinders were dried for different lengths of time. This was done to establish to what degree such concrete should be dried to achieve sufficient impregnation. Using the impregnator as a reservoir for the monomer and with a hose connected through the pipe at the bottom of the vessel, three specimens could be impregnated simultaneously with MMA. After polymerization in hot water, the specimens were tested in the splitting tensile test to determine the tensile strength and the extent of successful impregnation. The method is found well suited for large size, cast-in-place concrete structures such as bridge decks, although

the strength and polymer loading might be less than normally encountered with conventional laboratory impregnation.

**B215** Dansby, J. B., and Sawyer, H. S., "Prestressed Polymer Impregnated Tubes as Reinforcement," Prestressed Concrete Institute Journal, Vol 23, No. 5, Sep-Oct 1978, pp 84-102.

A new type of corrosion resistant tensile reinforcement for concrete termed polymer-impregnated concrete (PIC) tubes is proposed. A PIC tube is a tension member which consists of a cylindrical outer casting of high strength, impermeable PIC precompressed by a central prestressing strand.

A method of producing PIC which does not depend upon evacuation or pressure impregnation was developed and the results of tests conducted to maximize the strength of the PIC produced according to this method are reported. Handling stresses for PIC tubes are considered and a force-strain curve for a PIC tube, basic to any subsequent analysis and design of structural members using such tubes, is presented.

**B216** Donato, A., "Studies on Polymer Impregnated Cement for Radioactive Waste Conditioning in Italy," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 193-209.

Studies on incorporation of radwaste in cement wholly impregnated with polymers have been underway in Italy since the end of 1974. Several aspects of the process have been clarified and properties of PIC incorporating wastes of different types evaluated. An experimental pilot plant for testing the process with nonradioactive runs has been built, and blocks of 100 kg have been produced directly in 60-liter drums. Hot tests with actual radioactive wastes are scheduled in the near future. The possibility of using PIC for construction of radwaste containers is under investigation.

**B217** Dutruel, F., "State of Progress of Research Conducted at the Cerib on the Impregnation of Concrete with Polymerizable Resins," Betons Industriels, No. 61, Jan 1978, pp 27-58.

After briefly recalling the technological principles of total and partial impregnation and the corresponding results obtained which show the influence of the increase in strength of the surface zone on concrete characteristics (tensile strength in bending and compression, resistance to wear, creep, modulus of elasticity) and the influence of the limitation of porosity on concrete properties (resistance to frost-thaw, dimensional variations of concrete, resistance to chemical agents), the authors examine the technical and economic lessons learnt on a given pilot unit. The first industrial development of this technique is described.

**B218** Feldman, R. F., and Beaudoin, J. J., "Studies of Composites Made by Impregnation of Porous Bodies; Part 2, Polymethyl Methacrylate in Portland Cement Systems," Cement and Concrete Research, Vol 8, No. 4, 1978, pp 425-432.

Porous bodies formed by autoclaving portland cement-silica mixtures and by normally curing portland cement were characterized by measuring Young's modulus, microhardness, and porosity. These bodies were impregnated with methyl methacrylate and irradiated, the procedure being carried out twice. The bodies were almost completely impregnated. Increases in mechanical properties were greater for microhardness but less for Young's modulus when compared to sulphur impregnation. It was concluded that polymethyl methacrylate forms a stronger bond with the matrices studied than does sulphur.

B219 Fowler, D. W., and Paul, D. R., "Corrosion Protection of Reinforcing Provided by Polymer-Impregnated Concrete," ACI Journal, Vol 75, No. 10, Oct 1978, pp 520-525.

The problem of freeze-thaw deterioration in concrete for bridge deck and corrosion of reinforcement due to deicing agents was studied on 12 pairs of slabs of 14 by 102 by 109 cm in size. The pair consisted of one plain and one reinforced concrete slabs. Reinforcement consisted of seven No. 8 bars with a cover of 3 cm. The concrete had water-cement ratio of 0.58 with cement content of 334 kg/m<sup>3</sup> and compressive strength of 450 kgf/cm<sup>2</sup>.

After curing for 90 days, the slabs were dried for 3 days at 60 to 65°C. After cooling the slabs were covered with 0.6-cm layer of fine aggregate to hold the monomer on the slab. The slab placed with a 2 percent slope was wetted with 1 percent benzoyl peroxide initiator and 10 percent trimethylpropane trimethacrylate cross linking agent. The monomers used were methylmethacrylate, 150 butyl methacrylate, and isodecyl methacrylate. After soaking for 10 to 24 hr, the slabs were cured by heating blankets with surface temperature of 52 to 60°C. Two slabs were used for controls. The slabs were subjected to spray of 114 l of 3 percent saltwater, twice daily for 618 days.

The control slab developed cracks above the reinforcement and failed after 30 to 40 cycles. The corrosion expressed in terms of percentage of area corroded, was 24 and 30 percent. The ratio of chloride content taken at average depth of cover was 23.3 to the threshold value. On the other hand, monomer treated slabs were very good in condition, percentage area of corrosion was 1.1 and ratio of chloride content to threshold varied from 1.1 to 8.9.

B220 Fowler, D. W., et al., "Strength and Behavior of Reinforced Polymer-Impregnated Concrete Beams," Polymers in Concrete - International Symposium, SP-58, pp 187-204, 1978, American Concrete Institute, Detroit, Mich.

Conventionally reinforced and post-tensioned polymer-impregnated concrete beams were loaded to ultimate to determine the flexural behavior. The variable was percentage of flexural reinforcement. Two point symmetrical loads were applied. Stress-strain curves generated from the tests indicated more nonlinearity than previously reported. Conventionally reinforced PIC beams developed up to twice the moment with equal or greater ductility as control beams. Load-deflection



response and ultimate loads were predicted with good accuracy. An underreinforced posttensioned PIC beam developed only 10 percent higher ultimate strength but twice the deflection as a companion control. A PIC posttensioned beam with 4 times as much reinforcing developed 3 times the ultimate load with the same deflection at ultimate as the control. Deflection response and ultimate loads were predicted with reasonable accuracy with a computer program. Further tests are in progress to determine the effect of other variables.

B221 Fukuchi, T., and Ohama, Y., "Process Technology and Properties of 2500-kg/cm<sup>2</sup> Strength Polymer-Impregnated Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 45-56.

Recently greater interest has been focused on development of high strength concrete, which is a companion of high performance concrete. The purpose of this study was to find appropriate process conditions for developing high strength concrete and to understand its properties. High strength concrete was prepared by the combination of mix proportioning with semi-polymeric water-reducing agent, autoclaving, and impregnation with polystyrene. Its strength properties and chemical resistance were tested. The reproducibility of its compressive strength development is discussed. It is concluded that super high strength concrete having a compressive strength of 2200 to 2800 kg/cm<sup>2</sup> is obtained by the above-mentioned process with good reproducibility. However, the ratios of various other strengths of the concrete to its compressive strength are lower than those of ordinary concrete. The use of polystyrene-impregnated autoclaved concrete (PIAC) in structural applications appears to be promising technically and economically from the results of this study.

B222 Fukuchi, T., and Ohama, Y., "Experimental Study of a Process for Manufacturing Extremely High Strength Concrete," Polymers in Concrete - International Symposium, SP-58, pp 215-224, 1978, American Concrete Institute, Detroit, Mich.

The objective of this study was to find an appropriate process for manufacturing high-strength concrete. The high-strength concrete is produced by a combined process involving mixture with a semi-polymeric water-reducing agent, autoclaving, and modification by polystyrene. Also the reproducibility of the compressive strength development was investigated.

It is concluded that concrete having a compressive strength of 2240 to 2490 kgf/cm<sup>2</sup> (32,000 to 35,000 psi) (220 to 244 MPa) can be prepared by this combined process with good reproducibility.

B223 Hallin, J. P., "Field Evaluation of the Polymer Impregnation of New Bridge Deck Surfaces," Polymers in Concrete - International Symposium, SP-58, pp 267-280, 1978, American Concrete Institute, Detroit, Mich.

Because of the excellent durability exhibited by polymer-impregnated concrete, a procedure was developed for the in situ polymer impregnation of bridge deck surfaces to a minimum depth of 1 in. (25 mm).

This procedure consists of: (1) drying the deck utilizing forced hot air, with concrete surface temperatures in the range of 250 F (121 C) to 275 F (134 C); (2) soaking a monomer system of 95 weight percent methyl methacrylate and 5 weight percent trimethylolpropane trimethacrylate into the concrete at a rate of 1.2 to 1.7 lb/sq ft (5.9 to 8.3 kg/sq m); and (3) thermal-catalytic polymerization of the monomer utilizing forced hot air and an azo type catalyst. This procedure is now being evaluated under field conditions. During the summer of 1975, two full bridge decks were impregnated using regular construction crews. Impregnation depths of 1 to 2 in. (25 to 51 mm) were achieved on these projects.

B224 Kaeding, A. O., "Building Structural Restoration Using Monomer Impregnation," Polymers in Concrete - International Symposium, SP-58, pp 281-298, 1978, American Concrete Institute, Detroit, Mich.

By applying the newly developed techniques of polymer-impregnated concrete (PIC) in conjunction with existing epoxy repair technology, severely deteriorated, low quality concrete can be restored to an adequate structural material. The problem of handling techniques and safety of PIC used in a closed building environment are discussed along with costs of commercial use. Testing, analysis, and design leading to a restoration contract for a condemned, structurally deteriorated jail building are reported. Restoring a cracked and crumbling reinforced concrete slab with a compressive strength of less than 800 psi by injecting an acrylic monomer were achieved.

B225 Limsuwan, E., et al., "Flexural Behavior of Post-Tensioned Polymer-Impregnated Concrete Beams," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 361-380.

Post-tensioned polymer-impregnated concrete (PIC) beams were tested using two symmetrically-placed concentrated loads to determine the flexural behavior. The I-shaped beams contained a variable number of unbonded tendons. An under-reinforced post-tensioned PIC beam with two wires developed only 10 percent higher ultimate strength but twice the deflection observed for a companion control beam. PIC beams could accommodate eight wires (versus two for the control) and developed an ultimate strength three times greater than the control beam, with about the same maximum deflection. Tendon stress increase, friction coefficients, equivalent rectangular stress block, compressive stress distributions, ductility index and modes of failure were determined from the test results. A numerical iteration procedure, used to predict load-deflection curves and tendon stress responses, yielded good agreement with the test results. A proposed design criteria for post-tensioned PIC beams is presented.

- B225(1) Locke, C. E., and Hsu, C. N., "Measurement of the Depth of Partial Polymer Impregnation of Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 25-35.

It is difficult to measure the depth of polymer penetration in partial depth polymer impregnation of portland cement concrete. A non-destructive resistivity measurement made from the surface of the concrete has been found to be a feasible method of determining the penetration depth. The measurements are made using the Wenner-4 pin surface resistivity determinations. An integral method of data treatment is used to delineate the penetration depth. It is possible to determine the impregnation depth within 0.6 cm for a depth of 2-4 cm.

This method also may indicate the extent that the polymer has filled the pores of the portland cement concrete. Further work needs to be done in this area. The resistivity of portland cement concrete varies with moisture content so this technique may also be used to determine the dryness of the concrete prior to impregnation.

- B226 Manson, J. A., et al., "Salt Penetration In Concrete And Polymer-Impregnated Concrete By Electron Microprobe Analysis," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 139-156.

Electron microprobe analysis was used to determine total chloride concentrations in concrete and polymer-impregnated mortars (PIC). The technique proved to be quick, accurate, and usable for detecting the presence of chloride in small areas of concrete (~1  $\mu\text{m}$ ) as well as in the PIC's. Results showed that the physical presence of polymer in capillary pores of mortar reduces the long-term penetration of chloride dramatically. Glassy poly(methyl methacrylate) was shown to be more effective than the rubbery poly(n-butyl acrylate) in hindering the penetration of chloride ions. This observation may be interpreted as a consequence of better interfacial bonding or lower chain mobility in the case of the glassy polymer. In all cases, the higher the polymer loading, the better the resistance obtained.

- B227 Mehta, H. C., Chen, W.-F., Manson, J. A., and Vanderhoff, J. W., "Stress-Strain Behavior of Polymer-Impregnated Concrete Beams, Columns, and Shells," Polymers in Concrete - International Symposium, SP-58, pp 161-186, 1978, American Concrete Institute, Detroit, Mich.

In previous studies it was found that ductility in polymer-impregnated concrete could be significantly enhanced by combining a plasticizing comonomer, n-butyl acrylate, with methyl methacrylate. By varying monomer composition, it was possible to obtain a wide range of compressive and tensile stress-strain and failure characteristics. This paper describes extension of this work to the deformation of concrete beams, columns, and cones reinforced with brittle and ductile polymers, with steel fiber and mesh, and with combinations of steel with polymer.

The effects of combined states of stress as in beam bending or compression of a cone were of particular interest. It was found that with the bending of a beam and compression of a column, use of a ductile comonomer can enhance ductility with little sacrifice in strength or, if steel fibers are present, with some increase in strength. Also, impregnation of hollow cones (reinforced with steel wire or mesh) with a ductile copolymer confers not only high ductility, but also high strength and modulus. The beneficial effect of combining ductile polymer with fibers is attributed to the ability of the polymer to form a tough and flexible interface between the fiber and matrix.

*B228 Ohama, Y., and Demura, K., "Length Change of Polystyrene-Impregnated Concrete During Processing," Proceedings of the Twenty-First Japan Congress on Materials Research, The Society of Materials Science, Japan, Mar 1978, pp 197-200.*

Until now a few papers concerning the length change of polymer-impregnated concrete have appeared, but they have not dealt with the length change through full processing from molding of base materials to polymerization. Consequently, this work has been undertaken to determine the length change of polymer-impregnated concrete products through full processing, which is an important factor influencing on their quality. In this paper, polystyrene-impregnated concrete and mortar are prepared and their length change is measured through full processing from molding of base materials to polymerization.

*B229 Ohama, Y., and Nishimura, T., "Improvements in Brittleness of Polystyrene-Impregnated Mortars," Proceedings of the Twenty-First Japan Congress on Materials Research, The Society of Materials Science, Japan, Mar 1978, pp 219-223.*

This investigation was conducted to find out the method to improve the brittleness of PIC.

In this paper, polystyrene-impregnated mortars are prepared by adding internal and external plasticizers and the effects of the plasticizers on their mechanical properties involving toughness and extensibility are examined. Moreover, annealing treatment and reinforcement with steel fibers are discussed in order to improve their brittleness.

*B230 Ohama, Y., and Demura, K., "Length Change of Polymethyl Methacrylate-Impregnated Concrete During Processing," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 57-66.*

Polymethyl methacrylate (PMMA)-impregnated mortar and concrete are prepared and their length change is measured through full processing, from molding of base materials to thermal polymerization in hot water. The length change of the PMMA-impregnated mortar and concrete during full processing is found to be mostly shrinkage due to drying and volume contraction of the monomer during polymerization. The change slightly

exceeds the normal drying shrinkage of cement mortar and concrete at the age of 28 days. The shrinkage due to drying appears to depend on cement content or water-cement ratio of the base mortar and concrete used, and the shrinkage due to polymerization seems to be dependent on polymer loading. Expansion takes place during the polymerization process, because of the thermal expansion of the base materials and the volume increase of the monomer.

B231 Raichuk, F. Z., Men'shikov, V. S., and Semin, G. I., "Development of a Technology for Modification of Concrete Products to a Predetermined Below the Surface Depth," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 130, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The resistance of concretes to corrosive media, their water impermeability and cold resistance can be improved by selecting impregnating compositions with higher viscosity than the monomers generally used, or by changing the conditions of processing of the initial materials.

The purpose of these experiments was surface modification of concretes by removal of water from this layer in the process of drying by "thermal shock," i.e., by brief exposure of the surface of the product to a heat-transfer medium at high temperature, e.g., 300 C or higher.

It was shown that the time required to dry the specimens to a predetermined depth decreases with increasing temperature of the heat-transfer medium.

B232 Raychuk, F. Z., Blinov, G. A., Bakirov, V. M., and Ratnikov, Iu. P., "Modification of Large Cross Section Concrete Blocks and the Structural Changes Occurring in Various Stages of the Process," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 132, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

An installation has been developed at the L.Ia. Karpov Scientific Research Institute for Physics and Chemistry for the treatment of model blocks measuring 1 by 0.5 by 0.18 m. Blocks of grade M400 concrete were subjected to all stages of processing, i.e., drying at temperatures of up to +125 C, cooling to room temperature, vacuum treatment, saturation

with MMA and irradiation with gamma rays.

The results of the experiments and calculations led to the following conclusions:

1. The most dangerous stage in the process of modification of concrete, from the standpoint of development of internal stresses, is the stage of heating of the concrete during drying, particularly if the heat is applied suddenly.

2. Drying of concrete by heating on one side only is more dangerous.

3. Cooling of blocks from +150 C can be performed at any rate.

4. Vacuum treatment, impregnation and radiation polymerization cannot cause significant stresses.

**B233 Sanjana, Z. N., and Gunasekaran, M., "Automatic Dielectrometry of Polymer Impregnated Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 255-269.**

An automatic dielectrometer was used to study the effect of catalysts, temperatures and the presence of cement on the relative polymerization rate of a monomer mix used in a specially formulated polymer impregnated concrete. It is shown that dielectric analysis can be successfully used in studying the polymerization in bulk and in situ. Differences in relative polymerization rates and activation energies were found between the in situ polymerized samples and bulk polymerized samples. The differences found for a peroxide catalyzed system are in accordance with other published results. Dielectric analysis can also be used to determine the end of polymerization. By placing electrodes at different locations, the cure profiles for a large structure can be obtained, which would permit a full cure without waste of energy.

**B234 Schrader, E. K., "The Use of Polymers in Concrete to Resist Cavitation/Erosion Damage," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 283-309.**

Concrete structures such as dams, culverts, and bridges that are subjected to high velocity water flows often experience severe damage due to cavitation and/or erosion. Polymer concrete and polymer-impregnated concrete have demonstrated an unusual resistance to such damage both in large tests and in actual field use. PIC has been used at Libby and Dworshak dams to repair such damage. Besides the technical success, both projects serve as demonstrations that this type of work can be accomplished safely, under adverse conditions, with normal Union construction crews, and in a "heavy construction" environment.

**B235 Schrader, E. K., Fowler, D. W., Kaden, R. A., and Stebbins, R. J., "Polymer Impregnation Used in Concrete Repairs of Cavitation/Erosion Damage," Polymers in Concrete - International Symposium, SP-58, pp 225-248, 1978, American Concrete Institute, Detroit, Mich.**

This paper discusses the use of polymer impregnation in the

repairs of concrete damaged by cavitation/erosion forces at a major dam. Impregnation was performed on conventional concrete, fibrous concrete, dry-pack patches, vertical surfaces, and horizontal surfaces. The project area and damage are describe. Preliminary testing which demonstrated the feasibility of impregnating concrete on this large field project is explained. The basic design concept and procedures used to obtain a competent contractor on a low-bid basis are summarized. The construction procedures used and some of the lessons learned are included as the major part of this paper. Approximate cost, impregnation depths, and performance to date are given. To date, this is the largest and most complex known field project of its type.

B236 Shetly, M. S., and Sikand, D., "Application of Polymer Concrete in Developing Countries," SP 58-11, pp 205-213, 1978, American Concrete Institute, Detroit, Mich.

Developing Countries are trying their best to achieve rapid progress in the fields of agriculture, industry, and housing. Progress in these spheres involves large-scale construction activities. Cement concrete, hitherto has been one of the important materials of construction, in spite, of its many drawbacks. The newly developed "Polymer Concrete" possessing many superior properties over conventional cement concrete, renders itself as one of the most versatile construction materials. Polymer concrete in particular, is highly suitable in case of prefabricated building industry, irrigation structures, marine structures, nuclear power production and desalination plants. It is worthwhile for these countries to develop or borrow polymer concrete technology and apply it judiciously for achieving tangible benefits.

B237 Shirokov, V. S., et al., "The Strength and Deformation Properties of a Polymer Concrete in Relation to the Degree of its Polymer Impregnation," Stroitel'stvo I Arkhitektura, No. 11, 1978, pp 63-65.

Data are given on the strength and deformative characteristics of concretes partially or completely impregnated with polymethyl methacrylate. It is shown that with an increase in the degree of impregnation the bending and compression strength limits increase.

B238 Subrahmanyon, B. V., et al., "Strength and Plastic Ductility of Polymer Impregnated Concrete Beams and Columns," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 229-244.

For the development of structural applications and for performing realistic cost-benefit analyses, studies high-lighting the strength and plastic ductility behavior of polymer impregnated concrete structural members are essential. This paper reports an analytical investigation of the ultimate strength and the plastic ductility of beams and columns made with polymer impregnated concretes having "brittle-linear" and

"ductile-nonlinear" stress-strain behavior. The relative advantages and strength improvements are discussed.

B239 Webster, R., Fowler, D. W., and Paul, D. R., "Bridge Deck Impregnation in Texas," Polymers in Concrete - International Symposium, SP-58, pp 249-266, 1978, American Concrete Institute, Detroit, Mich.

Research has led to the development of monomer formulations and procedures for partial-depth polymer impregnation of concrete bridge decks. The addition of polymer to the concrete greatly increases the watertightness of the surface which improves the resistance to freeze-thaw deterioration and resistance to corrosion of the reinforcing steel. Methyl methacrylate monomer with 0.5 percent (weight) of initiator and 5 percent (weight) of cross-linking agent is recommended for the impregnant. The concrete is dried by use of an enclosure, cooled, and soaked with the monomer by use of a sand cover. The monomer is cured by heat inside of an enclosure. A polymer depth of 0.5 to 1.5 in. (1.3 to 3.8 cm) or more is obtained. An impregnation test of an actual bridge deck is described. The Texas Department of Highways and Public Transportation has two new bridges under contract for construction and polymer impregnation.

1979

B240 Blankenhorn, P. R., et al., "Penetration of Concrete with Various Linseed Oil/Mineral Spirits Mixtures," Cement and Concrete Research, Vol 9, No. 3, 1979, pp 353-364.

Field impregnation techniques were simulated in the laboratory using concrete cylinders (different water:cement ratios) dried either in a forced air oven or with a gas-fired infrared heater after which they were impregnated (by ponding) with different linseed oil/mineral spirits mixtures. Mass uptake was obtained for impregnation with various mineral spirits concentrations and impregnation temperatures. Generally as the water:cement ratio, impregnation temperature, and mineral spirits concentration increase, the final mass uptake (or rate of mass uptake) and penetration depth also increase. Further, the infrared dried specimens displayed a deeper final penetration depth than the oven-dried specimens. Regression analysis produced equations that predict the final penetration depth in the concrete as a function of percent mineral spirits in the linseed oil mixture.

B241 Chen, W.-F., et al., "Experiments on Axially Loaded Concrete Shells," American Society of Civil Engineers Journal of the Structural Division, Vol 105, No. 8, Aug 1979, pp 1673-1688.

Described herein are tests of 13 conical concrete shells under monotonically increasing axial load conditions. The load-deformation response, internal stresses and crack propagation through the elastic, inelastic, and ultimate stress ranges are presented. The properties of



concrete and the behavior of the shells are varied by (1) polymer impregnation; (2) steel reinforcement as ring stiffening, and (3) general wire-mesh reinforcement. The stress-strain behavior of concrete for both reinforced and unreinforced specimens is tailored to range from strong linear elastic but brittle to tough and ductile by the combination of rubbery and brittle polymers like butyl acrylate and methyl methacrylate, respectively. The load carrying capacities for polymer-impregnated concrete specimens are found approximately 2 to 3 times that of plain concrete control specimens. Ductility for MMA/BA shell specimens is found approximately twice that of MMA specimens and 2 to 4 times that of plain concrete control specimens.

B242 Cook, D. J., and Crookham, G. D., "Premix Polymer Cement Concrete," Cement and Concrete Research, Vol 9, No. 2, Mar 1979, pp 171-184.

On the basis of previous work, three monomers (methyl methacrylate, butyl methacrylate, and styrene) were selected for extensive investigation as premix additives for concrete. For comparison purposes, polymer impregnation with methyl methacrylate and butyl methacrylate was investigated. Styrene was not used because of difficulties in polymerization. The results indicated that only methyl methacrylate dispersed well in the fresh concrete. It also increased workability substantially. The strengths of all concretes containing premix additives were less than the strength of the control series. Shrinkage values were increased relative to the control series; and in the case of the polymethyl methacrylate series, this increase was substantial. The strength of the impregnated series was higher than the controls, as would be expected. The impregnated concrete exhibited negative shrinkage in a drying environment, a finding consistent with previously reported information on the creep of polymer impregnated concrete.

B243 Jamrozny, Z., et al., "Properties of Steel Fibre Reinforced Concrete Impregnated With Methyl Methacrylate," International Journal of Cement Composites, Vol 1, No. 3, 1979, pp 117-124.

The paper describes the results of an investigation on the effects of impregnation by methyl methacrylate of plain and fibre reinforced concretes using granite aggregates and lightweight (expanded shale) aggregate. The effects of polymer impregnation and cement-water ratio on strength, porosity, water absorption and mode of failure of plain and fibre concretes made with granite aggregates are reported.

The influence of impregnation on the bond stress between the fibres and matrix has also been analysed. On the basis of the results of this study and the observation of the failure modes, it is shown that impregnation of granite fibre concrete increases the bond between steel fibre and concrete matrix by about four times.

B244 Massidda, L., and Sanna, U., "Impregnation with MMA of Pozzolana-Lime and Slag-Cement Compacts," Cement and Concrete Research, Vol 9, No. 6, Nov 1979, pp 723-730.

The possibility of improving the properties of porous concrete by impregnation and polymerization with organic monomers was studied. The monomer applied in this investigation was methyl methacrylate (MMA) with a catalyst. Pozzolana-lime and slag-cement compacts steam cured and impregnated with MMA have been studied. Mechanical strength and porosimetric values obtained in dependence of different curing conditions and polymerization have been measured. The results obtained with these materials were compared with existing data regarding concrete and similar porous supports.

B245 McNeerney, M. T., "Interim Field Procedure for Bomb Damage Repair (Using Crushed Limestone for Crater Repairs and Silikal<sup>R</sup> for Spall Repairs,)" Interim Report No. ESL-TR-79-01, Apr 1979, Air Force Engineering and Services Center, Tyndall AFB, Fla.

Oven-dried concrete specimens were impregnated with methacrylate monomers and the monomers polymerized by thermal-chemical means. Subsequent tests for compressive strength, abrasion resistance, and moisture absorption showed the impregnated concrete to be superior to untreated concrete.

Measured penetration of the polymer was approximately 19 mm after 18 hr soaking in the catalyzed monomer solutions.

B246 "Polymer Impregnation Used on Demonstration Project on the Greenport Bridge," Constructioneer, 15 Jan 1979, pp 14-15.

Discusses a successful, full-scale demonstration project in restoring a badly-deteriorated reinforced concrete bridge deck through a method of polymer impregnation. While the project was in progress, traffic was maintained on the 50-year-old bridge without major disruption. The cost of this new method greatly exceeds the cost of portland cement, but is balanced by greater ductility, faster setting time, and savings in the cost of detours, demolition, forming, etc., for new structures.

B247 "Vacuum - A New Accessory to Repair," Concrete Construction, Vol 24, No. 5, May 1979, pp 315-318.

On-site repair of deteriorated concrete and stone and other masonry is being done by a new technique developed in Britain. The process uses vacuum to impregnate concrete or friable stone with silane formulations, thus consolidating and weatherproofing it. Defective areas of concrete pavements or structures can be filled and repaired with polymers by this method.

Polymer repairs of concrete or stone carried out under vacuum or low pressure are demonstrably better than similar repairs done at normal pressure, if only because the polymers adhere more closely to crack surfaces. This benefit, added to the possibility of doing vacuum repairs on site, seems to offer great potential for future use of the process in an even wider variety of situations.

B248 Wieneke, R. E., et al., "Polymer Impregnated Tritiated Concrete: Final Report," Contract No. DE-AC04-76-DP00053, Sep 1979, Monsanto Research Corporation, U. S. Department of Energy.

The polymer-impregnated tritiated-concrete process for aqueous tritiated waste as developed by Brookhaven National Laboratory involves the solidification of tritiated aqueous waste in concrete. The solidified block is then soaked in styrene monomer which permeates the concrete and, when polymerized, effectively microencapsulates the tritium bearing concrete, thus providing added protection in case of a broken package.

Small-scale samples (in 500-ml polyethylene bottles) were fabricated and tested in order to determine their characteristics in relation to differences in tritium release from the package due to variation of process parameters, radiation effects on the polystyrene, and gas generation. It was determined that varying the factors that increase the polymerization rate of the styrene (higher temperature or more catalyst) will increase the tritium permeation rate because the porosity of the polystyrene layer has been increased. Compressive strength tests, conducted after 75 weeks, showed that the tritiated blocks were consistently weaker than their nonradioactive counterparts, and that the gas release rate from PITC samples was nearly the same as that from nonpolymer impregnated samples.

The Brookhaven process for polymer impregnation of full-scale, 30-gal waste drums, was modified in order to make the process compatible with glovebox operations. To date, two full-scale, nonradioactive packages have been successfully produced.

#### 1980

B249 Mindess, S., The Fracture of Fibre-Reinforced and Polymer Impregnated Concretes, The Construction Press Ltd., 1980.

The literature on the applications of fracture mechanics to fibre-reinforced and polymer impregnated cements and concretes is reviewed. The difficulty of applying linear elastic fracture mechanics to these systems is discussed. It is suggested that a nonlinear fracture mechanics criterion would be more suitable for describing the fracture processes in these materials.

B250 Sliwinski, J., "Influence of W/C Ratio on the Physical Properties and the Resistance of Cement Pastes Impregnated with Methyl Methacrylate," Materials and Constructions, Vol 13, No. 73, 1980.

This article sets out the results of research on changes in the properties of hardened cement paste brought about by its impregnation by methyl methacrylate.

An appraisal has been made of the influence of the water-cement ratio on the physicomechanical characteristics of the impregnated hardened cement paste and an analysis made of the results of this research. These have enabled us to formulate conclusions concerning the choice of the most advantageous cement paste from the point of view of impregnation.

SECTION C  
LATEX-MODIFIED CONCRETE

1922

- C1 Rideal, E. K., "On the Flow of Liquids under Capillary Pressure,"  
Philosophical Magazine, Series 6, Vol 44, 1922, pp 1152-1159.

The rate of penetration of liquids into capillary porous materials, of importance not only in biochemical problems but also in the study of the phenomena of adsorption by materials such as charcoal and substances constituting the membranes of semipermeable osmometers, has attracted but little attention.

The rate of penetration of a liquid into a fine capillary under its own forces is shown to be expressed by the relationship

$$t = \frac{2\eta}{\gamma r} \chi^2 - \frac{\delta r^2}{8\eta} \log \chi$$

For relatively large capillaries penetration coefficient is  $\gamma r/2$ .

The experimental determination of the coefficient is shown to agree with the calculated values. In the case of mixed solvents the dynamic surface tensions and not the static values are probably the governing factors.

The reciprocal of the penetration coefficient is proportional to the square root of the period of molecular relaxation as defined by Maxwell, and on analogy with reactions in the solid state is probably important in reactions taking place in liquid media.

1938

- C2 Wren, W. G., "The Properties of Cement-Latex Compositions for  
Flooring," Transactions of The Institution of the Rubber  
Industry, Vol XII, 1937-38, pp 189-229.

Although little has been published, sufficient evidence is available to show that a surfacing material of considerable promise can be produced from mixtures containing cement and latex. This was the position of the outset of the present investigations, which were undertaken with a view to providing information about the structure, the processes involved in preparation, and the mechanical and chemical properties of the products obtainable from mixtures of cement and rubber latex. During the course of the work, considerable data has been obtained, but so far, only one type of cement, aluminous cement, has been investigated, only one type of concentrated latex has been used, and an enormous variety of fillers and aggregates still remain to be tested.

The account of the investigations is divided into three sections. The first deals with the structure, and the functions of different constituents of cement latex mixtures; the second gives an account of the physical properties of various cement-latex products; and the third section deals with the general appearance and behaviour of commercial samples of cement-latex compositions as compared with other standard flooring materials.

1946

- C3 *Marvel, C. S., Elliott, F. R., Boettner, F. E., and Yuska, H., "The Structure of Urea-Formaldehyde Resins," Journal of the American Chemical Society, Vol 68, No. 9, 17 Sep 1946, pp 1681-1686.*

A mechanism for the polymerization of urea-formaldehyde resins, based on the view that urea is an amino acid amide has been suggested. The polymerization is postulated as proceeding in two stages: first, the formation of trimethylene-triamine rings from methylene urea or the nonomeric methylene methylol urea, and then the formation of methylene-bis-amide links to tie the rings together to form a cross-linked molecule.

As support for this theory, resins have been prepared from the reaction of glycinamide and  $\epsilon$ -aminocaproamide with formaldehyde. The composition of these resins indicates that they are composed of trimethylenetriamine rings linked by methylene bridges between amide groups on different rings.

The trimers of the methylene-imine derivative of glycine methylamide and urethan have been prepared.

Sarcosinamide appears to react with formaldehyde to give a low molecular weight linear polymer.

1950

- C4 *Farmer, N. W., "Thermoplastic in Resilient Concrete," Plastics, Apr 1950, p 89.*

Resilient concrete is now an established material, which finds its chief use as a flooring medium. The composition of such floors is a concrete containing a thermoplastic resin, which is added to the concrete mix in the form of a dilute aqueous dispersion of polyvinyl acetate. This addition increases the flexibility of the concrete and also its adhesion to the base floor. Floors of a thickness of 3/16 to 1/4 in. have been successfully laid on an ordinary concrete base, and the resiliency obtained is equal to that of wood.

Since these floors possess a high degree of elasticity, they show no tendency to develop cracks, as is the case when more rigid flooring materials are used. Large areas can be had continuously, and expansion joints are not required. Various decorative effects can be obtained by the use of white or ordinary Portland cement, coloured fillers and different aggregates.

1952

- C5 *"Concrete Evidence," Industrial and Engineering Chemistry, Vol 44, No. 5, May 1952, p 13A.*

Superior physical qualities can be obtained for mortar or concrete by the addition of polyvinyl acetate. S. V. Amagna, B. B. Mellor, and

J. M. Geist, MIT, reported that the polymer-fortified mortars had tensile strengths three to five times that of plain cement mortars with the same water-to-cement ratios, and extensibilities more than ten times as great. Best results were obtained using a PVA-to-cement ratio of one to five. The PVA-cement mortar shows maximum improvement in properties when cured in air at ordinary temperatures and humidities. This is a practical advantage over plain cement mortars, which achieve optimum properties when cured under water. The authors indicated that bond strength, abrasion resistance, impact resistance, and corrosion resistance of the PVA-cement were all markedly superior. The material should be particularly good for floor toppings and road surfaces, wall and ceiling cement plasters, and masonry surfaces and it may find limited structural uses in such items as tanks and pipes, where tensile strength is important.

1953

- C6 Geist, J. N., et al., "Improved Portland Cement Mortars with Polyvinyl Acetate Emulsion," Industrial and Engineering Chemistry, Vol 45, No. 4, 1 Apr 1953, pp 759-767.

Results of this work show that the portland cement mortars containing polyvinyl acetate emulsions as admixtures have maximum improvement in properties when cured in air in ordinary temperatures and humidities. This is in contrast to plain cement mortars which require a water or damp curing in order to achieve optimum properties. This self-curing, combined with improvements in tensile and bond strengths, extensibility, and resistance to abrasion, impact, and corrosion, makes this material extremely interesting as a possible means of improving some of the qualities of portland cement mortars.

Among the uses for which this material may offer particular advantages are: floor toppings and road surfaces, wall and ceiling plastic, masonry surfaces, and limited structured uses.

It is particularly significant that the polyvinyl acetate to cement ratio of 0.2 which produces the optimum physical properties is the most workable mixture. It is highly probable that because of the excellent workability the physical properties can be even further improved by decreasing the water to cement ratio. This conclusion was supported by limited experimental evidence.

1954

- C8 Eastwood, J. A., "Aerocem," Indian Concrete Journal, Vol 28, No. 8, 15 Aug 1954, pp 328-333.

The Aerocem Process is complementary to "aerated" or "cellular" concrete which has been developed in recent years. "Aerated" or "cellular" concrete is a compound of cement, sand and other suitable aggregates. The air with pores or bubbles of air or gas within the cementitious matrix must be entrained into the concrete in the form of microscopic uniformly distributed cells.

The tensile strength of Aerozem can be increased from 5 to 10 times by the addition of "Keytex" AE.18 to the mix, "Keytex" AE.18 is a grade of Polyvinyl Acetate Emulsion which has been specially developed for Aerozem. Besides increasing the tensile strength, "Keytex" also improves the bond, adhesion and resilience of Aerozem, making it more resistant to cracking. This extends the field of application.

1955

- C9 *"Polyvinyl Acetate Emulsion as an Addition to Cement," Cement and Lime Manufacture, July 1955.*

Experiments by the Department of Chemical Engineering, Massachusetts Institute of Technology indicate that a polyvinyl acetate to cement ratio of 0.2 produces the optimum physical properties and is the most workable mixture. Portland cement mortars containing polyvinyl acetate emulsions have maximum improvement in properties when cured in air at ordinary temperatures and humidities. This self-curing, combined with improvements in tensile and bond strengths, extensibility, and resistance to abrasion, impact, and corrosion, makes this material very interesting as a possible means of improving some of the qualities of portland cement mortars.

1958

- C12 *U. S. Army Engineer Waterways Experiment Station, CE, "Review of Information Available on Polyvinyl Acetate for Admixture for Concrete," Technical Report No. 6-486, Jul 1958, Vicksburg, Miss.*

Polyvinyl acetate, a synthetic organic chemical compound, when used as an admixture with portland cement has been reported to produce excellent bonding of fresh mortar to old concrete, and to improve several properties of concrete. Among the uses for which portland cement mortars prepared with PVA are conjectured to be advantageous are floor and road toppings, concrete road patches, masonry surfaces, wall and cement plasters, bridges, and storage tanks. A review of the available literature pertaining to the incorporation of polyvinyl acetate into mortar or concrete mixtures suggests that improved physical properties may be obtained when the modified concrete is cured in a dry atmosphere. However, when mortar containing PVA is immersed in water or subjected to weather conditions involving high humidities, considerable loss of strength, warping, and cracking result.

Since polyvinyl-acetate emulsions, because of their inherent characteristics, lack the ability to resist water, it is recommended that the Corps of Engineers not investigate the possibilities of using mortars and concretes prepared with PVA at the present time.

1960

- C13 *"Bridge Repair Uses Special Epoxy Mortar," Public Works, Vol 90, No. 6, Jun 1960, pp 150-151.*



How to repair concrete roadways quickly yet with watertight permanence, was demonstrated recently by a remedial project on the Richmond-San Rafael Bridge in California. A dip existed in the bridge roadway; 3/4 in. deep and 10 ft wide; it was 35 ft long and extended across several lanes.

The engineers considered accomplishing the repair with polysulfide-modified epoxy adhesive and a new concrete overlay. This would have required merely sandblasting the area to be covered, applying the adhesive and laying the thin concrete overlay. From past experience the engineers felt that such a technique would cut the cost and time, and at the same time provide a permanent overlay for the roadway. But this too had a drawback. The time required for the concrete to set and become sufficiently strong would still tie up traffic longer than was desirable.

C14 *Cirodde, R., "Report of Experimental Results," Annales de L'Institut Technique du Batiment et des Travaux Publics, Paris, No. 156, Dec 1960, pp 1375-1411.*

These compulsory rules for chimneys whose height exceeds 98.4 ft can usefully be applied to chimneys of lesser height.

The rules referred to lay down the minimum conditions for: materials, calculation and execution of these structures.

In the Materials chapter the rules deal with reinforced concrete cast in place (cement, aggregates, reinforcements), prefabricated elements in reinforced concrete and linings.

In the Calculation chapter, they deal with the allowable stresses (concrete and steel, foundation soil), the General Rules concerning calculation of strength, effects of different stresses (weight, wind, earthquake, smoke, temperatures, action on the shaft, action on the foundations) and the Special Rules (thickness and reinforcements of the shaft, openings). The presentation of calculation notes and drawings is specified.

In the Execution chapter all the rules concerning the forms, the reinforcements, the concrete (placing, setting and hardening, control test) and the tolerance are given.

Two chapters are further devoted to the putting into service and use.

In appendixes, the calculation of the temperature of the inner surface of the shaft is given, as well as a bibliography.

C15 *Brocard, M. J., "Use of Plastics in Large Construction," Annales de L'Institut Technique du Batiment et des Travaux Publics, Paris, No. 156, Dec 1960, pp 1357-1371.*

Recapitulation of general principles:

Definition of a plastic material and difference between a thermo-plastic material and a thermosetting material.

Formation of resins.

Properties of aqueous emulsions.

Search for an emulsion that can be incorporated into mortars and concretes, and influence of the main characteristics of the emulsion.

Choice of polyvinyl acetate and special properties of this plasticizer.

Study of the influence of polyvinyl acetate:

- on the properties of mortars and fresh concretes;
- on the mechanical properties of mortars and hardened concretes (Bending and compressive strength, modulus of elasticity, deformability, variations in dimensions, cracking, wear resistance, glueing and water absorption).

Problem of waterproofing of masonries.

Conclusions and future prospects.

C16 Cardone, S. M., Brown, M. G., and Hill, A. A., "Latex-Modified Mortar in the Restoration of Bridge Structures," *Highway Research Board Bulletin 260*, pp 1-13, 1960, Highway Research Board, Washington, D. C.

A synthetic latex emulsion admixture was used with portland cement mortar in thin patching mixtures. Laboratory study showed improvement in shear bond strength, compressive strength, tensile strength, and a reduction of water-cement ratio as compared to regular mortar. The latex emulsion was added in amounts of 10 to 20 percent based on latex solids to cement weight. It was used in mortars having sand-cement ratios of 3:1 and 2:1 by weight.

Thin patching was applied to a bascule bridge deck in Cheboygan, Michigan, during the fall of 1957. Evaluations of the thin patched deck show that areas where the latex mortar was applied over a sound, wet substrate held up well through two winters. Bond failed during the first year in varying degrees in areas covered dry, with latex-cement slurry, or with a brush coat of the latex emulsion only.

The 1957 areas where bond failed were repaired in late 1958 by applying a different latex mortar over a cleaned substrate soaked with water prior to the patching application. After one winter these areas appear to be well bonded to the old surface. A few areas contain some fine shrinkage cracks but do not appear to be loosening.

The mortar mixes of 1957 contained a water-dispersed resin of a styrene-butadiene copolymer. A new latex emulsion of a Saran type was used in the 1958 patching mortars.

C17 Evans, C. C., et al., "Epoxy Resin Asphaltic Concrete," Proceedings of the Association of Asphalt Paving Technologists, Technical Sessions, Memphis, Tenn., Vol 29, 25-27 Jan 1960.

A new composition shows promise as a binder in flexible pavements which must withstand heat, solvents, or heavy standing loads. This binder is made by forming a polymer in normal paving asphalt while it is being mixed and laid and after it is in place. Since this system is undergoing chemical reaction during handling, control of the temperature and the time from initial mixing to final compaction is particularly important. Typical installations include filling stations and oil loading racks, warehouse floors, and airport maintenance areas.

In this paper properties of epoxy resin asphaltic concrete are

compared with those of asphaltic concrete and portland cement concrete using laboratory procedures developed for the conventional materials. Performance under severe conditions in actual installations is given. At 140°F, Marshall stabilities of 15,000 lb can be attained. At 540°F, the Marshall stability of epoxy resin asphaltic concrete is still nearly three times that of asphaltic concrete at 140°F.

C18 *Howe, R. T., "Polyvinyl Acetate and Portland Cement Mortars," Journal, Construction Division, American Society of Civil Engineers, Vol 86, No. C01, Feb 1960, pp 31-40.*

Polyvinyl acetate, a synthetic resin widely used as a base for paints and adhesives, offers some promise as an admixture for portland cement mortars. This paper describes polyvinyl acetate, and outlines research on its possible use in a concrete floor surfacing material. Full-scale applications made several years ago are described and their present conditions evaluated.

Mortar containing polyvinyl acetate has three outstanding characteristics: (1) it will bond to almost any type of reasonably clean, firm surface; (2) it has high tensile strength; and (3) it cures itself in the presence of air and light without special attention. In addition, it is easy to mix and place, and has good durability as a floor surfacing material. The major disadvantages are: (1) it cannot be exposed continuously to water, although periodic wetting will not affect it seriously; and (2) it cannot be applied in thicknesses much greater than 1/2 in. without the danger of serious cracking.

C19 *"Latex Mortars, Show Promise in Pavement Repairs," Public Works, Oct 1960, pp 123-126.*

Portland cement mortars, modified with latex, show great promise in many applications requiring a mortar with high bond and strength qualities and great resistance to the effects of wear, chemicals, and weather.

Certain characteristics of latex-modified mortars are worthy of special note: They have a very high slump (8 to 10 in.) at lower than normal water to cement ratios (0.35 to 1.0); working life is short so screeding and finishing must be accomplished rapidly; during curing the latex-modified mortars turn "green" but assume a normal "concrete grey" after final cure; placement should not be made during freezing periods or in heavy rain; and because the mortar adheres tenaciously to tools, mixers, etc., thorough and rapid cleanup with water is essential.

C20 *Rust, C. F., and Wood, W. D., "Laboratory Evaluations and Field Testing of Silica-CMHEC-Cement Mixtures," Journal of Petroleum Technology, Vol 12, No. 11, Nov 1960, pp 25-29.*

Laboratory evaluations of silica-carboxymethyl hydroxyethyl cellulose (CMHEC)-cement mixtures indicate that: (1) Silica-CMHEC-construction cement mixtures provide satisfactory control of pumpability, which is not affected appreciably by the addition of silica. (2) These

mixtures yield low water loss. (3) Satisfactory compressive strengths are realized and can be controlled by the addition of proper amounts of silica. Results of six field tests using sand-CMHEC-cement mixtures to cement deep production strings are described.

C21 Simpson, W. C., et al., "Epoxy Asphalt Concrete for Airfield Pavements," Proceedings, Journal Air Transport Division, American Society of Civil Engineers, Vol 86, May 1960, pp 57-71.

Studies of airfield-pavement problems which arise from the combined effects of heavy load, fuel spillage, and jet blast have led to the development of a new type of paving material called epoxy asphalt concrete (EAC). Conventional hot-mix asphalt plants and paving equipment are used in its production.

This material has Marshall stability values of 15,000 lb to 20,000 lb and is capable of withstanding tire pressures in excess of 1,000 psi. In repeated gyratory loading simulating B-52 traffic, EAC resists densification and retains its load-carrying ability. Good retention of strength and stability under severe conditions of solvent and fuel spillage has been established by experience in aircraft maintenance areas. In jet-blast tests with military planes, EAC performs well under normal pretakeoff conditions and with prolonged after-burner operation producing pavement temperatures of 800°F.

Investigation of its mechanical properties shows that EAC has a flexural strength or modulus of rupture exceeding that of portland cement concrete by a factor of 3 to 6. However, EAC has flexibility which allows it to be bent to the same extent as asphaltic concrete before fracture. The new paving material thus combines the strength of portland cement concrete with the flexibility of asphaltic concrete.

C22 Simpson, W. C., et al., "Design and Construction of Epoxy Asphalt Concrete Pavements," Asphalt Characteristics and Asphaltic Concrete Construction, Bulletin 270, 1960, Highway Research Board, Washington, D. C.

A new paving material developed specifically to withstand high temperature jet blast and fuel spillage and to provide the high load-carrying ability demanded by modern airfield and highway traffic is described. Epoxy asphalt concrete (EAC) is a combination of graded mineral aggregate and an asphaltic binder containing an epoxy resin which is converted into a polymer with unusual solvent and heat resistance.

The mechanical properties of EAC as well as its resistance to heat and solvents are summarized. Various aspects of mix and thickness design in relation to the production of EAC pavements are discussed and preferred mix plant and construction practices which have been developed from field experience are outlined.

The minor additions required for handling the binder in conventional hot-mix paving plants are mentioned and the control of polymerization rate by choice of aggregate temperature is described. Importance of aggregate gradation and binder content in achieving dense, impermeable

pavements is demonstrated, and a preferred range of dense gradings compatible with good mix workability and aggregate availability is shown.

Thickness design of EAC pavements using some of the existing methods of flexible pavement design has been considered. Some examples are shown and adjustments in the design procedures are suggested.

#### 1961

- C23 Schmidt, R. J., et al., "Pavement Overlays Using Polyester Resin and Asphalt Laminates," Materials for Asphaltic Concrete, Bulletin 300, 1961, Highway Research Board, Washington, D. C.

Selected plastics have found wide use in industry because of their high tensile, flexural, and adhesive strength. These qualities, along with resistance to fuel, water, oil, detergents, and oxidation make some of them especially attractive to the highway engineer for pavement coatings.

The major limitations on current overlay systems are high initial cost and the need for precise control and timing during construction. It is now possible to apply resins with controlled setting rates over asphalt concrete (AC) or portland cement concrete (PCC) surfaces. With this type of system a substantial improvement in skid resistance, solvent resistance, and durability can be realized compared with conventional coatings and overlays. This paper describes a new overlay method that has these advantages. It is based on ordinary seal coat application methods which simplify construction problems. In addition to asphalt, polyester resin and selected aggregates are used to obtain the desirable qualities needed in the pavement overlay. This new overlay has been demonstrated to be effective by means of several large-scale field tests.

- C24 Tyler, O. Z., and Drake, R. S., "Superior Strength Properties with Polymer Modified Portland Cements," Adhesives Age, No. 9, 1961.

The tensile strengths of vinyl-modified cements are higher than the unmodified type cured under ideal conditions; that is, under water, but dry-cured tensile strengths are generally lower than those modified with commercially accepted latices; use of a vinyl copolymer with polyvinyl acetate latex improved dry-cured strengths without change in wet-cured strength. Butadiene-styrene latex additions are also considered. The general characteristics of these systems are considered but stress is laid on the increased cost, which may be appreciable since 15 to 20 percent of polymer is required to improve upon the natural properties of cement. Several formulations are given and various special applications are indicated.

#### 1962

- C25 "Big Promise in Patchwork," Chemical Week, 13 Jan 1962, pp 42-43.

Latex-modified cement gains most favor when construction men are faced with the problem - and cost - of wholesale concrete replacement.

Since old, badly spalled and cracked concrete won't bond easily to an overlayer, 2 to 4 in. of the old surface must be chipped away before fresh concrete can be applied. But LMC, which bonds well, can be applied in 1/2-in. layers. This means a sharp reduction in total concrete weight - important in bridge repair work.

- C26 Eash, R. D., Drubel, R. B., Foenicke, F. W., and Hill, A. A., "Latex Modified Mortar," Belgium Patent 611,916, 22 Jun 1962; Chemical Abstracts, 107 86, Vol 57, No. 9, 1962.

The mortar is composed of portland cement and a latex of a polymer or a copolymer of vinylidene chloride (I). Specifically mentioned are copolymers of I, Et acrylate, acrylonitrile, and vinyl chloride in a ratio of either 75:3:20:2, 74:3:3:20, or 88:7:5:0. A 4 percent suspension of poly(dimethyl siloxane) is added as an anti-foaming agent, and di- or triethylene glycol as a wetting agent. Mortar modified in this manner is suited for exterior purposes.

- C27 Foster, F. J., "Composition Comprising Butyl Rubber Latex, Styrene-Butadiene Copolymer Latex, and Hydraulic Cement," Chemical Abstract, U. S. patent 3,042,643 (CL 260-29.7), 3 Jul 1962.

This invention relates to synthetic rubber latex and hydraulic cement compositions.

Various synthetic rubber latices have been added to hydraulic cement, such as portland cement and aluminous cement, for use, with or without additional aggregate such as sand and gravel, in structures where the latex and cement composition must adhere strongly to such surfaces as concrete and glass. The difficulty is that such latex and hydraulic cement compositions made with a single synthetic rubber latex will not adhere well to both concrete and glass surfaces.

According to the present invention, a latex and hydraulic cement composition is provided that will adhere strongly to both concrete and glass surfaces.

- C28 Sanders, P. F., "Butadiene-Styrene Copolymer-Cement Composition," U. S. Patent 3,043,790, 10 Jul 1962; Chemical Abstracts, 12112, Vol 57, No. 10, 1962.

This invention relates to additive compositions for modifying the properties of portland cement compositions and to the resulting cement, mortar, and concrete compositions and methods for their manufacture. More specifically, the additive compositions to which the invention relates are characterized by containing a copolymer of styrene and butadiene-1,3 dispersed in water with certain minor amounts of nonionic, anionic, and polyorganosiloxane surfactants.

- C29 Wagner, H. B., "Dry Cement Composition Comprising Portland Cement, Methyl Cellulose, and POLY (vinyl alcohol)," U. S. Patent 3,030,258, 17 Apr 1962; Chemical Abstracts, 4333, Vol 57, No. 4, 1962.

This invention relates to improved hydraulic cement compositions and particularly to mortars, paints, stucco, plaster and material for patching roads. The invention also relates to methods of using these compositions and to methods of preparing them.

The objectives of the present invention include providing improved hydraulic cement compositions, dry-setting hydraulic cement compositions which do not lose substantial amounts of water to their surroundings during the curing stages, an improved mortar which forms strong bonds to masonry, tile, wallboard, and many other types of surfaces under widely varying conditions of installation, an improved paint having portland cement as a principal ingredient, and improved methods of setting ceramic tile.

According to this invention means are provided for preventing the loss of water from hydraulic cement compositions to a dry backing base, or to the absorptive back of dry tile pressed into contact with the composition.

C30 Woodard, G. W., and Merkle, G. H., "Composition of Hydraulic Cement and Polyvinyl Acetate and Use Thereof," U. S. Patent 3,058,520 (Cl 166-31), 16 Oct 1962.

The invention is concerned with well cementing. It is primarily concerned with an improved well-cementing composition and method of cementing wells.

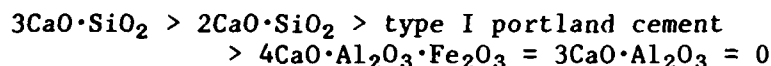
The principal object of the present invention is to provide a cementing composition and method of using such composition which retains essentially all the meritorious properties of the cement of U. S. Patent 2,819,239, but in addition thereto, has greater controlled thickening time and provides improved workability during its preparation and injection into the well.

#### 1963

C31 Blank, B., Rossington, D. R., and Weinland, L. A., "Adsorption of Admixtures on Portland Cement," American Ceramic Society, Vol 46, No. 8, 1963, pp 395-399.

In an attempt to verify theories on the effect of admixtures on portland cement, the adsorption isotherms for calcium lignosulfonate and salicylic acid on cement have been determined. The adsorption isotherms for these compounds on  $3\text{CaO}\cdot\text{SiO}_2$ ,  $2\text{CaO}\cdot\text{SiO}_2$ ,  $3\text{CaO}\cdot\text{Al}_2\text{O}_3$ , and  $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$  and on a mixture of these components in the ratio 60/25/5/10 have also been determined. Adsorption isotherms were determined at  $24^\circ\text{C}$  by a spectrophotometric method, using a Beckman DU spectrophotometer. As a check on the method, previous work of Ernsberger and France on the adsorption of lignosulfonates on portland cement was repeated and their results were confirmed. Results indicate that in aqueous solution the constituents of portland cement mainly responsible for the adsorption of the two compounds studied are the hydration products of  $3\text{CaO}\cdot\text{Al}_2\text{O}_3$  and  $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$ . Salicylic acid adsorption on cement compounds does not fit the Langmuir form. However, adsorption of salicylic acid on

type I portland cement, for equilibrium concentrations above 0.005 percent, fits the form. Calcium lignosulfonate adsorption on type I portland cement,  $3\text{CaO}\cdot\text{SiO}_2$ ,  $2\text{CaO}\cdot\text{SiO}_2$ , and partly on  $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$  fits the Langmuir form. Adsorption isotherms of salicylic acid on the major cement compounds were determined from ethyl alcohol solution to eliminate the hydration of the compounds occurring in aqueous solution. The adsorption of salicylic acid on the materials studied was found to be in the order:



The effect of water on the adsorption of salicylic acid from ethyl alcohol solution was studied. It was found that the smaller the amount of water present, above a minimum value, the greater was the adsorption on  $3\text{CaO}\cdot\text{Al}_2\text{O}_3$ ,  $2\text{CaO}\cdot\text{SiO}_2$ , and  $3\text{CaO}\cdot\text{SiO}_2$ . In the case of  $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$  the adsorption of salicylic acid was proportional to the amount of water present at all concentrations studied. It is observed in certain cases that it is probably not surface adsorption but a compound formation with salicylic acid.

C33 Hillhouse, R. T., "Cementitious Ceramic Materials," Technical Memorandum 1204, Aug 1963, Feltman Research Laboratories, Picatinny Arsenal, Dover, N. J.

A brief study of the chemistry of cementitious, or "air setting," ceramic materials for protective coating and potting applications is presented. Included are the three main types of bonding mechanisms - reaction, precipitation, and hydraulic. Fillers which can be incorporated into the compound, as well as other physical and chemical characteristics of the materials, are considered.

Two Air Force sponsored research programs deal with cementitious materials. The first is an attempt to develop inorganic air-setting adhesives for use to  $1000^\circ\text{F}$ . Results of this project indicated that shear values of 800 psi at room temperature and 1600 psi at  $800^\circ\text{F}$  may be expected. The second program, the development of a coating for thermal protection of structures to  $3500^\circ\text{F}$ , resulted in two promising acid-bonded oxide compositions.

C34 Kelly, T. M., "Mortar Additives," Chemical Abstract, U. S. Patent 3,090,693 (CL 106-93), 21 May 1963.

This invention relates to a new additive composition for incorporation in hydraulic cement mixes, and more particularly, masonry mortar mixes, and also relates to new and improved mortar mixes containing such additive composition.

C35 Monismith, C. L., "New Products in Paving," The Fifteenth California Street and Highway Conference, Jan 1963, pp 109-125.

In the last few years, a number of new products have been introduced for a multiplicity of applications in paving. All of the products



discussed herein have resulted from extensive industrial research, research which, while seldom enjoying the limelight that space research does, is nevertheless quite important to the road user.

The products are of four general types: (1) thermoset plastics, (2) thermoplastics, (3) latex-modified cement mortars, and (4) petroleum-oil and resin emulsions. These products have been utilized in seal coats, in thin overlays of existing pavements, for maintenance, and in improving traffic operations on existing highways. While all the products except the oil-resin emulsion are expensive when compared with conventional paving materials on a cost-per-ton basis, special features of each make them desirable in situations where conventional materials could not be used because of limitations of the materials themselves or other restrictions, such as roadway grade.

C37 Santucci, L. E., "Polyester Overlays for Portland Cement Concrete Surfaces," *Highway Research Record No. 14*, pp 44-56, 1963, Highway Research Board, Washington, D. C.

The use of thermosetting polyester resins in protective coatings for portland cement concrete (PCC) surfaces is described. Specific reference is made to the use of polyester-aggregate systems as coatings on PCC bridge decks.

Two polyester overlay systems are examined. One uses ordinary seal coat application methods in which polyester resin is sprayed directly onto a carefully cleaned PCC surface. Stone chips are added for skid resistance. The second system uses a polyester-sand mortar applied as a 1/4-in. overlay. This type of system also acts as a leveling course which allows readjustment or irregular wearing surfaces to a desired grade.

The properties of selected polyester mortars are examined in the laboratory. The mortar is shown to reach 80 percent of its ultimate compressive strength in less than 24 hr. The completed mortar is also shown to be resistant to hydrocarbon solvents.

Methods used for surface preparation and for applying the polyester overlays are examined. Special construction equipment is described. Both overlay systems have been shown to be effective in several large-scale field tests.

#### 1964

C39 Corkill, J. T., and Lee, G. R., "Effectiveness of Bridge Deck Waterproofing in Ontario," *RB57*, 1964, Ontario Ministry of Transportation and Commerce.

Since 1962 the Department of Highways, Ontario, has used two methods to waterproof concrete bridge decks in an effort to protect the concrete surfaces from the effects of deicing chemicals. This report gives the results of an investigation made in 1964 to evaluate the effectiveness of the two methods.

Every structure in the province which had been treated with either of the two methods, namely, the hot rubberized mastic asphalt or the

bituminous emulsion membrane waterproofing, was inspected visually in the spring of 1964. This visual survey indicated a high rate of failure of both systems, and a more detailed investigation was therefore undertaken which involved the removal of the hot-mix and waterproofing material from several locations on a number of decks which appeared to be leaking. This investigation has shown that the two methods have indeed failed in many cases, the extent of these failures, and for what reasons they were not successful as waterproof barriers.

C40 Eash, R. D., "Mortar Containing Latex," *Belgium Patent 623,809*, 19 Apr 1963; *Chemical Abstracts*, 11736, Vol 60, No. 10, 1964.

A mortar composition containing portland cement, sand, H<sub>2</sub>O, and a mixture of 2 aq. compatible dispersions of interpolymer latex, together with an antifoaming agent, developed high compressive, tensile, shear, and flexural strengths, absorbed less H<sub>2</sub>O and was useful where vibration was excessive, traffic heavy, and liquids corrosive. To a mixture of 4500 parts by weight of sand and 1500 parts portland cement, a mixture of 168.8 parts latex (75 percent poly dimethylsiloxane) in 4.05 parts H<sub>2</sub>O, and 480 parts H<sub>2</sub>O was added and the whole mixed 4 to 5 min.

C41 Hill, A. A., "Polymer-Modified Mortars for Structural Uses," *Adhesives Age*, Vol 7, Jul 1964, p 31.

The clay masonry curtain wall was constructed in 1962. It is 32 ft high, 60 ft long, and as can be seen, only one brick - or 3-5/8 in. - thick, exclusive of polystyrene foam insulation and interior finish. Actual vertical spans between lateral supports are 13 ft, and horizontal spans between columns are 20 ft. The wall contains no steel reinforcement.

What prevents lateral or other forces from destroying this wall? The answer to this question involves high strength mortar - a new masonry concept.

In comparison, high strength, or high bond, mortars used with medium strength bricks will result in walls with moduli of 370 psi or more, in many cases behaving as though they were homogeneous from a strength standpoint.

C42 Ohama, Y., Ibe, H., Mine, H., and Kato, K., "Cement Mortars Modified by SB Latexes with Variable Bound Styrene," *Rubber Chemistry Technology*, Vol 37, 1964, pp 758-769.

Recently, the practical research and development of SB latex for a cement modifier have taken place and the cement mortars so modified are used in the field of building or civil engineering. The physical and chemical properties of SB latex-modified mortars have already been reported, but the effects of various polymerization conditions for latex synthesis on properties of SB latex-modified mortars have hardly been noticed. The authors discuss the effects of polymerization conditions, in particular, styrene/butadiene monomer ratio on physical properties of SB latex-modified mortar and conclude that the physical properties such

as strength, drying shrinkage, adhesion, abrasion and shock resistance, etc., of SB latex-modified mortars are affected more intensely by the variation of bound styrene contents than by the rubber-cement ratios.

- C43 Weisend, C. F., "Hydroxyethyl Cellulose, Poly (vinyl pyrrolidinone) and Organic Sulfonate, Cement Slurries, and the method of Cementing Wells," U. S. Patent 3,132,693 (Cl 166-33), 12 May 1964; Chemical Abstracts, 5343, Vol 61, No. 2, 1964.

This invention relates to new and useful improvements in low water loss additives for cement and methods of utilizing the same.

It is therefore a principal object of this invention to provide a low water loss additive for cements which is resistant to high temperature and which maintains the fluid loss at the desired level without increasing the viscosity of the cement slurry appreciably or overly retarding the thickening and setting times of the cements or impairing the set strength thereof.

A further object of the invention is to provide an improved low water loss additive which may be employed in relatively low percentages in a cement slurry and which will produce the desired low fluid loss as measured under pressure and other prescribed conditions.

#### 1965

- C44 Bartoli, J. A., "Mortar Compositions," Chemical Abstract, U. S. Patent 3,169,877 (Cl 106-93), 16 Feb 1965.

The objectives of this investigation include providing (1) a new and improved mortar composition, (2) an improved mortar composition having excellent adhesive qualities over a broad range of temperatures and particularly at high temperatures, (3) an improved mortar composition which will set extremely hard to a variety of surfaces including porous dry surfaces under a broad range of temperature conditions, and particularly at high temperatures, (4) provide an improved mortar composition which may be applied to surfaces of up to 200° Fahrenheit temperature and which will set hard at such temperatures, (5) an improved mortar composition which will mix well with either hot or cold water over a temperature range of near freezing to near boiling, will have proper working consistency, good adhesive properties, proper hardness after setting, will not require too long a time to harden, and will not exhibit undue shrinkage in the hardened or set condition, and (6) a mortar composition which will mix readily with water without the need of special treatment and which may be added to plain cement directly on the job to form a practical cement mortar composition.

- C46 "Epoxy Bitumen Membrane Repairs Bridge Decks," Rural and Urban Roads, Vol 3, No. 7, Jul 1965, pp 58-61, 85.

A thin membrane of epoxy/bitumen cement is now being used to prevent deterioration of concrete bridge and viaduct decks on the New Jersey Turnpike. Adhering to the concrete and sealing it against

moisture, deicing chemicals and freeze-thaw cycling, the membrane is topped with 1-1/2-in.-thick bituminous concrete wearing course to complete the remedial steps which are expected to reduce maintenance costs.

The membrane and overlay treatment has so successfully reduced concrete cracking, scaling, spalling and pitting that the combination has been adopted by the Turnpike as the standard method to repair badly damaged concrete decks, as well as to shield the decks of new structures.

- C47 *Evans, R. M., "Cementitious Compositions Containing Acrylic Ester Polymers," U. S. Patent 3,196,122 (Cl 260-29.6), 20 Jul 1965; Chemical Abstracts, 9649, Vol 63, No. 8, 1965.*

The composition consists of sand, hydraulic cement, H<sub>2</sub>O, and H<sub>2</sub>O-dispersed particles of a H<sub>2</sub>O insol. film-forming acrylate polymer of a monomeric material. The monomer contains  $\geq 1$  alkyl ester of an acrylic acid having 3 to 4 C atoms; the alkyl radical of the ester has  $\leq 18$  C atoms. The polymer has a 2nd-order transition temperature below room temperature, and is used in the ratio of 1 polymer:3.7 cement by weight. The composition is not readily susceptible to leaching out, to hydrolysis by aq. media, or to corrosive attacks by lactic acid and citric acid, and in dil. form lends itself to use as an adhesive, masonry paint, or grout.

- C48 *Gibbs, O. S., and Johnson, L. C., "Latex-Modified Cements and Mortars," Belgium Patent 645,261, 16 Sep 1964; Chemical Abstracts, 16015, Vol 63, No. 12, 1965.*

The composition, preparation, and use of an improved latex modifier for concrete and mortars are described. The latex modifier consists of a stable colloidal solution of a copolymer of vinylidene chloride (I) in H<sub>2</sub>O. Its preferred composition is vinylidene chloride 87-8, ethyl acrylate 6-7, acrylonitrile 4-5, and Na sulfoethyl methacrylate (Ca 54,-20274f; 57, 2078c) 0.5 to 1.5 wt percent. In addition 2 to 8 wt percent of a nonionic wetting agent may be used. I is prepared by continuous polymerization of suitable monomers in an aq. solution containing a nonionic catalyst, such as H<sub>2</sub>O<sub>2</sub>. I (5 to 30 wt percent) is added to cement, preferably portland cement. The use of I increases the dry compressive strength of the cement from 685 to 986 kg/cc (ASTM C 109-58). The use of I gives a greater increase in strength and less leakage of the modifier during curing than comparable latex modifiers.

- C49 *Kriegh, J. D., "Protective and Skid-Resistant Coatings for Concrete Bridge Decks," RILEM Bulletin No. 28, Paris, 1965, pp 59-67.*

Bridge deck deterioration is one of the most serious maintenance problems encountered by bridge engineers in the United States and Canada. Many factors combine to produce cracks and other minor defects which are forerunners of larger defects resulting when aggravated by freeze-thaw action and deicing salts. Bridge decks are particularly vulnerable

because they freeze more readily, lacking an insulating barrier of earth beneath them.

Poor quality coarse aggregate is a major cause of surface defects, but the additional cost of importing suitable aggregate is frequently considered prohibitive. Even concrete with proper air-entrainment seems to be affected, especially in bridge decks constructed in the autumn which are salted before the concrete has had sufficient opportunity to develop resistance to sodium or calcium chloride. The search for less harmful deicing chemicals, however, has not been successful primarily because, as shown by research by the Portland Cement Association, the causes of deterioration from this source are physical rather than chemical. Therefore, considerable effort has been directed toward the development of protective coatings which could effectively and economically waterproof the concrete and prevent pavement distress.

The well-known ability of certain epoxy compounds to bond tenaciously to clean, sound concrete, as well as their resistance to chemical and solvent attack have made them logical materials for protective coating applications. With mineral grit broadcast over the coating's surface, they also can provide skid-resistance and wearability. Other possible applications for these materials include protective coatings for vulnerable surfaces such as bridge seats, pier caps, and abutment backwalls, for orthotropic plate bridge decks, and as a waterproofing treatment for decks subsequently surfaced with a bituminous concrete wearing surface. However, these latter applications are beyond the scope of this paper.

C50 Lange, H., "Epoxy Paving Cement Fights Bridge Deck Wear," Public Works, Vol 96, No. 6, Jun 1965.

In 1963-64, the upper and lower concrete decks of the Mystic River Bridge in Boston were surfaced with an epoxy coal tar resinous paving cement to seal them against salt solutions and moisture, prevent further sealing, spalling and pitting and provide skid resistance when wet or oily. To protect the 81,000 sq yd (12 lane miles) of roadway surfaces, over 250,000 lb of the paving cement and 700 tons of sand aggregate were used to produce a lightweight, weather and traffic resistant overlay 1/8 to 3/16 in. thick. Engineers expect the thin, tough layer to give up to 5 years of maintenance-free service.

C51 Pierzchala, H., "Physical and Strength Characteristics of Cement Mortars With an Admixture of Polyvinyl Acetate Emulsion," RILEM Bulletin No. 28, Paris, 1965, pp 129-139.

The program of laboratory investigations contained the examination of pastes and mortars of the Polish Portland Cements "250" and "350" most frequently met in the building practice. The aim of the investigations was expected to be achieved in three stages, i.e., in:

1. Establishing physical and strength properties of pastes and cement mortars containing an admixture of polyvinyl acetate emulsion.
2. Analysing the influence of the admixture of technological properties of pastes and mortars with regard to initial parameters and

curing conditions, and considering the course of physical-chemical processes which occur during setting and hardening.

3. Drawing conclusions concerning the applicability of the new type of the admixture in building industry.

C53 Shirayama, K., "Report of a Test for the Properties of Resin Mortars for Rendering," RILEM Bulletin No. 28, Paris, 1965, pp 139-145.

The mortars for rendering admixed with four types of resin admixture were tested. The admixtures were commercially available and their composition are as follows:

<u>Admixture Reference</u>	<u>Main Component</u>	<u>Percent of Solid Body</u>
A	Nitrile-butadiene rubber latex	40
B	Styrene-butadiene rubber latex	41.5
C	Synthetic rubber latex	40
D	Acryle-resin	50

The mix proportion of the mortars was portland cement: river sand:admixture = 1:2:0.1 or 0.2 (by weight). Mixing water was added to this mixture to get the suitable workability for rendering.

The test results showed that the resin mortars were between 70-152 percent in strength; between 13-63 percent in water penetration; and between 40-91 percent in drying shrinkage compared with the mortar without admixture, and that among four admixtures A is the moist suitable for rendering mortar.

C54 Sneck, T., Marttinen, P., and Eneback, C., "A Preliminary Investigation on the Properties of Some Furfuralacetone Resin Mortars," RILEM Bulletin No. 28, Paris, 1965, pp 95-103.

The use of furan-base resin mortars has greatly expanded since the early 1940's. The mortar is made by mixing an inert aggregate, e.g., carbon or quartz with an acid catalyst and a liquid resin. Resin concretes based on furfural acetone have been an object of research in the USSR during the last years. Sulfonic acids, sulfuric acid, fosforic acid and acid salts can be used for hardening of the resins. Various kinds of minerals have been used as aggregate. Trials in practice have been made with good results. Resin concrete based on furfural acetone has thus been used in dams and in the floors of factories. It has been also successfully used for pipes and as linings of tanks.

Bares and Hosek have carried out an extensive investigation on resin concrete based on furfuryl alcohol. Washed sand, gravel, various kinds of slag, clinker, and fly ash have been used as aggregate. Furfuryl alcohol and a partial polycondensate of it have been used as binder. Sulfuric acid, urea nitrate and sulfonic acids were found to be suitable catalysts.

- C55 Voina, N., Enculescu, M., and Schiller, E., "Use of Synthetic Resins in Concrete in Romania," Syn Resins Building Construction, Pap., RILEM Symposium, 1967, pp 238-53; Chemical Abstracts, 17674, Vol 77, No. 8, 1965.

Concretes containing poly(vinyl acetate) (PVA); urea-HCHO and melamine-HCHO resins; and PhOH-HCHO, epoxy, and monomer furfurylidene acetone resins are studied. Addition of PVA to concrete lowered the compressive resistance and increased resistance to stretching. The greatest compressive and stretching resistance was obtained for a composition having a high cement-aggregate ratio in the mixture and 40 percent PVA. Addition of PVA increased the contraction values. At a const. cement-aggregate ratio the deformation increased with increasing PVA content. Irradn. of concretes containing PVA with ir rays had a favorable effect on the decrease of contraction, on the elastic-viscous-plastic deformation, and on the improvement of water stability. Compressive resistances are also given for mortars containing urea-HCHO, melamine-HCHO resins, PhOH-HCHO, epoxy, and monomer furfurylidene acetone resins.

- C56 Wagner, J. B., "Polymer-Modified Hydraulic Cements," Ind. Eng. Chem. Prod. Res. Dev., Vol 4, Sep 1965, pp 191-196.

Certain fundamental characteristics of polymer-modified portland cement compositions were studied. Rate of generation of specific surface area of the cement gel is retarded by some latexes and accelerated by others. After about 28 days, however, the surface areas developed are comparable. The development of polymer coalescence is found to require from 8 to 72 hr, to occur gradually, and to depend primarily on water content of the composition. Structure of the coalesced polymer within such compositions is detailed microscopically and related to the inorganic components. A basis is laid for subsequent studies of the mechanisms whereby polymer modification effectively alters the physical and chemical properties of the conventional compositions.

- C57 Zivica, V., "The Properties of Cement Paste with Admixture of Polyvinyl Acetate Emulsion," RILEM Bulletin No. 28, Paris, Vol 64, 1965, pp 121-129.

By a PVA emulsion we can substantially influence the hardening of cement pastes, the tensile strength, the dynamic modulus of elasticity, changes of volume, and the durability of hardened cement pastes. The effect of the admixture depends on the applied amount, and the hardening conditions. A high relative humidity of the surrounding space, as well as water curing, unfavourably influence the properties of the cement pastes, which is connected with the physico-chemical process of destruction in the polymer phase.

The emulsion admixture influences the hydration process of cement, and the forming of the structure of the hardened cement paste. Under the influence of the admixture the hydration process is slowed down, owing to the change in the composition of the fluid phase of the cement

paste, and as a result of the adsorption effects. The emulsion components influence also the character of the hydration products.

1966

C58 Hosek, J., "Properties of Cement Mortars Modified by Polymer Emulsion," Journal, American Concrete Institute, Vol 63, Dec 1966, pp 1411-1423.

The aim of these experiments was to contribute to the understanding of the mutual influence of polymer and cement during the hardening of this combined system. Polyvinylacetate as water-emulsion was chosen as representative of polymers for all experiments.

This paper deals with the results of the experiments with polyvinylacetate-modified cement mortars; the effects of polymer admixtures on compressive, tensile, and flexural strength; on modulus of elasticity; the effect of relative humidity; and of polymer plasticizer on shrinkage. The dependence of strength on dimension of test specimens and the behavior of this mortar in water exposure and in weatherometer, rapid-cycle exposure are discussed.

Consideration of the results suggests fundamental ideas about the structure formation of polymer-cement mixtures.

C61 "Polymeric Cement Additives," Rubber and Plastics Age, Vol 47, No. 1, Jan 1966, p 69.

Among the many plastics materials for building there is one group which stands apart from the controversial aspects as to long-term and loadbearing suitability. Polymeric additives in the form of latices, emulsions and various resins are accepted as being highly beneficial provided they are correctly used.

In the middle of this spectrum is a newly developed material known as 'Estercrete'. A joint venture between British Resin Products Ltd., and The Cement Marketing Co., Ltd., this promises to be one of the most successful yet. Reasons are found in the unique cure method, which is the subject of world patents, and in the ease of utilisation coupled with good performance. 'Estercrete' is a one pack composition of 60 percent polyester resin in styrene and 40 percent cement which acquires thermosetting properties on the addition of water.

Towards the cheaper end of the scale are many modified cements in which a smaller percentage of polymer is added, and one of the most popular mixes is the polyvinyl-acetate dispersion type.

C62 Riley, O., "Three-Step Bridge Deck Surfacing," Public Works, Vol 97, No. 6, Jun 1966, pp 106-108, 164-166.

To summarize, our procedure is this: To patch and clean the deck and put down a coal-tar epoxy resin membrane - for waterproofing; to raise the expansion dams and inlet covers by one and one-half inches to contain the overlay, and then to place a one and one-half inch thick mat



of neoprene modified asphalt concrete with asbestos added, to protect the membrane.

The results to date have been most heartening. So far, over the past 3 years we have provided this treatment on three large bridges, two very large viaducts, and about thirty smaller overpasses. The total cost of the protective treatment has so far run \$2.4 million. On each bridge the treatment cost was about equal to the cost of the previous year's repair program on the old concrete deck.

Furthermore, there is no evidence of cracking in the surface in any of the overlays nor is there any sign of water leaking through the bridge deck either during, immediately after, or long after a rainfall.

C63 Roenicke, F. W., and Hill, A. A., "Cement Compositions Containing a Polymer Latex," U. S. Patent 3,239,479 (Cl 260-29.7), 8 Mar 1966, p 5; Chemical Abstracts, 13898, Vol 64, No. 10, 1966.

This invention pertains to an improved inorganic cement, and more particularly to a portland type cement containing a latex to which an additive is added to retard the setting time and tendency of the cement to crack upon setting.

It is therefore an object of this invention to provide a cement composition containing a latex which will not have a tendency to crack upon setting and a method for its preparation. A further object is to provide a cement composition latex which will have a delayed setting time.

C64 Wagner, H. B., "Compressive Strength of Polymer Modified Hydraulic Cements," I & EC Product Research and Development, Vol 5, Feb 1966, pp 149-152.

The principal variables determining compressive strength of polymer-modified hydraulic cements are the "gel-space" ratio and the degree of air entrainment. Secondary variables, of significance under particular conditions, are rate of evaporative water loss during the hardening period and degree of wetness. Polymer type can influence rate of evaporative water loss and also the magnitude of the compressive strength decrease due to wetting. A quantitative correlation of compressive strength is made with the two principal variables.

#### 1967

C65 Barber, R. F., "Admixtures and Chemical Surface Preparations in Precast Concrete," Australian Civil Engineering, Nov 1967, pp 55-59.

The purpose of this article is to present a wider knowledge of admixtures for concrete.

Curing compounds are brushed or sprayed onto the surface of freshly laid concrete to form a membrane which is impervious to water vapor. Their use allows low cost efficient curing and very easy application. There are two classifications for waterproofing compounds:

1. Surface coating compounds applied to finished or existing concrete surfaces to prevent the inward passage of water. There are only two main successful types - silicone solutions and acrylic solution compounds.

2. Integral waterproofers added direct to the concrete mixer. These are of more specific interest to the precast manufacturers than surface coating compounds.

Calcium chloride is used widely as an accelerator to speed up the set of concrete for time saving purposes and economics. Recently developed are the set accelerating compounds based on modifications of calcium chloride. These give more vigorous accelerating results where such are desired.

Plastic emulsions have probably had more effect on all types of concrete construction companies than all other admixtures put together. The main type in extensive use today is specially processed polyvinyl acetate emulsion (PVA).

C66 Cherkinsky, J. S., "Practice and Theory of Polymer Cement Concrete," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Compositions, containing nonorganic binders (cement, gypsum-alabaster, lime, etc.) and water dispersion of organic polymer (latex, and aggregate as well, for which we suggested the term polymer cement concretes, mortars, pastes are widely used in building construction of many countries. The results of the USSR Institute of Scientific Research on Concrete and Reinforced Concrete investigation and practice are generalized in this paper.

C67 Desov, A. E., "The Effect of Polyvinyl Acetate Emulsion and Synthetic Rubber Latex on the Strength and Deformability of Mortars," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Some experimental data upon the effect of polyvinyl acetate emulsion admixture in quantity from 0.6 to 30 percent of cement weight and synthetic rubber in quantity from 0.3 to 13 percent on the compressive and tensile strength and also on the limit deformability of mortars with rubber latex are given in this report.

C68 Dutron, P., and Coilet, Y., "Mechanical and Physical Properties of Cement Mortars with Resins" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

This report deals with tests carried out at the Centre National de Recherches Scientifiques et Techniques pour l'Industrie Cimentière - in order to investigate about properties of cement-resin mortars. Five types of resin-dispersions are studied.

For one of each type, a few results are given. The effect of

dispersion admixtures on properties of cement mortars in certain conditions is investigated.

- C69 *Elshin, I. M., "Experience in Using Plastic Concrete with Furan Resins in Different Structures," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.*

The paper gives the main characteristics of the new building material - the plastic concrete - describes the experience of using it for wear-resistant facings of hydrotechnical structures instead of the usual facings in metal, stone, etc.

The report describes an experience of the use of plastic concrete in chemical and oil refining industry, for the protection of building structures and equipment against chemical corrosion.

The communication presents the technical and economical characteristics of plastic concrete and recommendations for its use in different fields of construction.

- C70 *Fleming, C. J., and King, G. E. M., "The Development of Structural Adhesives for Three Original Uses in South Africa," RILEM Bulletin, New Series 34-37, Series 37, Dec 1967, pp 241-251.*

The paper outlines the development of epoxy adhesives for South African conditions and uses. It covers preliminary investigations undertaken to arrive at suitable formulation and then goes on to deal with three specific cases of original usage. The first of these is based on the glueing of of precast concrete units for use at the Sugar Terminal in Durban. This is a prestressed concrete structure in which 1440 precast units, each weighing 5 tons, were glued together in the form of an arch by epoxy adhesives. The second concerns the use of brick panels as structural elements within reinforced concrete framed buildings. By glueing the brickwork to the frames, enhanced strength and economy of cost were achieved. The third topic concerns the strengthening of reinforced concrete beams by glueing steel plates to the beam faces. Both bending strength and shear strength were enhanced in this way. Tests and practical examples are quoted in all examples.

- C71 *Frondistou-Yannas, S. A., Mechanical Properties of Cement Mortars Modified by Polymers, M.S. Thesis, National Technical University of Greece, 1967.*

Polymer-modified mortars and cements were investigated in this work, the dual goal of which was to improve certain properties of mortar and to clarify the mechanism by which such improvement is brought about. It was found that sulphate resistance of mortar can be significantly improved by incorporation in it of any of the three polymer emulsions used; when the polymer emulsion was styrene-butadiene the improvement was dramatic. It was also concluded that the strength of the matrix-aggregate bond depends upon the degree of interpenetration much more than it does on physicochemical interaction. Polyvinyl acetate emulsions were found to react chemically with cement during curing by

means of a mechanism which has been clarified in a preliminary manner and the styrene-butadiene emulsion was also found to be reactive. These chemical reactions gave rise to polymeric products which were superior mechanically. When wet cured specimens were dried, the rate of gain in strength was much higher than was that of specimens that were either dry or wet cured. In general, incorporation of polymers in latex forms leads to higher extensibility and higher toughness per unit strength but also to lower modulus and lower compressive strength. After 28 days all modified specimens had either reached or surpassed the flexural strength of the controls.

C72 Ghosh, R. K., and Pant, C. S., "Use of Low Percentage of PVA as an Admixture to Cement Concrete," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The investigations conducted on the addition of small quantity of a PVA emulsion, up to 3 percent by weight of cement, to cement concrete have been reported. Within the range investigated, PVA has been found to improve in varying degrees workability, flexural and compressive strengths, extensibility, resistance to abrasion, bond with steel and durability of the concrete containing it. The optimum benefit in most of the cases has been obtained with 2 percent PVA by weight of cement. Studies have further shown that PVA concrete may find preference in patch repair and overlay works of concrete pavements and bridge decks. An attempt has also been made to explain the physical behaviour of PVA in concrete.

C74 Hosek, J., and Sereda, P. J., "Effect of Organic Surface Agents on Properties of Hydrated Cement Compacts," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

This paper reports the treatment of bottle-hydrated portland cement with organosilanes, oleic acid and octadecylamine intended to reduce the sorption of water and the corresponding dimensional changes. Compacts were made from the treated hydrated cement powder to simulate cement paste and allow measurements of sorption-dimensional change characteristics and microhardness. It was found that organochlorosilanes are not suitable for the treatment because the HCl release during the reaction produced undesirable side effects and in some cases increase the adsorption and expansion of the cement. Hexamethyldisilazane was more effective, reducing adsorption by 10 to 20 percent. Oleic acid was effective at concentrations as high as 25 percent by weight, but serious loss in mechanical property of microhardness was experienced.

C75 Jakacki, E. J., et al., "Plaster Composition Containing Polyvinyl Acetate," U. S. Patent Office, 3,305,518, Feb 1967.

This invention relates to an improved gypsum plaster composition. It consists of gypsum plaster compositions having significantly improved properties attributable to the inclusion thereof of minor amounts of a

dead burned gypsum, the particles of which have specified Blaine surface area value. The dead burned gypsum additive having a minimum Blaine surface area value of at least about 10,000 square centimeters per gram significantly improves the working or trowelling properties of a plaster composition in which it is incorporated. The additive markedly improves the faltiness and water retentivity of the plaster composition with the result that upon trowelling the plaster to form a wall a smooth surface relatively free from trowel marks, catfaces and other blemishes is obtained. Moreover, incorporation of the additive does not adversely affect the strength and surface hardness of the plaster when set. These novel plaster compositions are particularly adapted as "thin-coat" plasters which are sprayed on or applied by hand to a surface in a relatively thin coat.

It has now been found, in accordance with the present invention, that gypsum plaster compositions of the type disclosed in the said copending patent application can be further improved for certain applications by the inclusion therein of a minor amount of polyvinyl acetate.

C76 Kent, J. A., "Preparation of Wood-Plastic Combinations Using Gamma Radiation to Induce Polymerization," ORO-2945-7, Mar 1967.

In order to broaden the base of potentially useful Wood-Plastic Combinations for use under a wide variety of conditions, a program was initiated to develop new plastic components. The work carried out under this program is described in this report and several new plastics for use in Wood-Plastic Combinations are recommended for further study.

Important factors to be considered in the development of a new plastic component include: cost of the monomers, ease of handling and impregnation of monomers, radiation dose requirements, heat of polymerization, physical and chemical properties of the final product.

Special attention was given to the development of a rubberlike system to complement the two hard plastics currently available, poly(methyl methacrylate) and poly(styrene-acrylonitrile). A WPC containing a rubber might be expected to exhibit improved resiliency and impact strength.

C77 Kubota, H., and Sakane, K., "A Study on the Improvement of Cement Mortars by Admixing Polymers Emulsion and Synthetic Fiber," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Many studies have been made by various researchers to try and improve the brittleness of cement mortar by admixing fiber or polymer emulsion but the method to admit both fiber and polymer emulsion has not yet been developed. This experiment is based upon the inference that there would be multiple effects by admixing the three components, polymer emulsion, fiber and cement, or in other words a three component system. This was proved by experiment. This experiment suggested new stage in the improvement of the brittleness of cement mortar, and this study is a step in this direction.

C78 Kubota, H., and Sakane, K., "Improving the Properties of Cement Mortar by Mixing With a Polymer Emulsion and Synthetic Fibers," Japan; Chemical Abstracts, 111184r, Vol 67, No. 24, 1967.

An emulsion of poly(Et acrylate) and the polypropylene or saran fibers was added to portland cement to decrease the brittleness of the mortar. Its mechanical properties, such as flow, flexural compressive strength, tensile strength, impact strength, dynamic Young's modulus, drying shrinkage, and load-deformation curve of these three components of cement mortar were measured. The surrounding fibers are improved in bonding strength and in equil. condition of the elasticity between the fibers and the matrixes surrounding the fibers and the stress distribution of the fibers is also markedly improved.

C79 Lezy, R., and Paillere, A. M., "Concretes, Mortars, and Plasters, Improved by Resin Additions" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The mechanical and rheological characteristics of hydraulic concretes, mortars, and grouts depend primarily on the value of the factor:

$$\frac{C}{E + V}$$

where C, E, and V are, respectively, the volumes of cement, water, and air contained in the unit volume of cement, mortar, or grout.

For a given quantity of cement, it is therefore of the greatest interest to introduce only a minimal quantity of water at the time of application. But this minimal quantity is limited by the necessity of maintaining an adequate fluidity of the mixture.

The L.C.P.C. study shows that the use, in relatively small quantities, of resins of the epoxy type in accordance with a procedure here described makes possible a substantial reduction in water content while still maintaining sufficient fluidity of the fresh products. The physical and mechanical properties of concretes, mortars, and grouts applied by this process are thereby greatly improved.

C80 Lilley, A. A., "Experience in the United Kingdom in the Application of Thermosetting Resin Mortars for the Surfacing and Repair of Concrete Floors and Roads," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.

Nearly 10 years of practical experience have shown that thermosetting resin mortars can provide surfacings with with excellent chemical and wear resistance. These mortars are also useful for repairing spalled or scaled concrete surfaces where early re-opening to traffic is essential.

The paper gives details of types of filler, mix proportions and methods of mixing and applying the mortars which have been found necessary to give satisfactory performance. Common causes of failure are also given.

C81 *Mattiotti, P., "Complementary Studies on the Use of Vinyl Derivatives in Mortars" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.*

The mixing of synthetic resins with mortars used for cappings is, at present, an ever-increasing technique. Results obtained from practical experience at jobsites have proved steadily successful, thus providing more precise data on the methods and application requirements of these resins.

To obtain also improved performance characteristics, i.e., to give the cappings that contain vinyl compounds higher water and wear resistance properties, study work has been carried out towards the following lines:

1 - Researches were primarily done to find out what might be the action of certain surface active agents which are present in resin emulsions. The tests have dealt with some 10 products which were incorporated at doses varying from 0.0045 to 0.225 percent of the cement weight. They were selected among those usually entering the composition on the following properties:

- plasticity or flow property of fresh mortar
- specific gravity value after hardening
- flexural strength and compression under dry or wet conditions.

2 - The influence caused by the nature of these vinyl esters when they are processed under their original form or after copolymerization has also been studied. As a matter of fact, it was found out that mortars have shown varied characteristics, depending on the type of vinyl ester selected. Accordingly, the plasticity modulus of fresh mortars, their specific gravity subsequent to hardening, and the flex and compression strength have provided a basis for establishing characteristic variations which were precisely due to the nature of the processed products.

C82 *Meazey, A. E., and Thomas, D. B., "Portland Cement Compositions Containing Synthetic Copolymers," British Patent 1,093,094 (Cl C08f), 29 Nov 1967; Chemical Abstracts, 32920v, Vol 68, No. 8, 1968.*

The title compositions were prepared by mixing portland cement (I) with five 40 percent butadiene-styrene acrylonitrile terpolymer (II), aggregates, antifoaming agent, wetting agent, and a nonionic emulsifier. Thus, 100 parts were mixed with 300 parts local zone 2 concreting (14 mesh and 45 parts 40 percent II latex (prepared by aq. emulsion polymerization), butadiene 35, acrylonitrile 30, and styrene 35 parts in the presence of 7.5 percent poly(oxyethylene) glycol alkyl phenyl ethyl and 0.75 percent poly(dimethylsiloxane) liq. to give a mortar product having tensile strengths 395 and 249 psi after 7 days dry cure and wet cure, respectively, as compared to 249 and 206 psi, respectively, for mortar composition without II. Other aggregates used were sand, gravel, quartz, or lime.

- C83 Ohama, Y., "Cement Mortars Modified by SB Latexes with Variable Bound Styrene," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Recently, the practical research and development of SB latex for a cement modifier have taken place and the cement mortars so modified are used in the field of buildings or civil engineering. The physical and chemical properties of SB latex-modified mortars have already been reported, but the effects of various polymerization conditions for latex synthesis on properties of SB latex-modified mortars have hardly been noticed. The author discusses the effects of polymerization conditions, in particular, styrene/butadiene monomer ratio on physical properties of SB latex-modified mortar and concludes that the physical properties such as strength, drying shrinkage, adhesion, abrasion and shock resistance, etc. of SB latex-modified mortars are affected more intensely by the variation of bound styrene contents than by the rubber-cement ratios.

- C84 Perenyi, C., "Polymer Modified Mortars," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

Aqueous polymer dispersions admixed to cement concretes or mortars affect their properties. Some research work has been made to find the optimum type and proportion of polymer dispersion admixture, and to see how concrete and mortar properties are thereby modified.

- C85 Schulze, W., and Lange, H., "The Effect of Bitumen Emulsion and Synthetic Resin Additives on the Behaviour of Concrete in Moist Conditions," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

This research work deals with the behaviour of mortar and concrete containing bitumen emulsion and plastic material additives in moist conditions. Especially, the effect of the additives on the equilibrium moisture content, moisture distribution, and water removal has been determined.

In view of the uniform moisture distribution, low water absorptivity and other good properties, such mortars and concretes lend themselves to outside wall elements, particularly to composition floorings of concrete, owing to their ability to dry out rapidly.

- C86 Shafer, H. H., and Wheeler, L. C., "Latex Modified Cement Mortar Coating Compositions and Method of Coating," U. S. Patent 3,354,169 (Cl 260-29.7), 21 Nov 1967.

This invention relates to novel latex modified portland cement mortar coating compositions and to a method of coating. More particularly, it relates to portland cement mortar compositions characterized by containing a copolymer of styrene and butadiene-1,3 and minor amounts of asbestos fiber dispersed in water with certain minor amounts of nonionic and anionic surfactants and a foam depressant.



It is, therefore, an object of this invention to provide improved latex modified cement mortar coatings which are particularly adapted for applying continuous, smooth, and highly durable protective coatings to solid surfaces such as metal and concrete.

It is a further object to provide a method for applying such coatings to the interior and/or exterior surfaces of such articles as corrugated metal or portland cement concrete pipes and the like.

C87 Skupin, L., "Polymer Mortar Structures and Their Durability" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The ratio between tensile strength and compressive strength generally varies, in an ordinary concrete, between 1/5 and 1/6. For a polymer mortar, it is possible to obtain a ratio of 1/3 to 1/2, a compressive strength twice as great, the tensile strength being five times as great. These properties militate in favour of the use of polymer mortars in thinwall structures without reinforcements. In the course of this communication the author compares, from the statistical and economic point of view, reinforced cement thin-shells improved by an emulsion of polyvinyl acetate and ordinary cement mortar shells, reinforced, however, by a lattice or bars. It is brought out that for the smaller spans nonreinforced polymer mortar shells would prove more economical than the traditional reinforced concrete shells. There remains the question of their strength, to which special attention is given in this communication.

C88 Smith, P., et al., "Performance Evaluation of Concrete Restoration Materials and Methods," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.

The report first describes a laboratory and field performance evaluation, of a number of concrete repair systems, which was undertaken to determine their suitability as bonded overlays in conditions of severe environmental exposure. A number of synthetic resin materials such as epoxy resins, polyvinyl acetates and lattices were used either as bonding agents in conjunction with overlays, or as the overlay itself, or to modify the properties of a mortar overlay; comparison was with conventional cementitious repair methods.

On the basis of the laboratory tests which included bond strength, compressive strength, freeze-thaw and salt scaling resistance and volume change, and from the observations made in the field of repaired bridge sidewalks over a 5-year period, it was concluded that, as bonding agents, only epoxy resins compared favourably with cementitious materials. The tests also revealed that the modification of concrete mortar overlays by the addition of the polyvinyl acetates and lattices tested offered no advantages over the unmodified mortars. Descriptions of practical applications of epoxy resins are given.

- C89 Solomatov, V. I., "Polymer-Cement Concretes and Polymer-Concretes," Izadtel'stuo Literaturny PO Stroitel'stua, Moscow, AEC-tr-7147, 1967; Computer translation from Russian, U. S. Atomic Energy Commission, Oak Ridge, Tenn.

This book is the first attempt at generalization and systematization of theoretical and practical knowledge of the technology and use of polymer-cement concretes and polymer-concretes - the new high-strength, stable materials whose properties can be changed at will within wide limits. Their high static and dynamic strengths and their resistance to wear and chemicals permit their wide use for chemical-resistant equipment, storage vessels and pipe lines for corrosive or biologically active liquids, chemical-resistant floors, sewage systems, and many other purposes.

- C90 Stibrany, P., "The Possibilities of Using Epoxy Ester Emulsions for Polymer Cement Mortars and Their Influence on Selected Physico-Mechanical Properties" (in Slovak), Stavivo, Vol 45, No. 10, 1967, pp 362-63; Chemical Abstracts, 40641v, Vol 68, No. 10, 1968.

A series of tests with the addition of some epoxy ester, polyester, and mixed emulsions to different cements was performed in order to establish their influence upon some properties (pressure, flexural and tensile strength, sorption ability, modulus of elasticity, swelling, and linear shrinkage) of the polymer cement mortars thus formed. Only the linear shrinkage can be improved (the optimum addition of emulsions being 4 to 8 percent); the other properties are influenced mainly by the quality of the cement itself.

- C91 Stibrany, P., "Dispersions of Plastic Materials; Criterion for the Choice of Type of Material" (in French), RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The Institut de Recherche du Bâtiment has examined a method whereby the possibility of using cement mortar materials can be determined by the observation of the progress of scatter saponification as well as by the determination of the constants of rate of hydrolysis in alkaline media.

Among the types examined, the scatters having a polyvinyl propionate or acrylate base proved to be the most appropriate.

- C92 Ujczka, P., "Surfacing Mortars Made Without Cement," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 2, 4-6 Sep 1967.

The best surfacings for medium and large slab buildings and panels are given by resin mortars. The criteria for mortars binders have been met by the following resins: the epoxy, the PVC and its copolymers, the polyurethane, SO2C1 polythene and the polyester.

Mechanical, thermal and acoustical tests helped to define the fields of use for resin mortars. All the tested materials applied as surfacings largely improved the sound and thermal insulation of the structure. The strength values largely exceeded those of conventional materials.

Resin mortars made with either coarse or fine aggregates give pleasant-looking, variegated surfaces. Mortars can be coloured either by using colour aggregates or by admixing some pigment to the resin. Based on moisture absorption and freezing-thawing tests, the useful life of the so-obtained surfaces can be assessed at 25 to 40 years as a minimum.

C93 Wagner, H. B., "Hydration-Limited, Polymer-Modified Hydraulic Cements," I & EC Product Research and Development, Vol 6, No. 4, Dec 1967, pp 223-231.

The rate of evaporative water loss from thin sections of compositions of portland cement mortar containing various polymers of different types and levels was studied. The polymer type and level do not affect the water loss rate. Moduli of elasticity and rupture were determined for various polymer types, levels, and hardening conditions, and found to depend primarily upon the extent of the cement hydration achieved and adhesion level developed. Results of microscopic studies of the structures of the compositions and fracture surfaces are given, and methods for evaluating adhesion levels in such compositions are described.

C94 Warris, B., "Bond Between Mortar Toppings and Concrete," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 4-6 Sep 1967.

The report contains data on the adhesion between mortar toppings and concrete. It was intended to improve the adhesion by using emulsions of polyvinylacetate (PVA) as admixture to the bonding grout or by using epoxy resins as bonding agent.

The adhesion was tested partly by a tension test, partly by a shear test, using the shear force produced in beams in flexion.

The results show considerable variation, but in general the bond was not found to be superior to that obtained with ordinary cement grout and careful workmanship. Application of epoxy resins seems, however, to increase the probability of obtaining a good bond.

#### 1968

C95 Aignesberger, A., and Krieger, H., "Addition of Anionic Melamine Resin Solutions to Cement and Gypsum (Zusatz von anionischen Melaminharzlösungen zu Zement und Gips)," Zement-Kalk-Gips, Wiesbaden, Vol 21, No. 10, Oct 1968, pp 415-419.

Three new types of resin based on anionic melamine resins are presented. Tests with cement mortars invariably resulted in improvements in the strength properties and produced marked improvements in the

bond strength of new to old concrete. These results were obtained also under wet conditions of loading. Durability tests (resistance to frost, deicing salts, sulphates and oil) have shown that the improvements in properties achieved by additives are retained or, at worst diminished to the same extent as occurs in cement mortars without additive. This is taken to indicate that the basic properties of concrete are not affected by the resins.

Depending on the type of resin, a plasticising effect or improved water retaining capacity can be obtained.

Tests with gypsum likewise resulted in improvements in the strength properties, more particularly the compressive strength, and in an increase in thermal stability.

C97 *Erickson, H. W., "Repair of Cavitation Damage in Concrete with Epoxy Resin Material," SP-21, pp 67-78, 1968, American Concrete Institute, Detroit, Mich.*

Portland-cement concrete in the floor of the outlet works at Fort Randall Dam, Pickstown, South Dakota, was damaged by cavitation from high-velocity water flow. An engineering study indicated that repair could be accomplished most economically with epoxy-resin materials. Mix proportions were developed in the Missouri River Division Laboratory of the Corps of Engineers for an epoxy-resin concrete, an epoxy-resin mortar, and an armor coating. The Omaha District office of the Corps of Engineers furnished comprehensive instructions and packaged materials to field personnel for accomplishing the repair at this remote location. The damage was successfully repaired by field personnel having little previous experience with epoxy-resin materials. Herein the materials, mixes, and procedures used are described in detail, including health and safety precautions. An inspection was made after the repaired area had been under water for 5 years, and the repair was found to be performing very satisfactorily. Suggestions for future work of this nature are given.

C99 *McConnell, W. R., "Epoxy Surface Treatments for Portland Cement Concrete," SP-21, pp 9-17, 1968, American Concrete Institute, Detroit, Mich.*

Widespread acceptance of epoxy surface treatments for pavements has been limited in part by problems associated with pinholing, poor surface appearance, and sheet detachment. Recent laboratory and field investigations promise to improve this situation markedly by use of 20 to 40-mesh rounded aggregates to stop pinholing, development of mechanical sand-spreading equipment to improve appearance, and improved techniques for deck preparation to obtain better adhesion. In addition, new application techniques permit one-step placement of premixed epoxy mortars in 3/8-in. lifts, which offer numerous advantages in increased wear, improved wetting of both deck and aggregate, and greater structural integrity of the overlay treatment. These new techniques appear to be adaptable to even very large contracts. Despite existing problems, the protection afforded by epoxy treatments, together with the combination

of thin courses and long life, continue to indicate a permanent place for these treatments in the highway industry.

C100 "Polymer Cements: Notes of the Month," The Indian Concrete Journal, Vol 42, No. 7, Jul 1968, p 263.

This article reports on 'Estercrete', a polymer cement.

When the standard product, a viscous liquid, is mixed with a properly graded aggregate in a positive-action mixer and a measured quantity of water is added, a mixture is formed which has a placing time of about 1 hr depending on the proportions of the mix and the temperature. The added water hydrates the cement in the product, and the by-products of this reaction catalyse the polyester and styrene which then set to form a tough rigid polymer. Hardened 'Estercrete' therefore consists of a continuous polymer phase containing a bonded crystalline filler. Just sufficient water is added to react completely with the cement to form a stable hydrate compound.

C101 "Polymer Cements," Concrete, Vol 2, Jan 1968, p 46.

Ordinary portland cement cannot be used for some applications in the maintenance of concrete pavements. To meet such requirements, convertible plastics materials have been developed providing a series of products known as polymer cements. The first of these released is composed of a dispersion of portland cement in polyester-resin/styrene with water-soluble redox catalysis. The system has practical advantages as a single-pack product and has been found to present improvements over traditionally catalysed and filled plastics systems, particularly in connection with the lower shrinkage produced on setting.

The particular product, 'Estercrete,' is a binder for strong inert aggregates and can be used for a full range of concretes and mortars. Economic considerations and the present limits of knowledge restrict its current use to dense mortar mixes using selected aggregates such as industrial floor toppings, repairs to concrete road and paved areas, and jointing and surfacing building units.

C103 Volkonskii, B. V., and Shteiert, N. P., "Cement for an Earthquake-Proof Construction," Foreign Technology Division, Wright-Patterson AFB, Ohio, 9 Feb 1968.

A study of the effects of various additives on the elastic properties of cements was conducted to provide materials with improved earthquake-resistant properties. The authors emphasize the need to implement existing knowledge in providing earthquake-resistant structures in areas requiring such construction.

- C104 Aignesberger, A., Rey, T., and Schräuli, W., "Electron Microscopic Studies of the Hardening Phenomena of Cement with Admixtures of Melamine Resins (Elektronenmikroskopische Studien der Erhärtungsvorgänge von Zement mit Zusätzen von Melaminharzen)," Zement-Kalk-Gips, Wiesbaden, Vol 22, No. 7, Jul 1969, pp 297-305.

With the aid of the electron microscope the average molecular weight of type N melamine resin was determined as being approximately  $2 \times 10^4$ . Atomisation of resin solutions, diluted to 0.1-0.001 ppm, on the Formvar sheet was found to be a suitable method for the preparation of specimens.

The anionic water-soluble melamine resins attach themselves as net-like structures to the hydration products. In consequence of their dispersive action they give rise to a similar texture over a fairly large region. The interlocking of these crystals in cements containing resin develops at a relatively early stage. The textures of hardened cement paste with and without resin admixture become approximately similar to each other after about 2 months.

Fan-shaped structures in etched polished sections of specimens containing resin present an appearance similar to that of polished resin surfaces and are therefore with good reason to be interpreted as consisting of resin. They affect the morphology of the hardened cement paste by impressing certain preferred directions within small regions.

- C105 "Concrete with Resin Admixtures," D.G.R. Documentation, Road Research Laboratory, Aug 1969.

A bibliography is presented which deals with the mix-design of concretes containing resin admixtures and their application to road construction (surfacing, repair of cracks, etc.), bridge surfacing and the building industry.

- C106 Crace, W. A., "Kentucky Bridge Decks Repaired with Latex Mortar Overlays," Better Roads, Vol 38, May 1969, pp 19-21.

Deterioration of bridge decks is a problem of concern to highway departments all over the country - including the Kentucky Department of Highways. This article reports on the search for a more satisfactory way to repair bridge decks. These experiments were carried out on bridges in Kentucky. Overall, this system of bridge-deck repair seems to be good. Although the riding surface leaves something to be desired, it is not nearly as rough as some of our surfaces. The material can be used to make permanent patches as well as overlays.

Minor surface cracks in the latex film appeared in all of the overlays. These could only be detected when the overlay was wet and was in the process of drying. The overlay on the east end of the bridge over the Levisa Fork showed excessive deep cracking in the direction that water would normally run off the bridge. Because of their excessive depth, an epoxy seal was used on these cracks. As far as we could

determine, the cracks did not affect the bond between the old concrete and the latex mortar.

C107 Davydov, S. S., "Controlled Changes in the Properties of Concrete and Reinforced Concrete by Means of Polymers," p 16, Sep 1969, Bureau of Reclamation, Denver, Colo.

Soviet institutes involved in advancing structural sciences have developed plastic cements and concretes, capable of overcoming the limitations of conventional concretes. Modern construction needs materials for its more diversified and larger structures that are strong, flexible, impact- and abrasion-resistant, chemically stable, and not susceptible to cracking or surface deterioration. By changing the composition and quantity of components, plastic-concretes can be designed to meet specific needs. Soviet research has studied many plastic additives and admixtures for binders and concretes, as well as polymer coatings, laminated structures, and synthetic glues.

C108 Dickson, J. T., and Silber, M. H., "Cements Containing Vinyl Chloride-Acrylic Copolymers," British Patent 1,150,376 (Cl C04b), 30 Apr 1969; Chemical Abstracts, 15780u, Vol 71, No. 4, 1969.

Portland cement compositions with excellent impact strength were obtained by blending the cement with 5 to 40 percent vinyl chloride copolymer latex or powder. The copolymers were prepared by emulsion polymerization of vinyl chloride (I) with acrylic acid (II) and possibly other vinyl monomers in the presence of a free radical catalyst and <0.5 percent emulsifying agent. Thus, water 3000,  $\text{Na}_2\text{S}_2\text{O}_5$  6, I 2000, and II 40 parts were heated to 40° in an autoclave and treated with 50 parts 1 percent aq.  $(\text{NH}_4)_2\text{S}_2\text{O}_8$ . An additional five batches of 50 parts catalyst were added at 30-min intervals. The polymerization was continued for 5.5 hr until the autoclave pressure dropped 30 psi. The latex obtained had 34.6 percent solids and was stable to electrolytes. Portland cement 400, sand 1200, copolymer latex 231, and water 19 parts formed a mortar which was used to bond two presoaked building bricks with a 0.25-in. mortar thickness. The bricks were cured 10 days and the bond strength was detd. by placing the mortar bond horizontal and striking the upper brick with a 15.26-lb pendulum having pendulum length 58.375 in. The pendulum displacement was increased from 10 to 5° increments until the bond was broken. The bricks had average impact strength 7.7 ft lb while a control with no latex added had impact strength 3.0 ft lb. Improvements in impact strength were also obtained using copolymers containing 0 to 29 percent vinylidene chloride, 0 to 29 percent vinyl acetate, and one to three parts II copolymerized with I.

C109 Dikeou, J. T., et al., "Polymerization Makes Tougher Concrete," Proceedings, American Concrete Institute Journal, Vol 66, No. 10, Oct 1969, pp 829-839.

Reports on a study of the feasibility and techniques of impregnating and in-place polymerizing of liquid monomers in preformed

concrete, and the use of monomers in a fresh concrete mix, followed by polymerization. Two methods of initiating polymerization - gamma radiation and thermal-catalytic - are being studied. Studies include development of impregnation techniques and determination of the effects of various polymer loadings on resultant properties. The radiation technique produces greater improvements in properties than does the thermal-catalytic method.

Dramatic improvements in concrete properties resulting from the impregnation-irradiation with methyl methacrylate are discussed. For example, compressive and tensile strength and modulus of rupture are increased by 256 to 290 percent; water permeability decreased to negligible values; water absorption decreased as much as 95 percent; and resistance to abrasion, cavitation, freezing and thawing, distilled water, soluble sulfates, and acid showed significant improvements.

C110 Egot, P., and Burgand, Y., "Powdered Coating Compositions Based on Cement, Sand, Vinyl Copolymers, and Methyl Cellulose," French Patent 1,583,630, (C1 C046), 21 Nov 1969; Chemical Abstracts, 59005r, Vol 73, No. 12, 1970.

The preferred composition of the coating is as follows: vinyl copolymers 1, poly(vinyl acetate) 0.5, cement 15, sand 37, silica 38, white chalk 1.5, clay 1.5, Me cellulose 0.1, asbestos 4.4, and CaCO<sub>3</sub> 1 percent. The coating should be used immediately after being mixed with 10 to 20 wt percent water. The coating is very hard, does not crack, and adheres to all substrates. It has a hardness equal to that of cement coatings.

C111 Ghosh, R. K., Sethi, K. L., and Pant, C. S., "Synthetic Resins for Concrete Repairs," Journal of the Australian Road Research Board, Vol 4, No. 1, Sep 1969, pp 50-68.

The laboratory investigation on concrete repairs with particular reference to concrete pavement, using synthetic resin preparations of both polyester and epoxy groups, has been reported. The paper also includes details of some field trials and evaluation of their performance.

C112 Gudev, N., and Nikolov, I., "Use of Butadiene-Styrene Latexes for Obtaining Latex-Cement Mixtures," Stroit. Mater. Silikat. Prom., Bulgaria, Vol 9, No. 7, 1968, pp 7-10; Chemical Abstracts, 5099u, Vol 70, No. 2, 1969.

By using Russian butadiene-styrene latexes SKS-65GP and SKS-50GP and East German type F, it was found that 4 percent stabilizer based on the polymer was required plus a filler-cement ratio of 0.2:1.0. A new method for stabilizing the latex prior to mixing with the cement by use of nonionic surfactants was devised, resulting in a mixture having improved physical and mechanical properties. Due to its great deformability, latex cement can be used in construction as an intermediate bonding layer.



C113 Pattengill, M. G., Crumpton, C. F., and McCaskill, G. A., "Bridge Deck Deterioration Study, Spot Treatment of Hollow Areas By Rebonding with Injected Epoxy Resin," *Bridge Deck Deterioration Study, Part 6, State Highway Commission of Kansas, 1969.*

Certain types of epoxy can be used to rebond near-horizontal fractures in concrete using simplified injection equipment. The fractures are often closely associated with the reinforcing steel or with large aggregate particles. This method of repair is relatively inexpensive, not time-consuming, and can be done with little equipment as compared to other repair techniques. Furthermore, the original deck surface is retained.

C114 Piatkowski, A., "Properties of Cement Mortars Containing Synthetic Resin Latexes" (in Polish), *Cem-Wapno-Gips, Vol 24/36, No. 2, 1969, pp 55-60; Chemical Abstracts, 41909n, Vol 71, No. 10, 1969.*

Mixes were prepared containing portland cements, clay, sand, gravel, water, and 40 percent Winacet D-5 poly(vinyl acetate) (I) emulsion or butadiene-styrene latex (II). The effects of I or II additions on hardening rate, consistency of cement paste, shrinkage (or expansion), adhesion, elasticity, compressive strength, resistance to freezing, and corrosion resistance of the concretes, reinforced concrete, and mortars prepared from these mixes were studied. The addition of II alone was not satisfactory because of its pptn. with  $CA^{2+}$ . Concretes containing I resisted corrosion by 2 percent  $Na_2SO_4$  solutions rather poorly. Mixes containing ~20 percent II stabilized by the addition of 0.4 percent (based on II) Olbrotol (nonionic detergent prepared from cetyl alc., oleyl alc., and ethylene oxide) and 1.2 percent Oskar (equiv. to Leucanol, i.e., anionic detergent, a condensate of HCHO and naphthalenesulfonic acids) absorbed less water, was mech. strong, elastic, and resisted low temperatures and acid media. Their compressive strength was slightly reduced and hardening time was increased.

C115 Pierzchala, H., "Effect of Poly (vinyl acetate) Dispersion on the Hydration of Portland Cement," *Tonind.-Ztg. Deram. Rundsch., Vol 93, No. 9, 1969, pp 337-40 (Geri); Chemical Abstracts, 128212d, Vol 71, No. 26, 1969.*

The effects of poly(vinyl acetate) (I) addition on the setting time of portland cement was studied by incorporating 2.5 to 30 percent I dispersion into two cement pastes and detg. the setting times. Setting times increased with the beginning of setting increasing from 3.83 hr at 0 percent addition to 10.75 hr with 30 percent addition. The end of setting was similarly increased from 6.33 hr at 0 percent addition to 13.67 hr at 30 percent addition. Microscopic examination of the gels suggested that the setting time retardation is due to adsorption of hydration crystn. seeds by coagulated I macroparticles in the cement paste.

C116 Rooney, H. A., and Shelly, T. L., "Thin Resinous and Aggregate Overlays on Portland Cement Concrete," Research Report No. M & R 635121, Jun 1969, Materials and Research Department, California State Division of Highways.

Fifteen different formulations of resinous binders for overlays have been evaluated. Seven were applied near Sacramento where freezing rarely occurs and eleven were applied at Kingvale near Donner Summit at about 6000 ft where severe snowplows and chain wear is encountered. All but one of the binders tested near Sacramento are in good condition after 3-1/2 years of service. At Kingvale one polyester seal coat applied in three layers over an epoxy primer is showing good durability but low skid resistance after nearly 3 years of service. Polyester overlays without an epoxy primer failed during the early part of the first winter. Single layer epoxy seal coats, about 1/3-in. thick failed in 1 year or less. Two double-layer systems, each about 1/4-in.-thick, lasted for 2 years.

Blistering was a problem on both installations. The blisters usually broke and spalled, decreasing the effectiveness of the overlay as a waterproof membrane.

C117 Societe Civile d'Etudes et de Brevets "VIDHOR", "Mortar Additive," Belg. Patent 717,500, 2 Jan 1969; Chemical Abstracts, 53223x, Vol 71, No. 12, 1969.

An additive for improving the surface detail and mechanical properties of moldings made with hydraulic-bonded aluminous or portland cement mortars consists of a mixture of nonionic sulfated alkylbenzenesulfonate wetting agent, dimethyl polysiloxane antifoaming agent, poly(vinyl acetate) plasticizer, and methyl silicate waterproofing agent, and, if desirable, LiCl hardener and  $(\text{NH}_4)_2\text{SO}_4$  retarder. The additive is made by first preparing partial mixtures of sulfated alkylbenzenesulfonate with dimethyl polysiloxane and methyl silicate. These two are then mixed and added to a dispersion of sulfated alkylbenzenesulfonate in poly(vinyl acetate) and the final mixture is added to the mortar in an amount from 1 to 15 percent.

C118 Ullrich, F., "Mortar with Polymer Component," South African Patent 6,707,716, 26 Nov 1968; Chemical Abstracts, 115889j, Vol 70, No. 26, 1969.

Synthetically bonded mortar was prepared by mixing cement or hydrated lime with a polymeric dispersion containing a thermosetting resin, accelerator, and interlacing agent. The mortar composition may also contain various stabilizers, fillers, nonreactive resins, and thinners. Thus, four parts laurylamine and 96 parts polyaminoamide were mixed and treated with 300 parts water to form a stable dispersion which was subsequently treated with 100 parts bisphenol A glycidyl ether epoxy resin to yield a dispersion with pot life 1 to 2 hr. The dispersion was stirred into 750 parts portland cement to yield a highly plastic, brushable mass with pot life  $>0.5$  hr and several hours if nonreactive

epoxy resins are mixed with the mortar. The mortar is suitable as an adhesive, protective coating, flooring, sealer, or plaster.

C119 Vesper, R. L., "An Evaluation of TUF Concrete Made with Lone Star Cement," p 52, May 1969, Fenix and Scission, Inc., Las Vegas, Nev.

A field test was conducted to determine the properties of "Tuf" concrete made with a recently developed cement. It was found that "Tuf" concrete made with the tested formula can be used as structural material for emplacement room liners. "Tuf" concrete made with the new Lone Star cement as compared to that previously tested has a markedly increased compressive strength, does not have a significantly increased tensile strength, and has a substantially greater heat of hydration which contributes to more shrinkage. "Tuf" fibers tend to segregate in larger concrete masses. However, the absence or presence of "Tuf" fiber in a specimen does not appear to affect the compressive strength. "Tuf" concrete does not initially set until approximately 2 hr after mixing, but a crust forms on the surface very rapidly if the material is allowed to come to rest. This results in the requirement of continuous movement or agitation to preserve the fluidity of the mix. The concrete does not significantly increase in strength after 7 days of moist curing.

1970

C120 Antonova, I. T., et al., "Use of Polymer-Cement Concrete on a Base of Furfural Resins," Hydrotechnical Construction, Vol 8, Aug 1970.

The All-Union Research Institute for the Construction of Trunk Pipelines has developed an especially dense, nonshrinking polymer-cement concrete on furfural resins, which has a high corrosion resistance, low permeability, and high resistance to vibrations and axial extension.

Water-soluble additions - the monomer furfuryl alcohol, the polymerization intensifier aniline hydrochloride, and the cement hardening accelerator calcium chloride - are added to the mixing water and subsequently pass into an insoluble state in the concrete by means of the polymerization intensifier. Gypsum-alumina cement, the expanding component for removing shrinkage deformations of the concrete, is added to the composition of the binder.

For polymer-cement concrete we used expanding portland cement (MRTU 51-165-66), which provides stable expansion of the cement stone during hardening under moist air conditions and has a normal setting time, high strength, and low permeability. The expanding portland cement consists of 74-62 percent portland cement clinker, 10-17 percent high-alumina slags, 18-12 percent granulated blast-furnace slag or an active hydraulic admixture, 7-9 percent gypsum, and up to 2 percent lime. At construction sites this cement can be obtained by thorough mixing of 75-80 percent portland cement or slag-portland cement and 25-15 percent of the expanding component (gypsum-alumina cement) in mixers.

C121 Bannister, A., and Walker, D., "Epoxy Resin-Pulverized Fuel Ash Mixtures," Journal of Institution of Municipal Engineers, Institution of Municipal Engineers, London, Oct 1970, pp 268-274.

The author discusses epoxy resin systems based on Epophen E1 5 resin and hardener EHT 8, purchased from the Borden Chemical Co., and in particular the properties and applications of epoxy resin mortars or concretes containing admixtures of pulverized fuel ash and sand to epoxy resin results in a mortar or concrete of greater strength than conventional cement concrete. The material is particularly suitable for use in structural joints and in skid-resistant and polishing-resistant surfacings on highly-trafficked roads.

C122 Division of Isotopes Development (AEC), "Division of Isotopes Development Research and Development Projects: 1960," Progress Reports, Feb 1970, Washington, D. C.

A 1969 summary of the objectives, progress, results, and future plans for each of the research and development projects of the AEC Division of Isotopes is presented. The projects are separated into the following categories: radioisotopes production and materials; thermal applications development, uses in environmental and ocean sciences; radiation analysis and control; process radiation; radiation preservation of foods; and information services related to radioisotopes uses.

C123 English, J. L., "Indexed Bibliography on Corrosion and Performance of Materials in Saline Water Conversion Processes-8," p 59, Sep 1970, Oak Ridge National Laboratory, Tenn.

Abstracts are given for 50 reports which have been issued by the Office of Saline Water relating to the corrosion and performance of materials of construction used in saline water conversion processes. The major portion of the report is a reproduction of a computer printout of information stored in a computerized storage and retrieval system for the Materials Information Center of the Office of Saline Water (OSW-MIC) located at Oak Ridge National Laboratory. An author index and a keyword index to the reports referenced are included. The publication also contains a progress report on research on concrete-polymer reports. This bibliography is a quarterly listing dated September 1970.

C124 Johnson, P. R., "The Properties of an Epoxy Mortar and its Use for Structural Joints," The Structural Engineer, Vol 48, No. 6, Jun 1970, pp 227-233.

The formulation of an epoxy mortar is related to existing knowledge of the design of resin mortar mixes. The results are given of several series of tests on this mortar and on joints made with it. These show that it is suitable for use in structural joints in precast concrete that transmit combined shear and compression, and that its flexibility and creep are little greater than those of concrete, and an order of magnitude less than those of the epoxy resins previously tested.

C125 Jones, C. W., "Effect of a Polymer on the Properties of Soil-Cement," REC-OCE-70-18, May 1970, Bureau of Reclamation.

A laboratory testing program was conducted on soil-cement specimens of silty sand and of silt with the monomer methyl methacrylate (MMA) added and polymerized. The purpose was to determine any beneficial effects on the properties of soil-cement as used in Bureau of Reclamation construction. By the preformed method, some specimens were impregnated with MMA and polymerization was by gamma radiation from Cobalt 60. Other specimens by the premix method had 3 percent or 6 percent MMA with 1 percent benzoyl peroxide as a catalyst incorporated during specimen preparation; polymerization was by heat. The compressive strength of the preformed specimens containing silty sand was increased about 3.4 times that of specimens without MMA, but the premix specimens did not increase in strength. Results of freeze-thaw tests did not show conclusive trends, but there were indications of improvement with the addition of MMA. The MMA reduced significantly the permeability of the silty sand specimens. Petrographic examinations showed that the MMA penetrated and filled the voids of portions of the silty sand specimens, but the voids in the silt specimens were nearly empty.

C126 McCaskill, G. A., et al., "Bridge Deck Deterioration Study, Part 9, Epoxy Resin Seal Coats and Epoxy Mortar Patching for Bridge Decks," 1970, State Highway Commission of Kansas.

In spite of improvements in epoxy resin application rates and sealing practices, the bridge decks under epoxy "seals" have continued to exhibit spall and hollow plane type of deterioration.

Epoxy mortar patching material with less than 1 percent absorption was obtained by mixing one part epoxy, one part portland cement, and five parts or less of fine sand. This mix makes a good patching mortar but all unsound concrete must be first removed from the pothole if the repair is to be successful.

C127 Nakashima, G., "Concrete Compositions Containing Epoxy Resins," Japanese patents: 70-12517, 70-12518, 70-12519, 70-12520, 1970; Chemical Abstracts, 90906, 90907, 80216, 80217, Vol 73.

A concrete composition with good mixing workability was prepared by mixing Epikote-828 8.6, cumarone resin 3.4 (Neuill resin), cement 430, sand 516, aggregates 1240, and water 210 parts. The bending strength of the cement concrete was 84.0 kg/cm<sup>2</sup> (based on JIS (Japan Industrial Std.)-R-5201 test), workability 13.9 cm, and water permeability 80 min.

C128 Ohama, Y., "Comparison of Properties with Various Polymer-Modified Mortars," Synthetic Resins in Building Construction 1, Eyrolles, Paris, 1970, pp 153-168.

Recently, new types of polymers such as acrylonitrile-butadiene (NBR) latex, vinyl chloride-vinylidene chloride (PVC) emulsion,

polyacrylic ester (PAE) emulsion, epoxy emulsion, etc., or products prepared by blending different latexes are developed as an admixture for portland cement mortar.

In Japan the researches and developments of polymer-modified mortars have been carried out recently and their superior properties have been widely known during the past 4 to 5 years. Consequently, various polymer latexes or emulsions for polymer-modified mortar have been in commercial use, and used extensively in the field of building and construction. Therefore, it is considered very important for their researches and application in future that properties of polymer-modified mortars be tested and compared.

In various commercial cement modifiers in Japan, 13 typical types of polymers are selected and the properties of the mortars modified by these polymers are tested.

From the above test results, it is obvious that the properties of polymer-modified mortars are affected more extensively by the variation of polymer-cement ratio, polymer type and its property. In general, an increase of their polymer-cement ratio brings on superior properties such as low water-cement ratio, high strength, waterproofing, little drying shrinkage, adhesion, good shock and abrasion resistance, in comparison with unmodified mortar. The properties of polymer-modified mortars are not always elevated in proportion to an increase of polymer-cement ratio. The mortar such as PVA emulsion-modified VA gives a lowering in strength of water-resistance and an increase in drying shrinkage with additional polymer-cement ratio.

C129 Nutt, W. O., "An Evaluation of a Polymer Cement Composite," Composites, Vol 1, No. 4, 1970, pp 234-238.

During 1962 a new concept of polymer cements was envisaged. This consisted of the coincident polymerisation of polyester resin and hydration of portland cement to provide an amorphous polymeric matrix within which a continuous crystalline scaffold of hydrated cement gel was structured. The presence of this structure has not been proved, but the practical properties have received an enormous amount of attention.

The chemistry of polyester resins and their polymerisation with soluble peroxy compounds is well-known. The chemistry of portland cement and its hydration is also largely understood and the study of cement hydration has increased the understanding of the physiochemical nature of the resultant gel. However, in polymer cements, a number of different aspects of the standard chemistry is involved.

The long-range objectives of the program are the investigation and development of a concrete-polymer composite for application as a new material of construction. The program includes the development of techniques for the preparation of the concrete-polymer material, the measurement of the pertinent physical and chemical properties, the preparation of full-scale concrete products, and the conceptual design and evaluation of various specific applications.

C131 Sefton, R. C., "Synthetic Resin Emulsion Hydraulic Cement Compositions," British Patent 1,172,007 (Cl C04b), 26 Nov 1969; Chemical Abstracts, 35405z, Vol 72, No. 8, 1970.

Hydraulic cement compositions useful for preparing concrete pipes were prepared by blending portland cement with a modified butadiene-styrene copolymer (I) emulsion containing 3 to 30 percent solids and with glass fibers. Thus, 20 parts white Type III portland cement and 25 parts I emulsion (prepared from 150 g acid-modified I and 450 ml water) were blended and applied as a base coat to a polystyrene foam substrate. A glass fiber mat was placed on the substrate followed by a second cement-I coating. The resulting mat was rolled and dried 24 hr to yield a laminate with excellent adhesion. A concrete pipe with excellent impact and bursting strength and corrosion resistance was also prepared from the cement-I blend.

C132 "Synthetic Resins in Construction," Editions Eyrolles, 1970.

The themes discussed at this symposium were as follows: Theme 1A: Concretes and Mortars, Improvement Through the Addition of Resins. Theme 1B: Concretes and Mortars Containing No Cement. Theme 2: Structures, Assemblies, Reinforcements. Theme 3: The Role of Resins in the Protection and Repair of Structures.

C134 Teodorescu, D., Pipera, G., Stamate, Gh., and Facaoaru, I., "Enhancement of the Acid Resistance of Cement Mortars by Addition of Latexes" (in Romanian), Material Plast., Vol 6, No. 5, 1969, pp 283-87; Chemical Abstracts, 124736a, Vol 72, No. 24, 1970.

The resistance of cement mortars to HCl and HNO<sub>3</sub> was increased by addition of butadiene-styrene latexes and, to a lesser degree, by addition of polychloroprene latex. The latexes did not prevent corrosion by H<sub>2</sub>SO<sub>4</sub>.

C135 Teodorescu, D., Pipera, G., Stamate, Gh., and Facaoaru, I., "Behavior of Cement Mortars Containing Rubber Latex in Dilute Acid Media" (in Romanian), Revision Construction Materials Construction, Vol 21, No. 7, 1969, pp 356-61; Chemical Abstracts, 35394v, Vol 72, No. 8, 1970.

The stabilizing effects of DOW-560 and B 3118 butadiene-styrene latexes and A 5213 polychloroprene latex on cement mortars were compared. Addition of latex increased their resistance to dilute HCl and HNO<sub>3</sub> but not to dilute H<sub>2</sub>SO<sub>4</sub>. The latexes also gave improved adhesion to the support, degree of impermeability, elongation capacity, and mechanical resistance. Mortars containing the latexes retained their form even when the cement was partially or totally solubilized, in contrast to cements without the stabilizers which were rapidly and completely degraded by the acids. B 3118 containing a silicone antifoam agent gave the best results. Corrosion of the cement with time was accurately detd. by ultrasonic vibrations.

- C136 Aignesberger, A., Fah, N. L., and Rey, T., "Melamine Resin Admixture Effect on Strength of Mortars," Journal, American Concrete Institute, Vol 68, Aug 1971, pp 608-615.

An analysis of variance was used to evaluate quantitatively the effect of a new type of melamine resin admixture, a 20 percent aqueous solution of a sodium salt of a special polymerized product of melamine and formaldehyde, on the setting, water-reducing effect and the compressive and flexural strengths of mortars made from ground clinker and portland cement. This resin greatly increases the retarding action of gypsum, acts as a powerful water-reducing agent and, above all, increases the compressive and flexural strengths by up to 150 percent for mortars of ground clinker and by up to 65 percent for mortars of portland cement. The maximum effect is obtained when 6 to 9 percent resin is added, though little additional improvement is achieved above 5 percent.

- C137 Boulware, R. L., and Elliott, A. L., "California Seals Salt-Damaged Bridge Decks," Civil Engineering, American Society of Civil Engineers, Oct 1971, pp 42-44.

The California Highway Department has been testing several bridge-deck sealants in search of a noncorrosive deicing material. It has not been found. Instead, the approach is to seal the deck to protect it from the corrosive salt brine. Although a "perfect" seal is yet to be found, several, such as emulsified coal tar and a thermoplastic sheet system, will extend the useful life of bridge decks in heavy salting areas.

- C138 Bridnya, P. A., Gotsiridze, Z. V., and Orlov, I. I., "Experimental Installation of Polymer-Cement Floors," 1971; Chemical Abstracts, 90968, Vol 75.

The following cement-polymer composition was tested and successfully used for the installation of a new floor in the centrifuge room of a sugar factory: portland cement 100, sand 240, butadiene-styrene copolymer latex 40, detergent 1.5, and water 25 wt parts. The top layer of the flooring was made of tinted cement and it addnl. contained 10 wt parts of poly(vinyl acetate) emulsion. The flooring did not crack or lose its initial impact strength after 1 year service.

- C139 Eash, R. D. and Emig, G. L., "Polymer Latex Modified Mortars and Concrete," Proceedings of the Conference, New Materials in Concrete Construction, University of Illinois at Chicago Circle, Chicago, Ill., Dec 1971.

Latex mortars have been used in most of their applications areas because of two important properties:

1. The ability to bond well to a substrate, usually concrete.
2. Excellent durability.



The first market to use latex mortars was that of floor underlayments to level a concrete floor prior to laying tile or carpeting. The success of the underlayment application of latex mortars almost naturally led to the use of these same materials for the restoration of interior concrete floors. Work over the past 15 years has demonstrated both the excellent bond strength and durability of latex mortar in this application. The latex modified portland cement (LMC) mortars have superior resistance to abrasion and to chemical attack when compared to concrete. The next area of application of latex mortars was in exterior applications to upgrade the properties of portland cement stucco. Another decorative use of latex mortars is their application to precast or cast-in-place concrete to achieve a more aesthetic appearance.

Another very severe use of latex mortars has been the resurfacing of badly deteriorated bridge decks. Work in this area began in 1957 and has grown steadily since then. This application demands good concreting practice, tight quality control of the mortar formulation and, above all, good surface preparation of the deteriorated substrate. We are now entering a new phase in the use of latex mortars on bridge structures; the use of latex mortars in new bridge construction.

The use of latex mortars in brick and concrete block masonry construction is probably the first truly structural use of latex mortars and has been made possible by the development of Saran latexes. These applications range from large prefabricated brick masonry panels to full load-bearing applications of brick walls and roofs. Another structural application of LMC mortars is in construction of LMC faced sandwich panels. LMC mortars have also been used successfully in thin shell applications since 1965.

Latex modified concrete is the next logical step in the evolution of latex modification of portland cement systems. Since the only major difference between a mortar and a concrete is the maximum size of the aggregate, it is reasonable to expect similar improvements in the physical and mechanical properties.

Latex modification does indeed improve the properties of portland cement concrete. More importantly, this is achieved without any radical departure from existing concrete construction methods. And, the economics of these in-place systems are favorable. Although these concepts are yet in the research stage, the results thus far indicate that latex modification will find a definite place in the construction industry.

C140 Fletcher, K. E., and Roberts, M. H., "Effect of a Polyethylene Oxide Admixture on the Strength of Concrete," Concrete, Vol 5, No. 10, Oct 1971, pp 321-322.

Water-soluble polyethylene oxide resins which produce high-viscosity solutions are finding increasing application as admixtures in concretes and mortars, particularly as an aid to the pumping of fresh concrete and to assist in the incorporation of fibrous materials in concretes and mortars. They are mainly effective because they thicken the water present in fresh concrete and mortar and do not produce any appreciable entrainment of air.

This note gives some limited test results for the influence on the workability and compressive strength of a nominal 1:2:4 concrete produced by a polyethylene oxide ('Polyox WSR-301') admixture at high rates of addition of 0.05 and 0.10 percent by weight of cement. It was found that this admixture reduced the workability of the fresh concrete to some extent, but it had no effect on the rate of hardening or on the compressive strength for concretes stored either in water or in air at 65 percent relative humidity for periods up to 1 year. There seems to be a need for more information concerning the interaction between the workability and pumpability of concretes containing polyethylene oxide.

C141 Fuller, J. O., and Kriegh, J. D., "Maintenance and Repair of Concrete and Masonry Structures: Epoxy Pressure Grouting," p 65, Jul 1971, Arizona University, Department of Civil Engineering, Tucson.

Existing and revised methods used for pressure grouting cracked concrete and masonry were studied. Hand gun and pressure tank grout injecting equipment were studied as well as epoxy resin grouts. Jobsite visitations, laboratory, and controlled field tests were used as mechanisms to perform the evaluations. As a result of studying existing grouting techniques, materials and methods were selected for use in the laboratory and field. The best characteristics of several grouting methods were combined to develop a new technique. Grouting materials were selected on the basis of viscosity and bonding capabilities. Three systems were used for study.

C142 Furr, H. L., and Ingram, L. L., "Bond and Durability of Concrete and Resinous Overlays," Research Report 130-5, Apr 1971, Texas Transportation Institute.

Tests were made on portland cement and resinous concrete overlays to determine their suitability as overlays for deteriorated concrete bridge decks. Direct shear strengths of overlays bonded with epoxy, portland cement grout, and latex modified cement grout were compared with those applied with no bonding agent.

Freeze-thaw tests were made to determine durability of bonding agents and of overlay concretes. Load tests were made on 8-ft span beams to determine the stiffening effect of overlays and the effect of repeated loadings on overlaid beams. Durability was studied further by gradually lowering laboratory temperature to 20°F during periods of repeated load applications.

Shear bond strength ranged from 214 psi to 668 psi. Epoxy and portland cement grout bonding agents withstood the ASTM C-290 test without failure. Two of three overlays of latex modified cement concrete came unbonded during the ASTM C-290 test. Latex modified cement concrete overlay provided better freeze-thaw scale resistance than did other materials. No overlay failed in any way, except for tension cracks, in 2 million cycles of load.

C143 Graham, J. E., et al., "Evaluation of Concrete for Desalination Plants," Mar 1971, Engineering and Research Center, Denver, Colo.

Laboratory tests were conducted on concrete under temperature, pressure, salinity, and structural stress conditions similar to those which would be encountered in a seawater distillation plant. The program included tests of concretes containing natural coarse aggregate and crushed limestone coarse aggregate exposed to a variety of temperature-pressure-salinity conditions; structural studies; corrosion studies on reinforcing steel; and concrete microstructural investigations. Significant conclusions are: (1) untreated portland cement concrete is not suitable for use in flowing distilled water, or in synthetic seawater brine at 290 deg F; (2) untreated portland cement concrete is suitable for use in synthetic seawater brine to about 200 deg F without sacrificial concrete and in synthetic seawater brine, vapor, and nonflowing condensed vapor to 250 deg F when sacrificial concrete is provided; (3) crushed limestone is not suitable for coarse aggregate in concrete exposed to hot brines; and (4) corrosion of steel reinforcement is insignificant after 4 yr exposure to flowing, oxygen-free synthetic seawater brine.

C144 Husbands, T. B., Derrington, C. F., and Pepper, L., "Effects of Water on Epoxy-Resins Systems," Technical Report C-71-2, p 59, Sep 1971, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

The effect of continuous immersion in water on the tensile strength, tensile elongation, tensile modulus, flexural strength, flexural strain, and bond strength of five different epoxy-resin systems was evaluated. The water absorption of the five systems was also obtained. One of the systems will meet Federal requirements for epoxy resins and another contains the same system but includes sand as a filler. All of the physical properties of these two systems were deleteriously affected by storage in water and, therefore, the systems should not be used when the cured systems will be subjected to immersion in water for periods longer than 1 month. In addition, every effort must be made to protect these two systems from undue exposure to water. The test results also indicate that the use of a modifier in proper amounts will produce a large increase in strength and elongation and a large decrease in tensile modulus and water absorption. Two of the modifiers tested, polyimide and amidopolyamine, produced epoxy-resins systems which were not deleteriously affected by immersion. The testing errors determined in this investigation are given as a guide for testing the engineering properties of epoxy-resin formulations.

C145 Irtuganova, S. Kh., and Dudukalova, N. I., "The Protective Properties of Coatings Based on Thermosetting Plastics," Structural Chemically Stable Polymer Concretes, pp 96-103, 1971, Israel Program for Scientific Translations, Jerusalem.

The protective properties of coatings on concrete, consisting of polymer mortars or polymer concretes depend largely on their composition tightness and permeability, chemical stability, adhesion to the surface to be protected, and the effects and characteristics of the corrosive agents. These factors determine the durability and effectiveness of a given coating under certain composition, concentration, temperature, and action of the corrosive agent.

Research carried out by the Nevinomyssk, Shchekinsk, and Lisichansk plants producing nitrogen fertilizer has shown that the most characteristic corrosive agents are saturated urea solution, melts, and dust, dust and saturated solutions of ammonium nitrate, ammonium sulfate, and sodium nitrate.

Cold-hardening polymer-mortar compositions are used as protective coatings for floors in plants of the industries mentioned. These compositions are mixtures of an organic binder and a finely ground filler. The material was selected according to the chemical structure of the binder, which determines its stability in any given environment, and according to the nature of the filler.

We used phenolic resin B, whose stability is excellent in any environment other than alkaline, ED-5 and ED-6 epoxy resins, and furfural-acetone monomer, which are stable in all nonoxidizing environments.

The fillers were Marshallite and graphite which strengthen the polymer compositions, the former because it reacts with resins having functional hydroxyl, metaxyl, and epoxy groups through hydrogen bonds, and the latter because transverse bridge-like bonds and a continuous spatial network are formed from the particles of the filler.

C146 *Isenburg, J. E., et al., "Microstructure and Strength of the Bond Between Concrete and Styrene-Butadiene Latex-Modified Mortar," Highway Research Record, No. 370, pp 75-89, 1971, Highway Research Board, Washington, D. C.*

Various surface preparations were used in resurfacing concrete with a latex-modified mortar. A 1-in. mortar cap was applied to the circular surface of 14-day-old, high early strength concrete cylinders treated in various ways. After aging 14 days, several cylinders of each group were fractured in a shear bond test, and an unfractured cylinder was sawed to provide a 1/2-in. cube that included the interface between concrete and mortar. These cubes were fractured normal to the interface, producing a surface free of sawing artifacts. After they were examined in the scanning electron microscope, these sections were fractured again to simulate the shear bond test and then reexamined. Several performance variations are explained by the scanning electron photographs.

C147 *Kukacka, L. E., Colombo, P., Steinberg, M., and Manowitz, B., Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol No. 97, No. ST9, Sep 1971, pp 2217-2227.*

The development of concrete-polymer composites is under investigation in a joint research program being conducted at Brookhaven National Laboratory and at the Bureau of Reclamation, U. S. Department of the Interior. Remarkable improvements in the structural and durability properties have been obtained. The results from this program indicate that the composites may have many applications.

The program includes the development of methods of preparation of both preformed and premixed concrete-polymer materials. The former consists of precast portland cement concrete impregnated by a monomer system which is polymerized in situ. Polymerization of the monomer can be induced either by Cobalt 60 gamma radiation or by chemical initiators. Premixed concrete-polymer materials are made by adding monomer to portland cement, aggregate, and water during mixing of the cement or by mixing monomer with aggregate. Polymerization is then initiated.

#### Conclusions

(1) Using controlled matrix porosities and suitable monomer impregnation arrangements, capillary absorption followed by thermocatalytic polymerization vastly improved the properties of cement mortars.

(2) For glass- and especially for steel-fiber-reinforced mortars, a synergistic increase of tensile and compressive strengths was obtained by polymer impregnation. This effect is believed to result primarily from superior filament-to-matrix bonding.

(3) For glass fiber reinforcement to be effective, the filaments should be dispersed individually and uniformly to improve bonding.

(4) Filament reinforcement combined with polymer impregnation can result in a cementitious composite material which is strong, flexible, tough, impermeable, and corrosion-resistant.

C148 Ohama, Y., "Deformation of the Polymer-Modified Mortars," Proceedings of the Fourteenth Japan Congress on Materials Research, The Society of Materials Science, Japan, Mar 1971, pp 177-179.

Polymer-modified mortars contain various polymers (latex or emulsion-type) as ingredients of their binder, so it is expected that their deformation properties differ considerably from that of ordinary cement mortars. This is because the polymer ingredients in polymer-modified mortars generally have an effect on their various properties remarkably. In this paper, the stress-strain curves of various polymer-modified mortars are made using the tensile test results, and their deformation properties are discussed.

The conclusions obtained from the test results are summarized as follows:

(1) With the increase in the polymer-cement ratio, the modulus of elasticity of polymer-modified mortars decreases and gets smaller in the order of NBR, SBR, and PVAc-modified mortars at 10 percent or 20 percent of the polymer-cement ratio.

(2) With the increase in the polymer-cement ratio, the deformation of SBR and PVAc-modified mortars at the breaking point increases considerably and that of NBR-modified mortars has the maximum at about 10 percent of the polymer-cement ratio.

C149 Orbelin, S. I., "Resistance to Wear of Polymer Solutions and Polymer Concrete Based on Thermoreactive Resins," p 16, Jun 1971, Foreign Technology Division, Wright-Patterson AFB, Ohio.

The wear resistance was determined of several compounds based on epoxy resins ED-5, ED-6, E-37, and E-40, polyester resin PN-1, and furfural acetone monomer. The epoxy compounds were more resistant to abrasion by sandblasting than the other compounds. The maximum wear angle (alpha) of concretes in sandblasting is 90 degrees for the unfilled epoxy compounds. Alpha is similar to 30 degrees. The addition of 10 to 30 percent Thiokol NVT-1 to ED-5 decreases its wear resistance and shifts alpha to 60 to 75 degrees. The plastification ED-5 with 10 percent dibutylphthalate decreases its wear resistance, leaving alpha unchanged. Fillers increase alpha and decrease the wear resistance. The best fillers are metal powders and corundum.

C150 Patterson, H. L., "Use of Silicone Admixture in Bridge Deck Concrete," Highway Research Record, No. 370, pp 61-74, 1971, Highway Research Board, Washington, D. C.

This report is the third in a series that resulted from a cooperative study, originally started in 1963 and sponsored jointly by the Dow Corning Corporation of Midland, Michigan, and the Michigan Department of State Highways, to determine the effects of using a silicone admixture in bridge deck construction.

The basic liquid silicone admixture DC-777, which was developed by Dow Corning, altered the properties of plain concrete in the following ways:

1. It entrained air;
2. It excessively retarded the set;
3. It served as an internal lubricant, permitting a reduction in mix water;
4. It raised the unit strength; and
5. It increased the resistance to freeze-thaw deterioration.

Although two of the bridges developed some type of shrinkage cracks in the silicone concrete, it was not conclusive that the admixture's set retardation was the main cause; however, it could have contributed significantly in the high-porosity slag concrete that was cured with polyethylene film. The limestone concrete developed no shrinkage cracks, and the craze cracking in the gravel concrete was common to both the silicone and the normal concrete.

In general, the liquid silicone admixture DC-777B could be described as being beneficial to the concrete, particularly in retarding the formation of scale as observed on all three test bridges. Rapid freeze-thaw testing conducted in the laboratory revealed the treated concrete to have a superior resistance to internal freeze-thaw breakdown. Whereas the test bridges have shown the silicone concrete to be somewhat superior to normal concrete, they are not old enough at this time to establish a substantial superiority.

C152 Puchnina, E. A., and Moshchanskii, N. A., "Investigations of the Stability of FF-1F Phenolic-Furan Resin," Structural Chemically Stable Concretes, pp 90-95, 1971, Israel Program for Scientific Translations, Jerusalem.

This paper gives test results for some mechanical and physico-chemical properties of putties based on FF-1F resin.

FF-1F resin can be hardened at 15 to 20°C in the presence of acid catalysts such as n-toluenesulfochloride, n-phenylurethylanesulfochloride, N-chlorobenzene sulfacid, etc. This resin hardens more completely at higher temperatures; this affects the chemical stability and thermostability of the polymer compositions. We used n-chlorobenzene sulfacid for hardening the resin. This acid is very cheap, being a by-product in the manufacture of DDT, and has until now not been utilized sufficiently.

The filler used was graphite (waste material of electrode plants). The binder:filler ratio was 1:1.

The chemical stability of the putty was investigated on prisms measuring 10 by 10 by 30 mm<sup>3</sup>, held in various corrosive solutions. The stability was determined from changes in the appearance, weight, and bending strength of the prisms after they had been held in corrosive environments. Tests at normal temperature were carried out in a desiccator, and at high temperature, in a heating chamber.

C153 Readdy, A. F., Jr., "Applications of Ionizing Radiations in Plastics and Polymer Technology," Report for 1960-1970, p 268, Mar 1971, Plastics Technical Evaluation Center, Dover, N. J.

The actual and potential uses of high energy ionizing radiations in processing or modifying polymers, particularly plastics, are surveyed. Included are discussions of: those methods and end-products which have reached commercial status; advanced developments and pilot plant studies with well-defined market potential; and preliminary or prototype work which may eventually gain commercial acceptance. Details are given on irradiation technology, products modification (with resultant properties and related data) and overall process economics. These important topics are complemented by limited discussions of the physics and chemistry of the irradiated polymer substrates. The last section gives a few projections on developments in the technology which are required for further efficiencies and economies. Such developments will lead to accelerated acceptance of ionizing radiation methods and the resultant end-items.

C154 Shafer, H. H., "A Structural Restoration System for Concrete Surfaces," Special Report 116, pp 48-50, 1971, Highway Research Board, Washington, D. C.

Based on research investigations and field test installations, a three-step restoration system was developed as follows:

1. To prepare the substrate, a Tennant G-12 concrete scarifier removes the required 1/4-in. from the surface at the rate of 150 to 200 sq yd/hr.

2. This is the keystone to quality control in the production of latex-modified portland cement materials. A truck-mounted, automatic, continuous concrete mixer is positioned to discharge directly in front of the screeding device. We use 8-cu yd mobile machines that, when properly calibrated, automatically proportion and mix the cement, aggregate, latex, and water either continuously or intermittently as required. Mixing water is controlled by a flowmeter and can be quickly adjusted for variable moisture in the sand. A metering device with ticket printout measures and records the production of the machine.

3. As with any portland cement composition, the strength of latex-modified materials is influenced by the water-cement ratio. In order to place and consolidate low-slump, modified mortar to concrete in thin sections, a self-propelled, vibrating-beam, strike-off machine follows closely behind the mixer. We ordinarily place latex-modified compositions at a water-cement ratio on the order of 0.35. When the struck-off surface has been floated as needed for smoothness and textured for traction, it is generally ready for the curing cover. One layer of wet burlap with a layer of polyethylene over it has been found to provide adequate curing conditions during warm weather.

C155 Sivitski, I. B., Alekseev, S. N., and Klauson, V., "Latex Coatings for Corrosion Protection of Reinforcement on Autoclave Concrete," 1971; Chemical Abstracts, 12098C, Vol 75.

A composition consisting of SKS-65GP (35:65 butadiene-styrene) latex (dry material) 20, casein glue OB 6, portland cement 100, and water 35-37 parts showed much better protective properties than casein alone when used as corrosion protection of reinforcements in concrete.

C156 Smith, H. S., and Waling, S. J., "Lightweight Castable Materials for Housing Modules," HUD Contract No. H-1316, Oct 1971, The Dow Chemical Co. Functional Products and Systems, Midland, Mich.

This research was undertaken to develop a lightweight, (50 to 70 pcf) castable, fire-resistant material which would provide economic advantage and allow design flexibility when applied to three-dimensional modular building systems. The successful completion of this program has yielded results which promise to be of great benefit to the industrialized building industry. The use of lightweight concrete will stimulate the use of highly industrialized casting techniques in housing production and will provide economic, durable, fire-resistant housing which is desirable to the American public.

The material testing program identified the most promising material combinations as portland cement/water systems which utilize expanded ceramic aggregate as the dominant aggregate. Silica fines and saran microspheres as companion aggregates to the dominant ceramic component permit low density to be achieved while maintaining sufficient structural properties. Methyl cellulose and saran latex are modifiers which provide processing advantages which may be required for the modular application. Saran latex also provides exceptional material property improvement when high latex contents are used.



The research was organized in the following sequence to insure maximum material development.

(1) Determination of the criteria for material selection, and a broad review of all materials which might contribute to a lightweight castable system.

(2) Initial testing (screening) of material combinations to select those showing the most promise for this application.

(3) Intensive testing to determine the physical properties of the most promising material combinations.

(4) Structural analysis of the lightweight castable systems as applied to modular configurations.

(5) Economic evaluation of the castable materials as applied to three-dimensional modular building systems.

The range of material components evaluated during the program was very broad. Expanded ceramic aggregates, hollow micro-aggregates, perlite and conventional lightweight aggregates were evaluated. Portland cement/water combinations were selectively modified with either conventional air entrainment and water-reducing agents, saran latex or methyl cellulose. Cellular concrete systems containing saran latex and expanded ceramic aggregate were investigated. The several resin binder systems investigated were phenol formaldehyde resin, water extended vinyl ester resin, fire retardent polyester resin and thermosetting resin systems containing a high percentage of monomers.

C157 Smith, B., "Polymer Modified Cement Materials," Building, Vol 221, No. 46, 12 Nov 1971, pp 156-158.

Organic polymers are used as admixtures for cement mixes. They possess many of the properties lacking in inorganic cements, such as high tensile and flexural strength and good chemical resistance. It is, therefore, logical to consider polymer admixtures for applications where these properties are important and the increased cost would be justified. When used within the range of 10 percent to 40 percent of the cement in a mortar or concrete, a composite polymer-cement composition may be produced which retains the basic properties of unmodified cement mixes such as high general bulk strength, good general resistance to weathering and relatively low volume cost, but which now has to some degree the complementary properties of the modifying polymer.

A portland cement modified with Crodabuild 50, the result of a development programme aimed at the production of a low-cost copolymer emulsion, has the following general properties compared with an unmodified mix: cohesion and wet adhesion of the mix is improved, facilitating placing, compaction and finishing and minimising segregation and bleeding. The finely dispersed polymer particles in the mix contribute to plasticity and ease of working; thin surfacings may be applied, which develop optimum tensile, flexural and bond strength and abrasion resistance, in direct contrast to unmodified mixes; permeability is reduced or eliminated, increasing resistance to water penetration and eliminating freeze-thaw degradation; drying-shrinkage may be reduced.

C158 Strehle, K., and Geidel, H., "Synthetic Resin Dispersions for Increasing the Elasticity and Strength of Concrete," German Patent 1,471,376 (Cl C04b), 22 Apr 1971; Chemical Abstracts, 24776g, Vol 75, No. 4, 1971.

The elasticity and flexural strength of concrete mortars containing poly(vinyl propionate) (V) or poly(vinyl acetate) is further increased by addition of 0.5 to 10 percent water-soluble polyols including ethylene glycol (II), glycerol, and sorbitol. A concrete mix containing I and 0.5 to 10 percent II (based on emulsion weight) is treated with 200 to 500 volume percent water to form a concrete mix which has improved strength, workability, and requires a lower water-cement ratio than controls.

C159 Sussman, V., "Cementitious Plastics," Soc. Plast. Engrs., Ann. Tech. Conf., Tech. Pap. 2812, 1970; Chemical Abstracts, 6186, Vol 74, 1971, pp 72-74.

The addition of organic polymers to cement gave cementitious plastics that had improved adhesion, higher tensile strength, faster setting, and lower d. than conventional cements. For example, an epoxy emulsion 2, portland cement 3, sand 6, and water 1 part were mixed, trowelled into 2-in. molds, and allowed to cure 24 hr. The resulting compd. had specific gravity 1.8 and tensile strength 400 psi compared to a 2.1 specific gravity and 10-psi tensile strength for com. portland cement mortar.

C160 "Thin Polymer Concrete Overlay Tested," Engineering News-Record, Vol 187, No. 17, Oct 1971, p 22.

The first major test strip of a polyester resin overlay material is now under traffic on an access ramp to the New Jersey approach to the Lincoln tunnel under the Hudson River. The material can be spread thin, set in an hour and is as strong as the concrete below. It is rigid, can be formulated to match the elasticity and thermal expansion of existing concrete, and handles like no-slump concrete. Being more expensive, than asphalt or portland cement concrete, it appears not to be a suitable substitute. It is, however, less expensive and easier to mix and place than epoxies. Also, it is not sensitive to temperature and has a rough surface. Because an overlay is thin, there is no need to raise curbs, manholes, and catch basins and can be applied on bridges without significantly raising dead load.

C161 Wicht, P., and Volken, K., "Aqueous Synthetic Resin Dispersions as Additives for Mortar Mixtures," Ger Offen. Patent 2,061,797 (Cl C08f), 24 Jun 1971; Chemical Abstracts, 100955g, Vol 75, No. 16, 1971.

Aqueous vinyl chloride resin dispersions for improving the strength of mortars are prepared by copolymerizing 30 to 80 percent  $\text{CH}_2:\text{CHCl}$  with 20 to 70 percent polymerizable internal plasticizing monomers in the presence of aqueous phase containing nonionic and anionic emulsifiers,

catalyst, water-soluble solvents, water-soluble monomers, and buffers. The resin dispersions are alkali-resistant and the copolymers obtained have a glass transition temperature 15 to 25°. An aqueous phase comprising water, hexylene glycol, H<sub>2</sub>C:CHCO<sub>2</sub>H, nonionic emulsifier, anionic emulsifier, Na<sub>3</sub>PO<sub>4</sub> and K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> is treated with a monomer mixture comprising H<sub>2</sub>C:CHCl, vinyl propionate, and Bu acrylate and polymerized at 68 to 70° for 3 to 4 hr to yield a 53 percent solids dispersion containing 43 percent H<sub>2</sub>C:CHCl and with glass transition temperature 17°. The dispersion is treated with a silicone antifoaming agent and mixed with quartz sand and portland cement with a resin-cement factor of 0.125 and water-cement factor 0.380. The hardened mortar has tensile strength 6.0 kg/cm<sup>2</sup>. Other copolymers are prepared using vinyl acetate or dibutyl maleate as the internal plasticizing monomers.

C162 Yazev, R. E., "Selection of the Compositions of Polymer Mortars Protecting Concrete Against Cavitation Erosion," Structural Chemically Stable Polymer Concretes, pp 109-113, 1971, Israel Program for Scientific Translations, Jerusalem.

Investigations have shown that concrete based on cement offers little resistance to cavitation erosion (hundred times less than polymer mortars), so that it frequently becomes necessary to protect it against cavitation erosion. Metal linings of concrete are now being replaced in the U.S.A. by protective coatings of epoxy polymer mortars.

Studies carried out by the research section of Gidproekt have shown that the highest resistance to cavitation erosion is exhibited by ED-6 epoxy resin, plasticized by low-molecular NVT Thiokol, SKN-18 synthetic rubber, and MGF-9 and TMGF-11 nonsaturated polyesters. This material is used as base for the synthetic binder of polymer mortars.

#### 1972

C163 Beall, F. C., and Witt, A. E., "Polymerization of Methyl Methacrylate by Heat-Catalyst and Gamma-Irradiation Methods," Wood and Fiber, Vol 4, No. 3, Fall 1972, pp 179-184.

Methyl methacrylate (MMA) was bulk-polymerized with 0 to 4 percent crosslinker (ethylene glycol dimethacrylate, EGDM, and trimethylol propane trimethacrylate, TMPTM), initiated with 0.05 to 5 percent catalyst (Vazo) at 65 to 75 C or 0.1 to 1 Mrad/hr gamma radiation at 20 C. Heat-catalyzed MMA conversion to polymer versus time was obtained directly from polymer mass, which indicated that about 90 percent conversion had occurred at the exothermic peak temperature. The time to the exothermic peak temperature was used to determine sample polymerization time. The overall polymerization rate varied with the half-power of initiator concentration. An Arrhenius plot of the initiator-time data gave an activation energy of 18 kcal/mole. A log-log relationship was found between crosslinker concentration and polymerization time over the 65 to 75 C temperature and 0.1 to 0.4 percent initiator range. The crosslinkers were found equally efficient in reducing polymerization

time. Peak exothermic temperature varied directly with time, irrespective of the initiator and crosslinker concentrations or bath temperature, except as they affected time.

C164 Berman, H. A., and Chaiken, B., "Techniques for Retarding the Penetration of Deicers into Cement Pastes and Mortar," Interim Report, p 39, Dec 1972, Federal Highway Administration, Office of Research, Washington, D. C.

Several techniques were tried for limiting the penetration of deicing salts into concrete and thereby preventing the corrosion of reinforcing steel in concrete bridge decks caused by the presence of chlorides. Factors affecting the penetration of deicing salts were studied with hydrated cement pastes and mortars as the penetration medium. Salts tested were, in increasing order of degree of penetration: ammonium fluoride, sodium chromate, calcium chloride, effective retardation technique was impregnation with methyl methacrylate monomer and subsequent polymerization by irradiation. Part of the investigation also included efforts to develop means for reducing dangerous chloride levels already existent in concrete. A back-flushing technique was effective in reversing chloride penetration to a limited extent and efforts in this direction are being continued.

C165 Blum, W. E., "Bridge Deck Waterproofing in Ontario," TR50, 1972, Ontario Ministry of Transportation and Commerce.

This report presents the results of an investigation into the failure of waterproofing methods used on bridge decks in the Province of Ontario.

The waterproof decks selected for study included four different types of waterproofing; hot rubberized mastic asphalt (H.R.M.A.), the emulsion membrane method (E.M.B.), asbestos modified asphaltic concrete (A.M.) and the Uniroyal flexible membrane. None of these methods was completely effective as a waterproofing barrier.

The best methods, according to the results of this study, are the hot rubberized mastic asphalt and the Uniroyal flexible membrane. The other two methods lost most of their effectiveness as waterproofing barriers after the first year of service.

The reasons for the failures were varied, with the major single factor being the lack of attention given to those areas where surface water could enter and contact the deck, such as curbs, expansion joints and deck drains.

C166 Dotsenko, Yu. G., Belitskii, Y. L., and Moroz, V. N., "Quick-Setting Cement Resin Mix for Elimination of the Absorption of Drilling Fluid," Razved. Okhr. Nedr., Russia, No. 7, 1972, pp 53-54; Chemical Abstracts, 105133p, Vol 77, No. 16, 1972.

The quick-setting mix contained (wt. parts): resin TSD-9 50, water 100, formalin 20, cement 150, sand 150. The strength of the cement-resin mix after 4 hr is 18.4 kg/cm<sup>2</sup>, after 24 hr 18.7 kg/cm<sup>2</sup>,

after 30 days 34 kg/cm<sup>2</sup>. The strength increases and the setting periods are shortened with increasing amount of resin, cement, and hardening agent. The plugback mix was tested in the drilling of a well at a depth of 840 m with a zone of 100 percent absorption 20 m long.

C167 Frandistou-Yannas, S. A., and Shah, S. P., "Polymer Latex Modified Mortar," Journal, American Concrete Institute, Vol 69, Jan 1972, pp 61-5.

Polymer latex modified mortars are portland cement mortars to which polymer latex emulsions have been added during mixing. Mechanical and durability properties of modified mortars, the effects of curing history on modified mortars and latex films, and bond strength of modified mortar to plain mortar were studied. Significant improvements were observed in extensibility, bonding properties, and durability of mortar. Hence, mortar modified by latex emulsion may be useful for surface coatings, pavement toppings, and patching of damaged concrete. Higher volume changes during wetting and drying, lower modulus of elasticity, and lower compressive strength were observed for modified mortars. Although continuous wet curing reduces the strength of modified mortars, subsequent drying increases their strengths. For polyvinyl acetate emulsions, this was partly explained by the performance of latex films in saturated lime solutions.

C168 Ghosh, R. K., and Pant, C. S., "Use of Low Percentage of PVA as an Admixture to Cement Concrete," RILEM Symposium on Synthetic Resins in Building Construction, Paris, Vol 1, 1967, pp 91-104; Chemical Abstracts, 62835d, Vol 76, No. 12, 1971.

All work was done with  $\leq 3$  percent PVA [poly(vinyl acetate)], based on dry weight of the cement. The higher the PVA content, the higher the air entrainment, the shorter the setting time, and the higher the Poisson ratio. The highest compressive and flexural strength was obtained at  $\sim 2$  percent PVA. The increase in stress-strain and static modulus of elasticity was greatest at lower levels of PVA. PVA increased bonding strength to steel, freeze-thaw durability, and abrasive resistance. Microscopic examination showed a continuous cement gel phase.

C169 Keeton, J. R., Alumbaugh, R. L., and Hearst, P. J., "Concrete Polymer Composite for Military Underseas Facilities," Technical Note N-1230, Apr 1972, Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Mixtures of polymer-cement-mortar and polymer-cement-concrete were formulated with (1) epoxy, polyester, and epoxy-acrylate resins; (2) acrylic, vinylacetate, styrene-butadiene, and polyvinylidene chloride latices in varying proportions in relation to the weight of the cement. Both Type III portland and regulated set cements were used. Curing method included low pressure steam, high pressure steam, dry heat, and ambient laboratory air. Highest ratios of compressive

strengths of polymer-cement mixtures to similar mixtures without the polymer (control) were 3.0 for mortar and 3.5 for concrete, both at a test age of 1 day. Highest compressive strengths obtained for mortar were 10,740 psi at a test age of 7 days and, for concrete, 11,170 psi at a test age of 28 days. Control strengths for these ages were 4,490 psi and 5,080 psi, respectively.

C170 Mattiotti, P., "Use of Vinyl Derivatives in Mortars," (in French), RILEM Symposium on Synthetic Resins in Building Construction, Vol 1, 1967, pp 141-52; Chemical Abstracts, 49366g, Vol 76, No. 10, 1972.

The plasticity of mortars prepared with different amounts of some surface-active agents was related to the surface tension of the solution. Mortar specimens made with copolymers of vinyl acetate with vinyl propionate and butyl acrylate showed resistance to compressive and bending stress lower than those of the correspondent specimens containing vinyl acetate only.

C171 Mattiotti, P., "The Use of Polyvinyl Acetate Emulsions in Mortars," Translation No. 72-4, Apr 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

A first section discusses additives for mortars in relation to admixtures and resins used as binders instead of cement. After listing the fields of application of mortars modified by resins, the author classifies the usable products into the four groups of polymers to which they belong.

The second section of the report deals more particularly with polyvinyl acetate emulsions. The laboratory results concerning the mode of action in the mortar, and the properties that result from the incorporation of this resin are presented.

Information is presented concerning the water resistance of mortars with polyvinyl acetate which demonstrates that even in such a case the bond is constantly higher to that obtained with a mortar without acetate.

The last section, finally, is devoted to the practical conditions of use of polyvinyl acetates for mortars, with indications pertaining to the economic aspect of the question.

C172 Mazhara, P. I., Kharitonov, N. P., Kromikov, V. A., and Lyutyi, V., "Organosilicate Materials in Prestressed Reinforced-Concrete Structures," p 12, Aug 1972, Foreign Technology Division, Wright-Patterson AFB, Ohio.

The coatings used allow the application of the electrothermal prestressing process requiring a temperature of 300 to 400 C, or the steam-curing of concrete, and provide a good, long-lasting anticorrosive protection. The compositions, in form of fine suspensions of silicates and oxides in toluene solutions of polyorganosiloxanes VN-30 (STU-30-2943-66) and C 2 (TU 17-59), viscosity 20-5 sec on the VZ-scale, were spread on the reinforcing elements in three layers, and dried 30 to

40 min at 10 to 20 degrees to produce a 0.3- to 1.0-mm-thick coating. The elements, steel bars or strings, were used inside straight or curvilinear concrete products like blocks, slabs, or beams. A good strength, carrying capacity, and a lack of cracks were noted in the concrete products thus obtained.

C173 Ohama, Y., "Formulas of Estimating the Compressive Strength of Polymer-Modified Mortars," Proceedings of the Fifteenth Japan Congress on Materials Research, The Society of Materials Science, Japan, Kyoto, 1972, pp 151-153.

Based on laboratory tests a formula for estimating the compressive strength of polymer-modified mortars (except PVAC-modified mortars) having various mixing proportion can be proposed, regardless of the type of polymer and sand, as follows:

$$\log F = \frac{A}{B^{1/\alpha}} + C$$

where F : compressive strength of polymer-modified mortars (kg/cm<sup>2</sup>)  
α : "binder-void ratio" of polymer-modified mortars  
A , B , and C : constant.

The relation between 1/α and F of PVAC-modified mortars is exceptional, but can be expressed, regardless of the type of sand, by the following formula:

$$F = \frac{A}{B^{1/\alpha}} + C$$

where F : compressive strength of PVAC-modified mortars (kg/cm<sup>2</sup>),  
α : "binder-void ratio" of PVAC-modified mortars  
A , B , and C: constant.

C174 Perenyi, C., "Polymer Modified Mortars," RILEM Symposium on Synthetic Resins in Building Construction, Vol 1, 1967, pp 182-97; Chemical Abstracts, 49341v, Vol 76, No. 10, 1972.

Bending-tensile and compressive tests indicated that optimum dosage of both PVA (poly(vinyl acetate) Mowilith DM1H) and vinyl copolymer Vinitex is 10 to 20 percent by weight of cement. PVA mortars were superior to cement mortars by exhibiting optimum strength behavior at 45 to 50 percent relative humidity, practically eliminating the need for moist curing. After aging for 28 days PVA increased and vinyl copolymer decreased the bending-tensile strength; both resins reduced compressive strength. Polymer admixture increased abrasion resistance. Shrinkage of PVA-modified mortars exceeded that of cement mortars. Water absorption of polymer-modified mortars was about the same as that of cement mortars. Freezing-thawing cycle tests showed that polymer-modified mortars suffered a greater loss of bending-tensile and compressive strength in 28-day cycles, than polymer-free specimens, nevertheless final failure was protracted. Bond tests between concrete surfaces showed bonding of polymer-treated surfaces by polymer-modified mortars to be the most advantageous.

C175 Pike, R. G., and Hay, R. E., "Polymer Resins as Admixtures in Portland Cement Mortar and Concrete," p 57, Oct 1972, Federal Highway Administration, Materials Division, Washington, D. C.

The report covers the studies made of two admixtures for concrete that were investigated primarily for their use as overlays or as patching materials for bridge decks. The first, Epoxon, is a mixture of pozzolan and a two-component epoxy resin emulsion. The second, Tufchem, is an "organic water-soluble polymer". When compared with normal concrete, it was found that: Epoxon modified concrete exhibited increased strengths for concentrations of 20 percent epoxy resin or less based on the weight of the cement, satisfactory bond-to-concrete, and increased resistance to attack by sulfuric acid. Tufchem modified concrete exhibited increased early strength, increased early shrinkage, and decreased bond-to-steel and hardened concrete. Both materials showed adequate freeze-thaw resistance, resistance to scaling, to abrasion, and to skidding.

C176 Ranney, M. W., Berger, S. E., and Marsden, J. G., "Silane Coupling Agents in Mineral-Reinforced Elastomers," Paper No. 21-D, Feb 1972, Union Carbide Corporation, Tarrytown, N. Y.

Today, partial or complete replacement of carbon black with a silane coupling agent, in conjunction with extending or reinforcing fillers, approximates the performance properties of completely filled carbon black compounds. In addition, the use of silane coupling agents with mineral fillers in light-colored goods enhances the filler/polymer bond. As a result, the properties contributed by low-cost extending fillers can be modified or changed and the compounder is given greater control over all performance properties.

Unlike most additives, silane coupling agents do not adversely affect the hardness of the compound. They provide a desirable balance between dynamic and mechanical properties. Elastomers containing coupling agent approach or equal the hysteresis and mechanical properties of carbon black-filled elastomers. In the processing operation, coupling agents can reduce viscosity and shorten cure time.

C177 Rossetti, V. A., and Giavarini, C., "Mixtures of Inorganic Binders with Synthetic Resins - Note IV: Mortars and Cement Pastes Containing Epoxy Resins," Il Cemento, No. 4, Oct/Dec 1972, pp 223-236.

Cement pastes and mortars were studied containing epoxy resins in varying quantities from 2 to 30 percent by weight of cement. Two methods were found for adding the resin which eliminate the drawbacks caused by entrained air. The first is to add the resin as it is to the freshly prepared mortar; the second to make the mortar with sand which has been previously mixed with the proper quantity of resin. Test samples were prepared with constant and reduced w/c ratios (the reduction was made possible by the noteworthy fluidifying power of the resin). Tests were carried out of setting, flexural strength, compressive strength,



shrinkage, water absorption, acid attack with HF and HCl, both diluted and concentrated, and microscopy. Both methods achieved considerable improvements in mechanical and chemical resistance; adhesion increases considerably while shrinkage is practically eliminated.

C178 Shamsutdinov, A. F., Yusupov, I. G., Gazizov, A. Sh., and Garifullin, A. G., "Polymer-Cement Binding Material Used for the Preparation of Oil Well Mortar," USSR Patent 326,157 (Cl C04b), 19 Jan 1972; Chemical Abstracts, 38660t, Vol 77, No. 6, 1972.

The title binding material was prepared containing an oil-well cement 86-8, a polymeric component, such as a resorcinol powder, 8-9, and a setting agent, such as paraformaldehyde, 4-5 wt percent. The resorcinol powder was used to assure stability of the oil-well mortar during the storage period.

C179 Steinberg, M., "Paper-Plywood, A Paper Polymer Composite (PPC), BNL-16630R, Feb 1972, Brookhaven National Laboratory, Upton, N. Y.

In a development program being conducted in the Radiation Division of the Department of Applied Science at BNL for converting solid waste into useful construction materials, newspapers have been converted into a plywood-like board having considerable structural strength. Paper makes up the largest component of urban solid waste, reaching as high as 55 percent by weight of the nearly 200 million tons per year of waste discarded in municipalities in the U. S. Thus, the recycling of waste paper into an economical building material could make an impact both on the solid waste disposal problem as well as on the building industry.

The technique of laboratory production has generally been along the following lines. Newsprint is flattened out in a tray and a low viscosity monomer such as methyl methacrylate or a styrene diluted polyester polymer is poured over and through the paper to thoroughly wet and saturate it. The stack of wetted paper is pressed between two metal platens to squeeze out the excess monomer (~500-psi pressure) and the monomer is either polymerized in situ by chemical initiation or by radiation while the assembly is under pressure. A hardened paper polymer composite (PPC) is thus produced.

C180 Stewart, C. F., "Bridge Deck Restoration Methods and Procedures," Interim Report, p 51, Nov 1972, California State Division of Highways, Bridge Department.

Problems associated with restoration of deicing salt damaged decks of highway structures are discussed. Types of restoration, methods for selecting the type, contract quantities, repair materials and repair methods are covered. In addition, galvanic corrosion and its effect on deck restoration is also discussed. It is emphasized that a restoration is a cost/benefit expediency for gaining additional deck service life.

C181 Auskern, A., Prach, T., and Horn, W., "Thermal Analysis of Polymer Filled Hardened Cement Paste," BNL-16605, Feb 1972, Brookhaven National Laboratory, Upton, N. Y.

For abstract see NSA 26 18, No. 45069.

C182 Voronokevich, S. D., and Ogorodnikova, E. N., "Hardening Sand with Carbamide Resins," p 21, Sep 1972, Foreign Technology Division, Wright-Patterson AFB, Ohio.

Factors affecting bonding strength between artificial cement and sand grains in strengthened sands are considered in detail. Pure quartz sand and sands with ferruginous films strengthened by urea HCHO resins (48, 36, and 24 percent H<sub>2</sub>O solutions are tested) (as a hardener, a 50 percent HCl solution was used). For estimation of resin sand interaction, the moistening method was successfully used. Resin H<sub>2</sub>O solution moistened the sands poorly. Some moistening improvement was observed on introduction of small amounts (similar to 1 percent) of FeCl<sub>3</sub> and furfuryl alc. into the sand resin system.

C183 Vyazemskaya, N. I., Kalinin, E. V., and Blyakhman, E. M., "Polymer-Cement Mortar," USSR Patent 326,153 (Cl C04b), 19 Jan 1972; Chemical Abstracts, 38661u, Vol 77, No. 6, 1972.

To increase the adhesion of a polymer-cement mortar to the concrete surfaces at temperatures below 0o and to the wet surfaces of an underwater construction, a surface-active additive based on dimethylalkylbenzylammonium chloride (deriv. of C<sub>17</sub>=C<sub>20</sub> fraction) (I) was introduced into the mortar. Thus, the mortar contained: epoxy resin 100, cement 220-30, dibutyl phosphate 15-20, aminophenol 30-40, sand 220-30, and I 10-12 wt parts.

C184 Yudenfreund, M., et al., "Hardened Portland Cement Pastes of Low Porosity I. Materials and Experimental Methods," Cement and Concrete Research, Vol 2, No. 3, May 1972, pp 313-330.

The paper is the first of a series on hardened portland cement pastes of low porosity, prepared with water-cement ratios of 0.2 and 0.3. A Type I and a Type II clinker were ground to Blaine surface areas ranging from 6000 to 9000 cm<sup>2</sup>/g, using a variety of grinding aids, 0.5 percent of the weight of the clinker. The ground clinker was dry-mixed with calcium lignosulfonate, 1.0 percent and 0.5 percent of the weight of the Type I and Type II clinker, respectively. Potassium carbonate, 0.5 percent of the weight of the clinker, was dissolved in the mix water. The three additives, grinding aid, calcium lignosulfonate, and potassium carbonate, jointly produced excellent workability of the paste and satisfactory setting times with as low water-cement ratio as 0.2. Because of the low porosity, much higher compressive strengths and much lower dimensional changes were obtained than with "normal" cement

pastes, i.e., pastes made with water-cement ratios of 0.4 or greater. The first paper describes the materials used in the research and the experimental methods.

C185 Yudenfreund, M., et al., "Hardened Portland Cement Pastes of Low Porosity II. Exploratory Studies. Dimensional Changes," Cement and Concrete Research, Vol 2, No. 3, May 1972, pp 331-348.

The first part of this paper deals with the exploratory studies on low porosity portland cement pastes. The clinker grinding and paste preparation method are those reported in the previous paper in this series. With the appropriate kinds and amounts of grinding aid, lignosulfonate, and potassium carbonate excellent workability could be obtained. With different grinding aids, the 1-day compressive strengths of 1-in. cube pastes varied from 300 to 14,000 psi; the 28-day strengths were between 20,000 and 29,700 psi; and the 180-day strengths between 33,700 and 36,400 psi. The second part of the paper deals with the dimensional changes of 0.2 water-cement ratio pastes, hydrated at 25°C for 1 day and for 28 days. The low-porosity pastes showed one-third to one-half as large length changes as pastes made from the same cement with a water-cement ratio of 0.4, and one-fourth to one-third as large as those made with water-cement ratio of 0.6.

1973

C186 Aignesberger, A., "The Use of Anionic Melamine Resin as a Concrete Additive," Cement Lime and Gravel, London, Sep 1973, pp 188-192.

The preparation from melamine and formaldehyde of a new type soluble anionic melamine resin is described and its effect on the properties of concrete evaluated. The use of this resin considerably reduces the amount of water required in the mix and increases the compressive and flexural strengths of the concrete. There is not only a marked increase in the early strength, but also an improvement in the final strength.

These anionic resins also improve the durability of the concrete by increasing its density. The combined use of these new melamine resins with common water repellents considerably improves the moisture-repellent properties of the concrete, while at the same time increasing the strength factors.

C187 Akihama, S., et al., "Improvement of Mechanical Properties of Concrete Through the Addition of Latex," Polymers in Concrete, SP-40, pp 319-338, 1973, American Concrete Institute, Detroit, Mich.

It was found that the strain at maximum compressive and tensile stress of polymer-modified concrete became steadily greater with the increasing polymer content. Compressive strain was measured to be 140, 170, and 320 percent of plain concrete and tensile strain to be 170, 210, and 300 percent when polymer/cement ratio was 10, 20, and

30 percent, respectively. Toughness was measured to be 146, 182, and 205 percent of plain concrete when polymer/cement ratio was 15, 25, and 30 percent, respectively.

Experiments were carried out with shear walls made of the polymer-modified concrete in order to examine the improvement of ductility and toughness under the shear force. The wall specimens were panels of 132 by 193 by 3.7 cm. It was found from the experiments that ductility increased by 160 180 percent and toughness increased by 140 to 200 percent of the corresponding values for the ordinary concrete shear wall.

C188 Alumno-Rossetti, B., "Properties of a Binding Mixture Composed of Plaster and a Poly(vinyl acetate) Emulsion" (in Italian), *Rend. Accad. Naz. 40 (Quaranta)*, 1969, pp 20-21, 153-66; Chemical Abstracts, 168157v, Vol 77, No 26, 1973.

Binding mixtures of plaster of Paris and 2, 4, 10, and 20 wt percent poly(vinyl acetate) emulsion (I) were tested at different ages for compressive strength, setting, leaching in water, sp. surface, and by optical and electron microscopic examination, thermogravimetric anal., and isothermal calorimetry. The results are rationalized on the basis of a model in which at all percentages of I the films are very thin and discontinuous but at higher percentages are continuous and form pockets.

C189 Dahl-Jorgensen, E., and Chen, W.-F., "Stress-Strain Properties of Polymer Modified Concrete," p 20, Feb 1973, *Lehigh University, Fritz Engineering Laboratory, Bethlehem, Penn.*

The experiment was designed to investigate some of the structural properties of polymer modified concrete. Three- by six-inch cylindrical specimens were prepared and tested in simple compression and split tension to obtain the entire stress-strain relationship for this concrete. For the polymer-impregnated concrete (PIC), the monomer methyl methacrylate was used. Polymerization was done by the thermal-catalytic method with benzoyl peroxide and azobisisobutyronitrile to initiate polymerization. The concrete used in the experiment was dense and of high strength. With the use of 3 percent benzoyl peroxide complete polymerization was not achieved, leaving a central core in the specimens containing unpolymerized monomer. 0.5 percent azobisisobutyronitrile, however, gave full polymerization. The results obtained for PIC are comparable and confirm the improvements in properties of concrete observed by many researchers in this field.

C190 Dallaire, G., "Halting Deck Deterioration on Existing Bridges," Civil Engineering, *American Society of Civil Engineers*, Oct 1973, pp 80-86.

This article provides some guidance about what to do with the hundreds of thousands of existing bridge decks across the U. S. whose surfaces have potholes and salt build-up in their deck's concrete. Among promising solutions: overlay the deck with a membrane and asphaltic concrete wearing course; overlay with some other waterproofing system;

install a cathodic protection system; repair subsurface fractures by injecting polymer into the deck.

C191 "Dow Latexes 460 and 464 Improve the Properties of Portland Cement Mortars," *Technical Bulletin*, 1973, Dow Chemical Co., Midland, Mich.

DOW Latex 460 and DOW Latex 464 are designed specifically for use with portland cement in LMC mortars and are considered the standard of the industry for both interior and exterior placements.

This bulletin provides customers with basic information on latexes, LMC mortars, LMC formulations, placement procedures, and LMC mortar property evaluations. Our development and field personnel will work with customers in use of these latexes to help solve specific mortar and concrete problems.

C192 *Isenburg, J. E., and Vanderhoff, J. W., "A Hypothesis for the Reinforcement of Portland Cement by Latex," Polymer Preprints, Vol 14, No. 2, 1973, pp 1197-1202.*

Little is known about why latexes in general reinforce portland cement and why vinylidene copolymer latexes in particular give the best properties. The reinforcement is greater for those latexes that form continuous films upon drying, but even among these, the vinylidene chloride copolymers are superior. The styrene-butadiene copolymer latexes give properties which are only slightly inferior to those obtained with the vinylidene chloride copolymer latexes. The polyvinyl acetate latexes give properties equivalent to those of the vinylidene chloride copolymer latexes when the specimens are tested dry, but much lower values when the specimens are tested under moist conditions. The purpose of this paper is to present a hypothesis for the mechanism of reinforcement of portland cement mortar by latexes.

We propose a hypothesis comprised of four parts:

1. The substitution of latex for all or part of the water in the mix, to give fluidity at a lower water/cement ratio.
2. The deposition and coalescence of latex particles in a thin layer around each unhydrated (or slightly hydrated) cement grain and aggregate particle, to form an interpenetrating network of polymer throughout the structure.
3. The formation of microcracks throughout the structure to relieve the strains introduced by the shrinkage of hydrated portland cement which occurs when the relative humidity falls below 100 percent.
4. The intersection of a propagating microcrack with the interpenetrating polymer network to form microfibers spanning the microcrack, sometimes so effectively that the propagation is halted, but always so that the microcrack is held together.

C193 *Jenkins, G. H., "Internally Sealed Concrete, Phase I," 401 865, p 65, Mar 1973, Monsanto Research Corp., Dayton Labs, Dayton, Ohio.*

Investigation of internally sealing concrete by incorporating small particles of polymers and waxes at the time of mixing and subsequently warming to induce fusion and flow of these additives is reported. Five types of additive were evaluated using a constant portland cement concrete. Sealed specimens and standards were exposed to a saline solution for up to 90 days at constant (70 F) temperature and 30 freeze/thaw cycles. All additives evaluated showed a significant ability to block chloride and water penetration. The most successful, an ester wax, limited chloride penetration to about 0.05 percent in the top (exposed surface) 0.5 in. after 90-days exposure. By comparison, the unmodified concrete specimens reached a saturation content of about 0.40 percent in less than 7 days.

C194 Krukar, M., and Cook, J. C., "Studded Tire Pavement Wear Reduction and Repair, Phase I," Research Program Report, p 179, Dec 1973, Washington State Department of Highways, Highway Research Section, Olympia.

The report presents results obtained from testing at the G. A. Riedesel Pavement Testing Facility at Washington State University during the period from 11 February to 4 May 1972. The purpose of this project was fourfold: to determine pavement wear caused by studded tires; to evaluate the resistance of different pavement materials and textures used in the states of Washington and Idaho to wear caused by tire studs; to test pavement materials and overlays to reduce tire stud damage; and to study the effect of studded truck tires on pavements.

C195 Maes, G. P. J., et al., "Polymer Containing Plaster Compositions," Belg. Patent 777,477 (C1 B28c), 29 Jun 1972; Chemical Abstracts, 88230u, Vol 78, No. 14, 1973.

The mechanical properties of plaster, more particularly the d., resistance to bending and compression, are improved by addition of polymers and other aggregates. The polymers may be chosen from poly(vinyl acetate), poly(vinyl alc.), methylcellulose, and CM-cellulose. The aggregates may be chosen from powd. glass, thermoplastic materials, clays, schists, vermiculite, perlite and mixtures of similarly finely divided materials. In addition, the plaster may contain the usual additives consisting of alum, alk. metal sulfates, alginates, bentonite, diatomaceous earth, and carrageenates.

C196 Naus, D. J., et al., "Cost Performance Analysis of Portland Cement Concrete - Fibrous Polyester Concrete Material System," TR M-45, Jul 1973, Construction Engineering Research Laboratory, Champaign, Ill.

Structural and shielding costs for hardened facilities represent a substantial portion of the construction effort in both cost and time. Presently, the selection of a material is made a priori in favor of reinforced concrete and steel which places limitations on conceptual designs. Potential does exist for reducing construction time and cost

of hardened facilities by utilizing new material systems which have been successfully formulated to meet given functional and performance requirements. The material system investigated using analytical and experimental techniques consisted of a conventional portland cement concrete beam which had a layer of fibrous polyester concrete at the compression surface.

An experimental investigation was conducted to identify laboratory techniques for fabrication of the concrete-fibrous polyester concrete material system and to determine the effect of several parameters on the load-deformation behavior of concrete-fibrous polyester concrete beams. Experimental results were compared to analytical results and a good correlation was found to exist.

C197 Ohama, Y., "Study on Properties and Mix Proportioning of Polymer-Modified Mortars for Buildings," No. 65, Oct 1973, The Building Research Institute.

Recently, the practical research and development of polymer-modified mortars have advanced and various polymer-modified mortars have been extensively used as flooring, waterproofing material, adhesive, etc., in the field of building works in Japan.

However, the systematic studies on the polymer-modified mortars from the viewpoint of building engineering have hardly been reported so far. So the purpose of this study is to grasp systematically the properties of the polymer-modified mortars for buildings and also to establish the basis of their mix proportioning.

In this paper, the experimental researches on the properties and the mix proportioning of the polymer-modified mortars using various polymer dispersions (latexes or emulsions) are carried out in the following range:

- (1) Relation between properties and polymer compositions of polymer-modified mortars.
- (2) Relation between properties and polymer-cement ratio of polymer-modified mortars.
- (3) Properties of fresh polymer-modified mortars.
- (4) Properties of hardened polymer-modified mortars.
- (5) Mix proportioning of polymer-modified mortars.

C198 Teichmann, H., "Polymer Dispersions for Concrete and Mortars," Paper 10, Resins and Concrete Symposium, University of Newcastle Upon Tyne, The Plastics Institute and Institution of Civil Engineers, Apr 1973.

In addition to improving the processing properties, bonding properties and reducing the abrasion wear, the flexural strength/compressive strength ratio in particular should be increased. However, in addition to the purely mechanical strength properties, other factors of interest are improvement of resistance to oil, gasoline and water, and also greater resistance to chemicals, i.e., deicing salts. The setting properties of the cement must not be affected by additives and in addition, the high alkalinity of the cements must not hydrolyse the

polymer additives or cause corrosion of the steel reinforcement.

Modification with polymers can considerably influence crack formation in new concrete (in combination with old concrete). The elastic and plastic deformation and also flexural strength and tensile strength of the concrete are increased. For the builder this means that the addition of approximately 10 percent polymer will guarantee non-formation of shrinkage cracks.

Polymer additives can be employed to improve patching, levelling and finishing cements due to the high adhesive strength and for highly wear-resistant industrial floorings. In addition, the resistance to water, mineral oil and deicing salts, ensure a wide range of special applications.

C199 Wagner, H. B., "Polymer Modification of Portland Cement Systems," Chemical Technology, Vol 3, No. 2, Feb 1973, pp 105-108.

Addition of organic polymers to cement systems is made for a variety of purposes. With brick mortars, for example, the purpose may be to increase tensile or adhesive strength; with grouting compositions the objective may be to obtain a hard joint surface, and so on. This diversity of purpose leads to a like diversity in "mechanism of action" of the polymer component in cement systems.

At present there are four important types of polymer-modified portland cement systems: (1) Water-retentive grouts and mortars; (2) Fiber-reinforced concretes; (3) Polymer-impregnated concretes; (4) Polymer latex-modified mortars and concretes. In all, the loading of the polymer component may vary from as little as a few tenths of a percent (system 1), to 6 or 7 percent (system 3). Physical forms of the incorporated polymer include powder, fiber, monomer precursor, and aqueous polymer emulsion.

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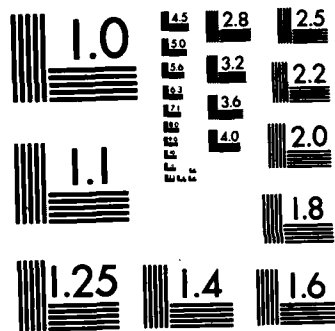
C200 Grenley, D., and Kuhlmann, L., "Chemical Resistant Resurfacing Mortar for Industry," Journal, Construction Division, American Society of Civil Engineers, Vol 100, No. C02, Jun 1974, pp 133-140.

While the addition of latex generally improves the performance of portland cement products, saran latexes are unique in delivering higher strengths, and retaining these strengths, under a wide variety of adverse exposures. The fact that the saran polymer itself is inert to a wide variety of agents is of importance. It is further believed that this polymer species is unique in providing an irreversible chemical bond within the cement paste, which contributes to its excellent performance. These properties assure superior performance of saran latex modified resurfacing mortars in a wide variety of chemical and mechanical exposure situations.

C201 Idorn, G. M., and Fördös, Z., "Cement Polymer Materials," Note, CEMBUREAU, Paris, Aug 1974.







MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

As a contribution to the 6th International Symposium on the Chemistry of Cement, Moscow, September 1974, Dr. G. M. Idorn, Chairman of the Cembureau Concrete Research Liaison Group, has submitted a Principal paper, in collaboration with Mr. Z. Fördös of the Aktieselkabet Aalborg Portland-Cement-Fabrik, Research and Development Division, Concrete Research Laboratory, Karlstrup, Denmark, on cement-polymer material.

In preparing the above paper, the authors have compiled a bibliography containing about 300 citations from literature available up to May 1974.

C202 *Isenburg, J. E., and Vanderhoff, J. W., "Hypothesis for Reinforcement of Portland Cement by Polymer Latexes," Journal, American Ceramic Society, Vol 57, No. 6, Jun 1974, pp 242-245.*

Vinylidene chloride and styrene-butadiene copolymer latexes are used commercially to reinforce portland cements. Although the technology is well developed, the mechanism of reinforcement is not well understood. A hypothesis is proposed to explain this reinforcement, i.e., (1) latex substitutes for all or part of the water to give the same fluidity at a lower water/cement ratio; (2) latex particles coalesce around each unhydrated (or slightly hydrated) cement grain and aggregate particle to form an interpenetrating network of polymer throughout the structure; (3) microcracks form throughout the structure to relieve the strain introduced by the shrinkage of the portland cement that occurs when the relative humidity falls below 100 percent; and (4) a propagating microcrack intersects the interpenetrating polymer network to form microfibrils spanning the microcrack, sometimes so effectively that propagation is halted, but always so that the microcrack is held together. This hypothesis was supported by scanning electron microscopy of latex-modified cement specimens, as well as by other experiments. More work is needed to determine how each part of the hypothesis contributes to the physical properties of latex-modified cement.

C203 *Macdonald, M. D., "Waterproofing Concrete Bridge Decks: Materials and Methods," LR636, 1974, Transport and Road Research Laboratory, England.*

From observations of bridges in service the necessity for waterproofing concrete decks has been identified and in 1965 a programme of research was undertaken to study and evaluate the materials and methods available. The requirements for waterproofing materials have been studied, both in the Laboratory and on bridge sites, against requirements for adhesion, stability, and thermal properties. Laboratory experiments to evaluate the resistance of the membrane system to substrate cracking and damage, by constructional work, to  $-10^{\circ}\text{C}$  and  $20^{\circ}\text{C}$  have been developed and standards of performance proposed. The problems of protection of the membrane against damage and of blistering are considered. Close liaison with the industry has led to the development of an increased range of materials, both of the prefabricated and applied in situ types, more suited to their working environment. A survey of over 30 bridges, in

service for about 8 years, has shown that waterproofing is generally satisfactory, but leakage can still occur through areas such as expansion joints. The importance of attention to the details of the waterproofing system and of good workmanship is emphasized.

C204 Meyer, A. H., "Polymer as Surface Treatment for Concrete," Journal, Structural Division, Proceedings, American Society of Civil Engineers, Vol 100, No. ST6, Jun 1974, pp 1205-1210.

It was determined in this research that a portland cement concrete surface could be treated with methyl methacrylate in monomer form and then polymerized in situ by natural sunlight. The penetration of the methyl methacrylate was 0.4 in. nominally with about 50 percent of the initial loading being polymerized in the concrete surface. The following conclusions were made: (1) It is feasible to use methyl methacrylate as a surface treatment for portland cement concrete; (2) such treatment will not significantly increase the strength characteristics of the concrete; (3) such treatment will significantly reduce the amount of water absorbed through the surface of the concrete; (4) such treatment will improve the durability of the surface; and (5) such treatment will reduce the skid-resistance of the surface.

C206 Piskarev, V. A., "Increasing the Durability of Concrete By Means of Aluminum-Methyl-Sodium Silicate," IRRD-103345, pp 31-32, 1974, Central Laboratory of Bridges and Highways.

The results presented demonstrate that the addition of a plasticizer (in an aqueous solution containing 33 percent of dry material), at the rate of 0.1 to 0.3 percent by weight of cement permits a reduction in the proportion of cement and of water (up to 10 percent), an improvement in workability, without strength of 10 to 90 percent with or without steam-curing. An explanation is given of the action of the plasticizer (water repellent, nonair entraining).

C207 Popovics, S., "Polymer Pavement Concrete for Arizona - Study I," ADOT-RS-10-144, Nov 1974, Arizona Department of Transportation, Phoenix, Ariz.

The report consists of three parts. In Part I a review of literature is presented concerning the combinations of polymers and concrete. The most important findings were that (1) as of 1973, reported investigations concerning the incorporation of polymerizable product into fresh concrete have been confined to limited and small-scale feasibility studies; and (b) disappointing results have precluded further investigations.

Part II presents four series of our own exploratory experiments as follows:

- (a) Experiments with four monomer systems;
- (b) PCC experiments with monomer + catalyst systems;
- (c) Experiments with a polyvinyl acetate emulsion; and
- (d) Concrete experiments with coated aggregates.

None of these experiments provided results that were good enough technically or economically to justify the continuation of these investigations on a larger scale.

In Part III the addition of urea-formaldehyde prepolymers to standard Ottawa-sand mortars was investigated. Certain combinations produced considerable increases in strengths. Thus, further investigations are justified but no implementation at this time.

*C208 Popvics, S., "Polymer and Portland Cement Concrete Combinations," Proceedings, Twenty-Third Annual Arizona Conference on Roads and Streets, The University of Arizona, Apr 1974, pp 107-124.*

This is a report that discusses all the presently available forms of the combinations of polymers and portland cement concrete.

1. Polymers are likely to occupy an important position in various engineering applications in the near future, including their combinations with concrete.

2. Hardened concretes impregnated with a suitable monomer system and polymerized in situ have shown tremendous improvement in various technically important properties of the concrete. Unfortunately, the technology of this method is quite complicated.

3. Polymer concretes, that is, aggregate particles bound with a suitable polymer, have also been used successfully. This kind of concrete has increased durability and chemical resistance, among other benefits. It is quite expensive.

4. Fiber reinforced concrete has been used for several years successfully in cases where high impact resistance is required or where it is important that the concrete hold together under load after cracking and fracture.

5. Polymer cement concretes are prepared by integrally mixing water solutions or emulsions of polymers, or pre-polymers or polymerizable monomers with cement and aggregate. These combinations of a polymer and concrete have great practical significance. Unfortunately, reported pertinent investigations have been confined to small-scale feasibility studies.

*C209 Seibert, G. M., "Extrusion of Corrosion Resistant Encased Strands," A report presented to the Department of Civil Engineering, University of Florida, 1974.*

The report evaluates the feasibility of using polymer-impregnated concrete to protect reinforced concrete from corrosion. It contains a review of the currently used method of protecting reinforced concrete from corrosion, and reviews work presently being done on polymer concretes. The proposed system consists of extruding a protective cover of polymer-impregnated concrete onto a prespressed strand. The polymer-impregnated concrete is highly impermeable and protects the steel. Tests were performed to evaluate the feasibility of polymerizing extruded concrete and to evaluate its strength and permeability properties.

C210 Smith, E. V., Gopan, J. L., and Bremner, S., "Evaluation of Membrane Waterproofing," *Mat. and Res. Technical Paper 73-1, Second Revision, Jun 1974.*

Laboratory tests were made on 19 membrane systems including our standard asphalt and glass fabric. The types tested fell into two categories as follows: reinforced and nonreinforced.

Uniroyal, although nonreinforced, does employ a flexible rubber material to cover joints and seal edges.

Protecto Wrap, Bituthene, and Nordel-Typar performed generally well enough in the laboratory tests to indicate field performance might equal or exceed that of our present system. They are written into our Special Provisions, 6 November 1972 (Appendix B). Protecto Wrap and Bituthene (because of low bid) were given field trial on northbound and southbound roadway, respectively, of I-295 structures over Fore River, South Portland in the fall of 1972. They are now both in wide use in Maine and the standard asphalt and glass fabric has been discontinued.

Mighty Plate 3000, Witmer 520, Triram PR-55CTP, Cationic Emulsion, Firestone, Fred A. Wilson, Edoco, Anti-Hydro Seamless, Keeper-Kote, and Royston No. 10 were rejected as not having satisfactorily met standard laboratory tests.

The others were accepted in the laboratory as worthy of field trial for simple span structures (where our former standard glass fabric and asphalt membrane has performed reasonably well).

The Polytok 165 Urethane did pass the cracked block test but bond to concrete after freeze-thaw testing was not overly good and it was restricted to simple spans until better means of sealing the edges have been developed.

C211 Stratfull, R. F., "Experimental Cathodic Protection of a Bridge Deck," *Corrosion and Corrosion Protection, Transportation Research Record 500, pp 1-15, 1974, California Department of Transportation.*

An electrically conductive asphalt concrete was made by substituting coke breeze for the natural aggregate. Paving a bridge deck with the electrically conductive asphalt concrete indicated that cathodic protection could be applied to the reinforcing steel. The cathodic protection was measured to be effective when the corrosion of steel strips embedded in concrete containing 10 percent calcium chloride by weight of the cement was stopped. It is estimated that, for the approximately 3300 ft<sup>2</sup> (307.6 m<sup>2</sup>) of bridge deck under cathodic protection, the top mat of reinforcing steel has an applied current density of 0.7 mA/ft<sup>2</sup> (7.5 mA/m<sup>2</sup>) of steel surface. The total current used is about 1.0 A with a driving voltage of 1.65 V for a total power requirement of 1.65 W. As an experimental method of repair, two polymers and an epoxy were injected to bond the undersurface fractures. The epoxy could be injected in all cases where the concrete emitted a hollow sound when struck with a hammer. However, the epoxy could not be injected when the concrete emitted a hollow sound from only the use of the chain drag but not from the use of the hammer. The cost of the cathodic protection installation is estimated to be about \$3/ft<sup>2</sup> of deck (\$33/m<sup>2</sup>).

C212 Stratton, F. W., and McCollum, B. R., "Repair of Hollow or Softened Areas in Bridge Decks by Rebonding with Injected Epoxy Resin or Other Polymers," Report No. K-F-72-5, 1974, State Highway Commission, Kansas.

The objective of this project was to develop a repair technique for bridge deck delaminations which could be used by highway maintenance personnel. The technique was to consist of injection of epoxy resin into the deteriorated areas to bond them back into one monolithic form with strength equal to or greater than the original deck.

Equipment has been developed which makes the injection of epoxy into bridge deck delaminations (hollow planes) practical. The equipment is simple in design and can be operated with a minimum of training. The operational procedure is given in the report. The equipment costs about \$2000 and plans are given in the report.

Four concrete crack grouting epoxies have been lab and field tested. All four can be injected into hollow planes, but only two are believed to be satisfactory and one of these appears to be best. A performance specification has been developed: The most satisfactory epoxy tested meets this specification; the other three do not.

#### 1975

C213 Aarset, I. R., et al., "Post-Cast Headers for Asphalt Concrete Surfacing at Expansion Joints of Highway Structures," Report No. CA-DOT-ST-4168-1-75-1, Feb 1975, California State Department of Transportation.

This report discusses the possible causes of problems with post-cast headers installed by contractors on California State Highway projects. The study consisted of an examination and evaluation of 178 headers constructed of various materials: epoxy-concrete, portland cement concrete, steel angles, urethane and several proprietary products. Portland cement concrete headers were found to perform reasonably well, but require additional set time before traffic loads can be applied. High alumina cement concrete, polymer concrete, and high strength quick-setting concrete show promise but have not been used in headers to date. Special header problems associated with snow areas are discussed.

C214 Allen, H. G., and Channer, R. S., "Some Mechanical Properties of Polymer Modified Portland Cement Sheets With and Without Glass-Fibre Reinforcement," *Polymers in Concrete*, The Concrete Society, London, May 1975, pp 282-289.

This paper describes work to modify the mechanical properties of cement paste in order to increase its ultimate strain in tension to a value more closely related to that of glass-fibre reinforcement. It was important that the modification should not also reduce the stiffness of the cement paste too much, because the high stiffness of the unmodified cement (compared with the stiffness of polyester resin) was regarded as a definite advantaged. Eventually an acrylic polymer emulsion was

chosen as the most promising admixture. It gave good tensile strength, large deflections at failure, and yet it retained a satisfactory initial modulus of elasticity.

Compared with a plain glass/cement composite, the polymer-modified glass/cement material (at  $s/c = 0.2$ ) has good values of ultimate stress and strain in tension (about  $14 \text{ MN/m}^2$  and  $6 \times 10^{-3}$ ). In compression, strength is reduced by the addition of polymer, but it remains satisfactory (over  $35 \text{ MN/m}^2$ ). In flexure the new material withstands stresses exceeding  $14 \text{ MN/m}^2$ , but performance is likely to be governed by deflection considerations.

The addition of polymer reduces the modulus of elasticity of the composite from perhaps 14 to  $5.5 \text{ GN/m}^2$ , and it also encourages creep, which is significant in the new material.

The polymer helps to produce a very fluid wet mix, which considerably simplifies the task of producing good quality composites. In the hardened state, the composites have an attractive smooth finish and are easy to machine.

C216 Bell, R. L., and Dingley, R. G., "The Mechanical Properties of Hydrated Portland Cement Pastes Modified with an SBR Polymer Latex," Polymers in Concrete, The Concrete Society, London, May 1975, pp 162-167.

The work reported forms part of a study of the interrelationship between mechanical properties and microstructure of cement pastes modified by the addition of a styrene-butadiene polymer-latex to the gauging water. Experiments were confined to cement pastes made at a fixed water/cement ratio of 0.35/1 but containing volume fractions of polymer,  $v_p$ , ranging from 0 to 30 percent. After setting, the specimens were placed under water to cure for either 28 or 180 days. Those cured for 28 days were divided into two batches for testing: those in the first batch were tested whilst fully saturated with water, those in the second were dried to 50 percent relative humidity before testing. The samples cured for 180 days were all tested in the fully saturated condition. Measurements of the elastic modulus, ultimate strength and elongation were made in compression, tension, and bending modes of testing.

C217 Carroll, R. J., "Continuing Field Evaluation of Membrane Waterproofing for Concrete Bridge Decks," Interim Report, Jan 1975, Bureau of Research and Development, Ohio.

This report presents the results of electrical resistivity testing, made in the field and on core samples, of membrane installations. It summarizes the results of such testing on the different products used in Ohio with lengths of service up to 7 years, discusses the condition and apparent effectiveness of existing installations; includes recommendations as to the use of specific membranes and comments on installation.



C218 Clear, K. C., and Ormsby, W. C., "Concept of Internally Sealed Concrete," Interim Report No. FHWA-RD-75-21, Mar 1975, Federal Highway Administration, Offices of Research and Development, Washington, D. C.

A promising new process for internally sealing concrete, which prevents the intrusion of chlorides from deicing operations or marine environments and the subsequent deterioration of the concrete, was developed by Monsanto Research Corporation under an FHWA contract. The work is described in Report FHWA-RD-75-20, "Internally Sealed Concrete," by G. H. Jenkins and J. M. Butler.

This report is intended as a supplement to the above publication. The work was performed to further document the concept of internally sealed concrete and to provide independent evidence that the wax particles which are mixed into the fresh concrete do, upon heating, migrate into the capillaries and voids of the concrete matrix.

The scanning electron microscope and an energy dispersive x-ray attachment were used to study heated and unheated concrete containing 2 percent montan wax. The conclusion was that montan wax, when melted, will migrate within, and thoroughly coat, the surrounding concrete matrix.

C219 Cook, D. J., "Hydration Characteristics of Premix Polymer Cement Materials," Polymers in Concrete, The Concrete Society, London, May 1975, pp 144-150.

In this paper the interaction of the monomer (and subsequently polymer) and the hydrating cement are investigated by conducting not only compressive strength tests on the premix polymer mortars but also setting time and hydration studies of premix polymer cement pastes.

C220 DeVekey, R. C., "The Properties of Polymer-Modified Cement Pastes," Polymers in Concrete, The Concrete Society, London, May 1975, pp 97-104.

Fourteen polymer dispersions were investigated to determine the effect of polymer type on the density, elastic properties, and flexural strength of cement paste. Also, the effect of polymer solids/cement ratio on the same properties was studied for a "hard" polymer and a "soft" polymer.

It would appear from the results of this study that for applications such as in situ flooring, where low stiffness is an advantage, cement pastes modified by pure acrylic or methacrylic copolymer dispersions should be suitable. For materials such as fibre-composite components, where high stiffness is desirable, the use of styrene acrylic or polyvinylidene copolymers may be preferred.

C221 Eash, R. D., and Shafer, H. H., "Reactions of Polymer Latexes with Portland Cement Concrete," Polymer Concrete, Transportation Research Record 542, pp 1-8, 1975, Washington, D. C.

This paper explains the physical and chemical actions and reactions of polyvinylidene chloride and styrene-butadiene polymer latexes on the aggregate and portland cement in concrete. It also describes how the polymer particles irreversibly bond to the aggregate and cement, form a monolayer of plastic particles over their surfaces, and subsequently coalesce to form a continuous polymer phase throughout the concrete. The need for curing procedures with latex concrete different from those required for the optimum care of conventional concrete is also discussed. These basic data are expanded to explain how polymer latexes reinforce concrete, improve its structural properties, control its elastic behavior, and greatly enhance its durability.

C222 Hughes, B. P., and Guest, J. E., "Polymer Modified Fibre-Reinforced Cement Composites," Polymers in Concrete, The Concrete Society, London, May 1975, pp 85-92.

Polymer fibres such as fibrillated polypropylene are more efficient at fracture in a cement paste matrix than in a mortar matrix, whether the matrix is impregnated or not. The reverse is generally true for steel fibres. Polymer premix mortar, however, improves the efficiencies of all fibres compared with the normal mortar.

Polymer-impregnation of cement paste is more difficult than with mortar and tends to produce little if any improvement in elastic stiffness, due to increased fibre efficiency before 'first crack', in either cement pastes or mortars. The increased Young's modulus for impregnated fibre-reinforced mortars is due almost exclusively to the increased Young's modulus for the matrix.

Polymer-impregnation without fibres gives a material with a brittle type of fracture. But when used in conjunction with the most suitable steel fibres it can give outstanding increases in toughness - up to 70 times the corresponding impregnated plain mortar for 2 percent (by volume) of fibres.

C223 Idorn, G. M., "Polymeric Materials for Concrete," Journal of Testing and Evaluation, Vol 3, No. 5, Sep 1975, pp 355-358.

Session III-9 of the VI International Congress of the Chemistry of Cement (held in September 1974 in Moscow) dealt with cement-polymer materials, or, as it appears from the papers presented, with various types of composites using ordinary cements and organic monomers together as binding materials.

Both the manufacture and the characteristics of these materials open up new potentials and problems to technology and construction development: potentials, because the excellent functional capabilities that can be attained with these composites will be much needed in further technical development; problems, because civil engineering has come to know ordinary cements and concrete quite well over a period of about 150 years' evolution, but is not as familiar as yet with these materials' development based upon modern scientific research.

This paper presents the "pros and cons" of this entirety, based upon the contents of the principal paper "Cement-Polymer Materials," by

G. M. Idorn and Z. Fördös, presented to the above session of the Cement Chemistry Congress.

C224 Inoue, S., "Durabilities of Cold Setting Epoxy Resin Mortars," Polymers in Concrete, The Concrete Society, London, May 1975, pp 191-194.

Paper describes experiments conducted to find the accelerated weatherability, heat-resistance, and water-resistance of test specimens made by jointing of successive pours of epoxy resin mortars onto cement mortar.

Durabilities of joints of cement mortar and epoxy resin mortars are comparatively affected by the water which seeps up to the interface of cement mortar and epoxy resin mortars through construction of cement mortar, and the degrees to which this occurs differ considerably according to the kinds of binders. Bond strengths increase somewhat with exposure in the case of some binders.

C225 Inoue, S., "Strength Development of Cold Setting Epoxy Resin Mortars," Polymers in Concrete, The Concrete Society, London, May 1975, pp 185-190.

Three experiments were conducted to determine (1) the relationship between the kinds of binders and tendencies of strength development of epoxy resin mortars, (2) the influence of fluctuating curing temperatures on short-term strength variations in long periods.

Many kinds of epoxy resin mortars were discovered which have better strength development in  $-6^{\circ}\text{C}$  than that of epoxy resin mortars of universal type in  $+20^{\circ}\text{C}$ , and have no problems in working properties, odour, and virulence.

The following facts were ascertained by the experiment designed to select the best epoxy resin mortar: practical strengths can develop even if they are exposed in  $-15^{\circ}\text{C}$  in the early state of curing; curing times necessary to attain maximum strengths were 0.5 to 4 months, and they differed with the kinds of strength; every strength is slightly decreased after attaining maximum strength.

C226 Jenkins, G. H., and Butler, J. M., "Internally Sealed Concrete," FHWA-RD-75-20, Jan 1975, Federal Highway Administration.

A process for internally sealing concrete was developed which prevents intrusion of chlorides and other corrosive compounds. Small particles of an inert thermoplastic sealant added to the initial concrete mix are later triggered by warming to fuse and flow into the fissures and capillaries of the cured structure. A low cost sealing additive, a blend of 25 percent ester wax and 75 percent paraffin, was developed which fuses at moderate temperatures and, at 2-1/2 percent concentration, completely blocked chloride penetration through 90-days ponding with a 3 percent NaCl solution. Particle shape was shown to affect the compressive strength of sealed concrete, and a process was developed to produce additive spheres for maximum strength.

C227 Mangat, P. S., and Swamy, R. N., "Properties of Polymer Modified Plain and Fibre Reinforced Concrete," Polymers in Concrete, The Concrete Society, London, May 1975, pp 296-299.

This investigation presents a wide range of structural properties of polymer-modified concrete and fibre-reinforced concrete systems. An acrylic polymer, in a water emulsion form, was used throughout to modify the concrete.

C228 McKeel, W. T., and Tyson, S. S., "Two-Course Bonded Construction and Overlays," Journal, American Concrete Institute, Vol 72, No. 12, Dec 1975.

Two-course construction has been suggested as an approach to preventing the spalling of concrete bridge decks. Under this procedure the deck is formed and concrete is placed to a level about 0.5 in. (13 mm) above the top mat of reinforcing steel. This first course is screeded, but no attempt is made to meet normal surface tolerances. When the first course has gained sufficient strength, a second course providing 2 in. (51 mm) of cover over the steel is placed to serve as a riding surface. Great attention can be paid to the quality of the relatively small amount of top course concrete, in both its mix proportions and placement.

The paper presents several advantages inherent in two-course construction, reviews the performance of similar concrete overlays commonly used in the maintenance of existing decks, and suggests materials, including latex-modified portland cement concrete, for use in the important top course.

C229 Ohama, Y., "Strength of Polymer-Modified Mortars Using Super High Early Strength Cement," Polymers in Concrete, The Concrete Society, London, May 1975, pp 151-156.

The object of this study is to examine the strength of various polymer-modified mortars using special super high early strength cement as compared with those using normal portland cement and grasp their possibility of applications to building and construction works.

The conclusions obtained from these experiments are summarized as follows:

(1) The bending and compressive strengths of polymer-modified mortars using special super high early strength cement are considerably larger than those of polymer-modified mortars using normal portland cement, regardless of the curing conditions and the age (except PVAC-modified mortar). Especially at the age of 6 hr or 1 day, this trend is remarkable.

(2) Comparing the difference between the curing conditions at the age of 28 days, the most suitable curing condition for polymer-modified mortars using special super high early strength cement is the combined air and water cure such as 2-day-20°C-moist, 5-day-20°C-water, 21-day-20°C-50 percent R.H.-dry cure, like those using normal portland cement.

(3) The bending and compressive strengths of SBR or PAE-modified

mortars using special super high early strength cement increase as the polymer-cement ratio increases, regardless of the curing conditions and the age. However, PVAC-modified mortar using special super high early cement gives an inverse tendency.

C230 Okada, K., et al., "Methods of Test for Polymer Cement Mortar," Polymers in Concrete, The Concrete Society, London, May 1975, pp 131-136.

The test methods tentatively specified and the procedure and results of joint tests are described, and some comments are presented on establishing standard test methods for polymer-cement mortar. Tentative test methods include selection of materials, mix proportion, moulding and curing, flexural and compressive strengths, water absorption, water permeability, initial setting shrinkage, dry shrinkage, adhesive strength, extensibility, abrasion, water retention, and resistance to chemicals.

C231 Pomeroy, C. D., and Brown, J. H., "Tailoring Fiber-Concretes to Special Requirements, Proceedings, RILEM Symposium on Fiber Reinforced Cements and Composites, Sep 1975.

Flexural tests were made on a range of polymer (PMMA) modified mortar beams that were reinforced with up to 1.5 percent volume of brass-coated steel fibres (0.13 mm dia by 15 mm long). The load deflection curves show clearly how even 0.5 percent of the fibres changes the failure from abrupt to docile. The stress at which first cracking was detected was almost independent of the fibre inclusion but it increased with polymer content.

The general conclusion from this work is that steel fibres can add ductility to a brittle polymer modified mortar, the presence of polymer apparently enhancing the bond between fibre and matrix.

C232 Pomeroy, C. D., and Brown, J. H., "An Assessment of Some Polymer (PMMA) Modified Concretes," Polymers in Concrete, The Concrete Society, London, May 1975, pp 9-13.

When judging the merits of polymer modified concretes, it is important to relate their properties to the best that can be obtained from conventional concretes and not just to those of the control mixes used. When this is done, it is found that there is a relatively small benefit to the compressive strength or elastic modulus to be gained from the polymer treatments, but that higher flexural strengths can be obtained, albeit with some unwelcome brittleness. This brittleness can be reduced by the inclusion of steel fibres. But the double treatment makes the resultant material very expensive and possibly an order of magnitude dearer than plain concrete. It seems, therefore, that the high strength properties are unlikely to be widely used, but that there may be particular applications when the extra cost is justified.

The greatest potential of the polymer treatment lies in the improved resistance that can be provided to the action of certain

aggressive fluids, such as sodium sulphate or hydrochloric acid. Although polymer treatments have been claimed to improve freeze-thaw behaviour, much the same improvement can be achieved from good mix design and air entrainment.

C233 Rio, A., "Cement Products," Chemical Abstracts, U. S. Patent 3,885,979 (CL 106-89), 27 May 1975.

A process for the manufacture of cement products with a very high mechanical resistance, wherein products manufactured with portland cements or with mixtures comprising from 50 to 90 percent of portland cement and from 50 to 10 percent of reactive siliceous materials are submitted, after the usual preaging at environment temperature, to a treatment with steam under pressure and subsequently to a thermal treatment in an anhydrous environment and cement products with a very high mechanical resistance, manufactured with the above process wherein they comprise a high content of hydrated calcium silicates corresponding to the tobermorytic form 11 A. The products can be impregnated with a polymerizable substance which is polymerized inside the products themselves.

C234 "Storage and Handling of Acrylic and Methacrylic Esters and Acids," Technical Bulletin, 1975, Rohm and Haas, Co.

The purpose of this bulletin is to furnish a complete guide for the safe storage and handling of Rohm and Haas monomers, including the acrylic and methacrylic esters and acids, at minimum cost.

Rohm and Haas also provides Material Safety Data Sheets offering condensed recommendations for the protection of personnel from the hazards of individual acrylic monomers. These sheets, which are available on request, outline the main hazards which these chemicals may present, such as fire, explosion, and health hazards, and give brief procedures for combatting these hazards, protecting personnel, providing first aid, and disposing of spilled material and vapors.

C235 Williams, P., and Jacobs, G. A., "Current Use and Application of Polymer Cement," Polymers in Concrete, The Concrete Society, London, May 1975, pp 367-374.

The combination of unsaturated polyester resins and portland cement to provide a polymer cement resulted from consideration of applications where neither material was individually suitable.

Compositions, typical properties, and uses are described for two mortar mixes, a slurry mix, and a concrete mix, all containing polymer cement.

C236 Wood, L., "Use of Polymer Modified Concrete for Strata Control in Deep Level Mining," Polymers in Concrete, The Concrete Society, London, May 1975, pp 397-402.

In an effort to improve concrete ductility, a program was initiated which included the addition of polymer latices to the cement, aggregate, and water at the mixing stage. Within the range of polymers examined, elastomerics, which are known to produce semi-flexible products, gave promising compositions. Of this class, natural polyisoprene was found to be the most efficient admixture for lowering the modulus and overcoming crumbling of the concrete on compression.

Over a series of tests, packs were produced with increasing load-bearing characteristics, the simplest being a 1-in. sandwich of polymer mortar between reinforced concrete beams. An undesirable characteristic of this pack is the shedding of load after the initial stiff response; otherwise this appeared to be promising. Although the site tests are not sufficiently advanced for any definite conclusions to be reached, the initial results appear favourable.

1976

C237 *Federal Highway Administration, "Bridge Deck Protective Systems (Membranes, Mastics, Polymer Concretes, and Special Portland Cement Concretes)," Interim Report NEEP No. 12, Mar 1976, Washington, D. C.*

Although a great deal of research and information is available on polymer concretes and polymer-impregnated concretes, operational application of most types is not a reality at this time. In place polymer impregnation of bridge decks has been accomplished in Colorado, Idaho, and California and is planned for Texas and West Virginia. However, Polymer Modified Concrete (PMC) is the only operational polymer type with widespread satisfactory use. The modifier is not proprietary, but it is currently manufactured only by DOW Chemical as SM-100 Modifier A and installed by licensed contractors. Cost dictates that PMC be used in a two-course system as the top course over the structural concrete and deck steel.

Internally sealed concrete (ISC) has been used very successfully in the laboratory to restrict chloride penetration into concrete slabs. FHWA research reports are available describing the ISC system. Several full-size slabs and decks have been placed with apparent success.

C238 *Chernyshev, Iu. P., Frolova, M. K., and Ozhiganov, I. I., "Using Multicomponent Coatings Made from Bitumen-Rubber and Polymer Portland Cement Materials for Waterproofing Pumping Stations and Foundations of Industrial Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.*

New designs for multicomponent coatings based on bitumen-rubber and polymer portland cement materials were developed by the Donets Promstroiniiproekt; these coatings are to be used instead of the labor-intensive backing-board type waterproofing with a protective brick

vener wall for insulating pumping stations and the buried parts of industrial buildings and structures.

The polymer portland cement compound is a mixture of portland cement, sand, synthetic latex, an emulsifying agent, and a stabilizing agent. A solution of sodium silicate with  $\gamma = 1.2 \text{ g/cm}^3$  and a 5 percent solution of sodium fluosilicate are used as the stabilizing agents for the synthetic latex. A surfactant additive (DB wetting agent) serves as the emulsifier in this case.

The use of special systems of stabilizing and emulsifying additives permits the production of polymer portland cement compositions of high homogeneity and long working life. This makes it possible to apply them to the surface mechanically under the conditions at the construction site.

Coatings based on polymer portland cement compound have adequate impact strength (not less than  $25 \text{ kgs/cm}^2$ ), adequate adhesion (not less than  $20 \text{ kgs/cm}^2$ ), and adequate resistance to weak solutions of acids, salts, and alkalis.

The main purpose of the polymer portland cement coating is to protect the waterproofing layer made from bitumen-rubber compound from mechanical damage during backfilling operations. In addition, the use of a polymer portland cement protective layer permits the labor expenditure for  $100 \text{ m}^2$  of surface to be reduced to 10 to 12 man-days, the work time to be reduced by 20 to 30 percent, and a savings of 300 to 360 rubles to be realized.

Multicomponent coatings made from bitumen-rubber and polymer portland cement compounds have been used for waterproofing the underground parts of cooling towers, pumping stations, tunnels, and foundations of industrial structures during construction of the facilities for the Avdeevka coke-chemical plant, on an area of more than  $25,000 \text{ m}^2$ .

*C239 Frait, T. M., et al., "Study of Polymer-Portland Cement Concrete for Cavitation Protection in Hydraulic Engineering Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.*

One of the most effective measures for enhancing the cavitation resistance of portland cement concretes is the introduction of polymer additives.

The great advantage of concretes with polymer additives is that it is possible to use standard production technology (with standard equipment); also, the consumption of polymer is very low (2 to 4 percent).

It has been demonstrated that adding polymers to concrete improves its properties. In particular, coarseness is reduced and the following parameters are increased: strength, ductility, crack resistance, adhesion of the cement binder to the aggregate, and adhesion of newly laid concrete to previously laid concrete.

The purpose of these studies was to develop a cavitation-resistant material (consisting of polymer-portland cement mortar and concrete) which could be placed in the conduits of hydraulic engineering structures



in the form of a protective surface layer of concrete 10 to 25 cm thick.

The main trend in the investigations was to study a means of mixing the polymer additive into the mortar and concrete, namely treating the aggregate and then mixing it with slurry.

C240 Khasin, B. F., "Reinforced Elastics (Based on Liquid Rubbers) for Energy and Water-Resources Construction," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

Research conducted since 1964 in the Gidroproekt NIS has resulted in the development of elastic binders based on Thiokol and liquid carboxylate rubbers, along with bonding reinforced elastoplastics based on these binders. These elastoplastics are coming into wider use for sealing expansion joints, for installation of continuous watertight revetments, and for crack-resistant coatings.

Tests conducted in the laboratory and at test sites have demonstrated the high strength, deformability, and waterproofness of the materials which were developed, as well as their water resistance and frost resistance, weatherproofness, and resistance to variable wetting-drying, freezing-thawing, and corrosive environments. Their service life in the zone of variable water level is not less than 20 to 25 years; in the absence of solar effects it is 50 years.

Their application is particularly effective for structures which are not crack resistant, units with complex geometry, joints, and corner joints. The reinforced elastoplastic with an elastic undercoat, which was developed for AES (nuclear power plant) conditions, has high (and stable) adhesion to steel and concrete in boiling water and in the use environment (temperature +60°C, humidity 97 percent, periodic emergency conditions with temperature +150°C, humidity 100 percent). It has been shown experimentally that the bonding reinforced elastic increases the fracture resistance of the concrete which is sealed with it, and reduces the checking frequency and crack size significantly. Reinforced elastic revetments were used for sealing three large-scale models (1:20) of the reinforced concrete protective housing of the fifth unit of the Novovoronezhskii AES; complete tightness was demonstrated by multiple testing at internal emergency pressure (0.5 MPa). Crack size reached 0.3 mm. In 1974 similar revetments were completed in a set of rooms in the Kursk AES.

The bonding reinforced elastics are used for antiseepage measures in the Kaunas GES (where they have been used successfully under a head of 35 m since 1970), in the Nizhne-Svirsk GES (in use since 1971 under a head of 21 m), the Verkhne-Svirsk and Votkinsk GES, the Mozhaisk hydraulic development, the Dneprodzerzhinsk lock, and other structures.

C241 Kisina, A. M., and Ladyschenskaia, L. L., "Bituminous Polymer Materials for Waterproofing," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

A successful experiment in producing and using the waterproofing and roofing materials ekarbit and armobite has demonstrated the advantages of materials with a bituminous polymer cover composition. A cover composition of ekarbit has an embrittlement temperature which is twice as low as that of a bituminous one, and it has increased flexibility and waterproofness. These results were the basis for expanding the search for new polymer additives. Of the known polymers, polyolefins have the greatest resistance to various aging factors. The shortcoming of polyolefins is their high glass transition temperature, which makes it impossible to make compounds with polyethylene which have an embrittlement temperature below  $-25^{\circ}\text{C}$ . New types of polyethylene and copolymers of ethylene with propylene with increased chain branching have significantly lower glass transition temperatures ( $-100$ ,  $-145^{\circ}\text{C}$ ). These polymers were investigated in compositions with bitumen; the polymer content was 1 percent to 70 percent. It has been shown that these types of polyethylene (PE) and copolymers of ethylene with propylene (CEP) can compete successfully with bitumen-rubber cover compositions for waterproofing roll-type roofing materials. This is because they have a high level of waterproofness (1.2 and 1.5 percent water absorption over 0.5 years), a wide plasticity range (from 110 to  $-45^{\circ}\text{C}$  at 15 percent polymer content), and low viscosity at a temperature of  $160^{\circ}\text{C}$  (the temperature of the coating bath). It is difficult to use compounds with a higher polymer content as cover compositions because of increased viscosity. It is recommended that materials with a polymer concentration of more than 20 percent be used in the preparation of materials of the izol type without a base. More homogeneous batches were obtained by addition of a small quantity of MT-16 oil. We were successful in obtaining embrittlement temperatures below  $-90^{\circ}\text{C}$  for similar compounds. Surfactants (the sodium salts of fatty acids) were used to increase the adhesion of the bituminous polymer compounds to the concrete surface.

C242 Koblischek, P., "Synthetic Resin-Bound Concrete," Proceedings, First International Congress on Polymer Concretes, 5-7 May 1975, The Concrete Society, London, pp 409-19, 1976.

This paper reviews the synthetic resins that can be used as binding material for synthetic resin concrete.

Reference is made to the mechanical and thermal properties of Acryl concrete and the use that can be made of it.

Descriptions are given of products that have been specially developed using acryl-concrete, such as: kerbstones, facades, sanitary articles, special lining stones, staircase units and electrically heated stairs, etc.

C243 Krivoi, E. A., and Shardoakov, V. K., "Polymer Coatings for Protecting Reinforced Concrete Products Used in Reclamation Construction," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

Reinforced concrete products made of standard portland cement in many instances cannot meet certain requirements of reclamation projects, namely resistance to corrosive media, impermeability, and frost resistance. In recent years there has been an increase in the use of various polymer compounds to improve these properties.

Sample pieces (tile, pipe elements, etc.) were produced under laboratory conditions according to the technology which was developed. Studies were conducted to determine the adhesive force between the polymer layer and the concrete. The effects of alternating cycles of water saturation and drying, of freezing and thawing, and of heating and cooling on the adhesion of the polymer layer formed in the molding process were determined. These effects were compared to those for samples coated with a polymer layer after their manufacture.

Waterproofness on the polymer side was more than 30 atm. Curing in 20 percent acid solution for 3 months caused no reduction in compressive strength of samples coated in the molding process. The wear resistance of polymer coating based on epoxy resin (with filler of ground quartz sand) was 0.003 gf/cm<sup>2</sup>.

The following conclusions can be drawn from these data: products made from concrete finished with a polymer layer during the molding process (we have named this material plasticized concrete) have exceptional physical and mechanical characteristics, increased durability and resistance to corrosive media, high impermeability, and high abrasion resistance. The reliability of the adhesion of the polymer layer formed during the molding process is considerably greater than when the polymer layer is applied to hardened concrete.

C244 *Lisenko, V. A., Drauch, I. M., and Babich, T. S., "New Polymer Mortars for Protection and Repair of Mooring Structures Exposed to Varying Water Level," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.*

Long-term investigations of the reliability and service life of concrete mooring structures exposed to varying water level have detected a high degree of corrosive abrasion. One of the best ways to increase the efficiency of these mooring structures and to extend their service life is to use high-strength epoxy adhesives for protection and repair of their reinforced concrete elements. A known obstacle to the development of this progressive method is the difficulty of working with adhesive compounds on moist concrete surfaces or under water. The goal of the present work was to produce reliable adhesive compositions for working under conditions of increased humidity and in water. Multi-component mixes based on new types of epoxy resins (VII-177-1 and VII-177-5) and hardeners (VII-0627 and VII-583) were studied. Particular attention was paid to the deformation properties in order to assure optimum compatibility of the deformations of the adhesive and the concrete under conditions of rapidly changing temperature and humidity. Attention was also paid to water absorption and water resistance.

C245 Manning, D. G., et al., "Durable Bridge Decks," Report No. RR203, 1976, Ontario Ministry of Transportation and Commerce.

The report deals with bridge deck durability in Ontario and considers available techniques for the construction and restoration of bridge decks in the light of existing technology.

The mechanism of corrosion of reinforcing steel in concrete is outlined and the most significant factors influencing corrosion are discussed. The effect of the material properties of the steel and the concrete are presented together with a review of the environmental factors which control the onset and rate of corrosion.

Several strategies for the prevention of corrosion in bridge decks are identified and documented in turn. The relative merits of the following strategies are considered: alternative deicers, corrosion inhibitors, bar coatings, surface treatments and impermeable overlays.

Techniques for evaluating the condition of existing decks are summarized and rehabilitation procedures for existing deteriorated decks are reviewed.

C246 Mantsevich, R. P., and Chernov, A. V., "Anticorrosion Coatings Based on Epoxy Resin and Modified by Reactive Diluents," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

In recent years the substitution of reactive diluents for the high-volatility solvents of epoxy paint compounds has been the subject of expanded research.

The Rostov Promstroiniiproekt, in collaboration with the Vedeneev VNIIG, has developed a series of compounds using reactive diluents. It has been established that the most effective compound is "EF", based on ED-16 epoxy resin. An aromatic aldehyde is used as the active diluent. The system is cured with an amine curing agent. A study of the processes taking place within the binder-diluent-curing agent system showed that the diluent and curing agent interact actively. This reaction results in a new compound which participates in the formation of a three-dimensional polymeric structure and enhances the protective properties of the coating.

Addition of carboxylic acid amide also considerably improves the properties of the given coating; it binds a portion of the solvent into a resin-like, elastic compound of complex composition, thus reducing shrinkage and increasing crack resistance of the cured system.

Studies of shrinkage effects confirmed the considerable reduction in the fraction of volatile constituents and in the linear shrinkage of laminar coatings, which was less by a factor of 1.5 to 1.7 in comparison with compounds containing a volatile solvent.

Resistance to heat, frost, abrasion, and checking have been studied, as well as other physicomachanical properties: bending strength, impact strength, hardness, coefficient of linear thermal expansion. Other structural-mechanical properties were also studied.

C247 Orlov, B. N., and Vysotina, S. S., "Acceleration of Coating Formation on a Wet Concrete Surface," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

The effect of curing accelerators on the properties of epoxy compounds (with surfactants) applied to wet concrete is studied in the present work. The aminophenol curing agent AF-2 was used. The use of curing accelerators reduces the formation time of the polymer film. Reduced formation time is a requisite condition for the technology of carrying out numerous painting operations to protect a wet surface. The initial curing rate of epoxy compounds with accelerators is 1.5 to 2 times faster than that of compounds without an accelerator.

The following physical, mechanical, and chemical properties were studied:

- (a) hygroscopicity
- (b) compressive strength
- (c) bending strength
- (d) adhesive strength
- (e) viscosity
- (f) completeness of curing (determined by extraction in a Soxhlet apparatus).

C248 Pokovskii, N. S., and Fedotov, E. D., "Waterproofing the Asbestos Cement Linings of Cooling Towers," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

Corrugated sheets of reinforced asbestos cement are widely used as lining material in forced-draft and natural-draft cooling towers. However, in regions with inclement climate such linings quickly deteriorate because of insufficient frost resistance. Elimination of this drawback and extension of the service life of cooling towers require the use of waterproofing. This can be achieved by painting or impregnating the asbestos cement with black organic binders or synthetic materials.

Various painted coatings based on asphalt, polyester, epoxy, "Etinol" and other materials were tested in the cooling towers of the Cheliabinsk heat and electric power plant (HEP) and on several other structures. The best reliability and durability were displayed by coatings produced from pigments based on 4,4'-isopropylidene-diphenol epoxy resins.

Impregnation-type waterproofing has distinct advantages over other means of protecting asbestos-cement linings from frost. It has high resistance to the action of dynamic and vibrational loads, does not change the weight of even such thin pieces as asbestos-cement sheets and can be produced by industrial methods.

In addition to the thermosoftening plastics, synthetic materials may also be used for impregnation-type insulation. The monomers styrene and methyl methacrylate are considered to be promising; they are

100 times less viscous than melted pitch and bitumen. In order to decrease the volatility and avoid the explosion hazard of the vapors of these liquids, it is expedient to use them in mixture with other substances. Various mixtures containing reactive solvents, epoxy resins, bitumens, and other substances were tested while the installation was in operation.

C249 Pomeroy, C. D., "Assessment of the Commercial Prospects of Fibre- and Polymer-Modified Concretes," Mag Concr Res, Vol 28, No. 96, Sep 1976, pp 121-129.

The principal effects of fibres of various types and of polymers upon the properties of portland cement pastes, mortars and concretes are discussed and possible applications are suggested in which the special properties of the modified cement-based materials may be exploited commercially. It is concluded that structural reinforced and pre-stressed concretes are unlikely to be replaced by fibre or polymer concretes.

C250 Slobodianik, I. I., "Waterproofing and Anticorrosion Coatings for Concrete, Based on Modified Furan Resins," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.

Waterproofing and anticorrosion protection for concrete structures is very important in reclamation construction. A large number of pumping stations and barrier structures are built each year. The underground portions of these installations need effective waterproofing and protection from the corrosive effect of ground water. There is a need for increased waterproofness of concrete wells and reservoirs.

In 1974-75, coatings based on the modified furan resin FAED-20 were developed and proven under working conditions in the UkrNIIGiM.

Laboratory investigations have shown that the coatings which were developed have high adhesion to dry and water-saturated concrete, are water-resistant, frost-resistant, resistant to alternating cycles of wetting and drying, and resistant to alkaline solutions of any concentration and ground waters with compositions based on those of the southern Ukraine. The coatings withstand a pressure of more than 10 atm after being applied to the surfaces of concrete samples.

The water-supply wells are filled with water only half the time; the water level always fluctuates. Examinations conducted after two watering seasons showed that the adhesion of the coating to the concrete did not break down.

The laboratory investigations and production testing of coatings based on FAED-20 modified furan resin have shown the promise of new developments in the waterproofing and corrosion protection of concrete structures in reclamation construction.

C251 Spellman, D. L., and Woodstrom, J. H., "Field Evaluation of Internally Sealed Concrete," California Department of Transportation; AS-Active; RD-Jan 1976; SD-Apr 1975; DC-Jun 1976.

The aim of the project is to investigate properties of "internally sealed concrete," which is a concrete made using wax beads as an admixture. The surface is then heated to melt the wax, coating an internal seal. In addition to laboratory studies a full-scale bridge deck is to be constructed and treated to obtain the internal seal.

C252 Tracy, R. G., "Bridge Deck Deterioration and Restoration," Investigation No. 639, Interim Report, Dec 1976, Minnesota Department of Transportation.

Mn/DOT has become increasingly aware of the problem of bridge deck deterioration during the last 5 years and has initiated a comprehensive program to resolve it. The two basic approaches to solving the problem are to:

1. Keep the salt and moisture out of the decks with protective overlays and membranes, modified concretes or sealers.
2. Protect the steel from corrosion once the concrete's protective nature has been destroyed by chloride contamination, using epoxy and zinc coatings.

Bridge decks were constructed or reconstructed using protective membranes, modified concretes, and coated bars. Testing and evaluation consists of visual observations, delamination detection, chloride content testing, depth of concrete cover over rebars and electrical potential measurement.

Modified or special concrete overlays perform better, from the durability standpoint, than membrane and bituminous systems in high volume traffic areas. Although both appear equally effective at keeping salt and water out, bituminous deterioration is occurring at an unacceptable rate. Concrete overlays, on the other hand, are holding up well. Postconstruction deficiencies on Low Slump Dense Concrete and Dow Latex Modified Mortar Protective Systems exposed to high volume traffic have not been significant. Isolated cases of bond failure or chucking out on the new overlay have been reported. These, however, are infrequent and minor. Surface distress similar to that found on bituminous overlays has not occurred.

C253 Van Til, C. J., et al., "Waterproof Membranes for Protection of Concrete Bridge Decks," Lab Phase, Report 165, p 70, 1976, National Cooperative Highway Research Program, Transportation Research Board.

The general objective of this two-phase study was to develop or discover an effective waterproof membrane system (or systems) for use in protecting concrete bridge decks against premature deterioration. This report presents the results of research carried out in Phase I to define the service requirements and significant properties of membrane waterproofing systems and to devise an experimental program for evaluating

the performance of candidate membrane systems under service conditions. Phase II is to include field evaluation of selected membrane systems.

The information required to initiate the study was developed by means of a comprehensive search of the literature, supplemented by inquiries to selected representatives of highway agencies and materials manufacturers. The literature search and review enabled the preparation of an extensive annotated bibliography consisting of 335 items by United States authors and 48 items by foreign authors.

Representative systems that had already been applied to bridge decks were selected for field investigation. Field data obtained for 49 installations of 25 different membrane systems included measured electrical resistance as an indicator of membrane permeability, and the results of bond tests. Electrical resistance tests indicated that most of the membranes were far from impermeable; no slippage failures were noted in the field, indicating that bond was sufficient in all installations investigated.

A comprehensive list of 147 membrane systems that had been used or proposed for use was compiled from the information search. Of this number, 69 were eliminated in a preliminary screening. The remaining 78 systems were subjected to a series of laboratory performance tests. The results of three of the laboratory performance tests (electrical resistance, crack bridging, and water absorption) were the primary means of screening the membrane systems. Minimum requirements for acceptable performance in terms of the results of these tests were established.

Materials and construction specifications were prepared for the five recommended systems. Specific types of systems meeting the requirements of the materials specifications were preformed sheets (applied-in-place systems passing all other requirements did not form water-impermeable films on placement) consisting of vulcanized, cured, or crosslinked elastomers that provided dimensional stability on exposure to water, to solar heat, to freeze-thaw conditions, and to hot asphalt concrete during construction.

C254 *Vasil'evskii, Iu. I., and Kobets, A. S., "Polymer Coatings for Repair of Reinforced Concrete Joints of Marine Wharf Structures," Third All-Union Scientific and Technical Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.*

In most ports of the Black Sea-Azov Sea basin, prism-shaped prestressed pilings are the basic elements of wharf structures. In the first years of their use, these pilings suffer significant numbers of failures in the form of longitudinal cracks, flaking of the concrete surface, or splitting off of the protective layer.

It has been established that the primary cause of surface-flaking failure is the inadequate strength and frost resistance of the piling concrete due to poor preparation technology and to driving the piles during the fall-winter period.

Failure of the longitudinal-crack type is caused by internal factors and external factors. Internal factors include flaws occurring



during the preparation of the pilings, and the joint effect on the piling concrete of preliminary reinforcement compression and dynamic forces arising when the pile is driven. The chemical effects of salt water, alternate freezing and thawing, alternate wetting and drying, wave impacts, the abrasive action of ice and sand, etc., may be classified as external factors.

Protective polymer coatings based on epoxy resins have been developed and used for restoration of pilings which have failed prematurely and for inhibiting further reinforcement corrosion. Investigations carried out under laboratory and on-site conditions have shown that these coatings have a highly protective effect, good adhesion to concrete, and long service life.

*C255 Viazemskai, N. I., and Kalinin, E. V., "Polymer-Cement Mortar and Epoxy-Polymer Mortar for Repairing the Concrete of Large Canal Structures During the Internavigation Period," Third All-Union Scientific Conference on the Use of Polymer Materials in Hydraulic Engineering Construction, 1976; Translated from Russian by USSR Ministry of Power Engineering and Electrification.*

An additive which appears to be promising for hydraulic engineering concrete is water-soluble polyamine resin No. 89, which improves the strength indices of the concrete and increases its waterproofness, crack resistance, and frost resistance.

Polymer portland cement concrete with resin No. 89 as additive can be used for the repair of hydraulic structures which are in use, as well as for the erection of new ones.

An investigation of the adhesion of polymer portland cement mortar to cement paste was conducted on composite specimens in the form of "figure eights". Resin No. 89 was added to the mix water in amounts of 1.0, 1.5, 2.0, and 2.5 percent of the dry weight of the cement. The optimum amount of the additive was determined to be 2 percent. The use of this polymer additive increased the adhesion by a factor of 1.5 to 2.0 in comparison to mortars without the additive. Specimens which hardened in water had the best adhesion.

#### 1977

*C256 "Cement Additives, Rhoplex E-330," Technical Notes, Jan 1977, Rohm and Haas Co.*

Rhoplex E-330 is a water dispersion of an acrylic polymer specifically designed for modifying portland cement compositions. Important application areas include patching and resurfacing, floor underlayments, terrazzo flooring, spray and fill coats, precast architectural building panels, stucco, industrial cement floors, and highway and bridge deck repair.

In general, cement mortars modified with Rhoplex E-330 and air cured have superior flexural, shear bond adhesion, and impact strengths when compared to moist cured unmodified cement mortars. In addition, polymer modification results in improved abrasion resistance and

comparable tensile and compressive strengths when compared to unmodified mortars. This information is presented in Table II and the figures represent average values of a large number of samples tested.

C257 Clear, K. C., and Forster, S. W., "Internally Sealed Concrete: Material Characterization and Heat Treating Studies," Report No. FHWA-RD-77-16, 1977, Federal Highway Administration.

The work described herein was aimed at developing the information and processes necessary for efficient experimental construction of bridge decks using internally sealed concrete. This concrete is sealed by means of wax included in the mix, and was developed for use in bridge decks to prevent the penetration of water and chlorides to the reinforcing steel.

Specific goals of the study were:

(1) The development of safe, efficient field heating systems needed to melt the wax and seal the concrete.

(2) The definition of the engineering properties of the particular internally sealed concrete specified for the experimental projects.

During the early testing phases, concrete cracking problems were encountered and circumvented by modifying the heating and bead-manufacturing processes.

Heating equipment experiments performed to develop both small, single pass, fast-heating equipment and equipment which slowly heats a large area at once are described. Also discussed are the tests performed to document the engineering properties of internally sealed concrete (i.e., strength, bond to underlying concrete and reinforcing steel, abrasion resistance, skid resistance, shrinkage, etc.). Finally, the findings of an analysis of two prototype internally sealed decks built in 1975 and heat treated in 1976 are presented.

C258 Keeton, J. R., and Alumbaugh, R. L., "Polymer-Modified Concrete for Military Construction," Technical Note No. N-1479, Apr 1977, Civil Engineering Laboratory.

Results are given of tests made with polymer-modified concretes in which the polymeric materials are added to the concrete in the mixer. Polymers used were either epoxy or saran latex. Epoxy- or latex-modified concretes provided compressive, splitting tensile, and flexural strengths from 2.8 to 4.6 times those of similar concrete without the polymer. Epoxy-modified concretes achieved compressive strengths from 7,770 psi to 10,150 psi over test ages of 1 day to 365 days. Latex-modified concretes reached compressive strengths from 4,160 psi to 10,110 psi over test ages from 3 days to 365 days. Splitting tensile strengths of epoxy-modified concretes ranged from 900 psi to 1,340 psi for test ages from 1 day to 365 days; corresponding strengths of latex-modified concretes ranged from 600 psi to 970 psi. Flexural strengths of epoxy-modified concretes ranged from 1,300 psi to 1,610 psi; corresponding strengths of latex-modified concretes ranged from 770 psi to 1,570 psi. Significant reductions were observed in water absorption of polymer-modified concretes. Bond strength of polymer-modified concrete was

slightly higher than in concrete without the polymer. Young's moduli of polymer-modified concretes were only 1.4 to 1.8 times those of similar concrete without the polymer.

C259 Manning, D. G., and Owens, M. J., "Ontario's Experience with Concrete Overlays for Bridge Decks," Annual Conference Preprints, Roads and Transportation Association of Canada, Design Volume, 1977, pp 61-78.

This paper details the experience gained in the 1976 program on both new and existing bridges. The emphasis is, however, on the repair of existing bridge decks because, by its very nature, this is the more difficult task. Many of the options suitable for new construction are not applicable to repair work and there are frequently operational constraints. Two of the most difficult problems for highway engineers to solve are (i) to determine the amount of chloride contaminated concrete that must be removed before permanent repairs can be made to a bridge deck and (ii) to effect repairs on a structure with working cracks. Despite these difficulties a solution has to be found in order to protect the investment in existing facilities. The paper discusses one of the approaches which Ontario has taken to solve these problems.

C261 Dow Chemical Company, Styrene-Type Monomers, Form No. 170-151B-3M-366, 1977.

This bulletin presents information on The Dow Chemical Company family of styrene-type monomers: styrene, vinyltoluene, and divinylbenzene. The physical data given represent the most accurate presently known and are based upon (1) published data, (2) calculated data, or (3) Dow unpublished data.

C262 Tyson, S. S., "Partial-Depth Repair of Jointed PCC Pavements: Cast-In-Place and Precast Procedures," VHTRC 77-R37, Jan 1977, Virginia Highway and Transportation Research Council.

The installation of durable patches on jointed portland cement concrete pavement using several types of cast-in-place concrete is described. The recommended procedures for pavement preparation and patch installation are given, and additional maintenance procedures as cleaning and sealing joints and assuring proper drainage are briefly discussed. The successful evaluation of proprietary products for repair concretes through a laboratory determination of concrete properties, field use of acceptable products, and the assessment of performance data during and after installation is discussed. Included in this study were some of the cements, admixtures, and other special products for repair concretes from a list maintained by the Materials Division of the Virginia Department of Highways and Transportation to provide assistance in the selection of the proprietary products. "A production chart is presented as an aid in estimating the number of patches that can be installed during typical and closure periods.

Concretes with short curing times increased potential production;

however, the selection of a repair product is acknowledged to also be dependent on factors such as cost and availability of materials. A procedure for installing precast patches for partial-depth repairs is described; however, the rate of pavement preparation is too slow to make this procedure a viable alternative to cast-in-place patching.

C262(1) Nawy, E. G., et al., "High-Strength Field Polymer Modified Concretes," Journal of the Construction Division, American Society of Civil Engineers, Vol 103, No ST12, Dec 1977, pp 2307-2322.

The objective of this investigation was to determine the effect of water/cement ratio and the polymer/cement ratio on the characteristics of polymer modified concrete. The first part of the investigation involved the comparison of different combinations of the resins and hardeners, determination of the effect of moderate heat, and the best stoichiometric ratio for the polymer (i.e., Resin/Hardener). Using the best combination of resin and hardener the effect of water/cement ratio and polymer/cement ratio on the strength properties of concrete were studied.

This investigation has shown that:

1. There is an optimum polymer/cement ratio for our polymer modified concrete at any given water/cement ratio below 0.6. Within a workable range for concretes this P/C ratio lies between 0.3-0.45.
2. Liquid polymers of the type used give better results when their viscosities are low and the ratio of resin to hardener is kept close to the optimum stoichiometric ratio (in this case 100:68).
3. Curing by the use of moderate heat has a negative effect on the polymer-cement system.
4. Better workability and strength (up to 20% more) are obtainable by first mixing dry aggregates with blended epoxy before cement paste is added.
5. Polymer modified concretes made based on these findings gave strengths of 12,218 psi (84.24 MN/m<sup>2</sup>) in compression and 1,186 psi (8.18 MN/m<sup>2</sup>) in tensile splitting at a W/C ratio of 0.2 and P/C ratio of 0.4. At a W/C ratio of 0.045 and P/C ratio of 0.6 the test results were 13,531 psi (93.2 MN/m<sup>2</sup>) in compression and 1,538 psi (10.60 MN/m<sup>2</sup>) in tensile strength. The preliminary work at Rutgers gave lower maximum strengths while the cement:sand:aggregate ratio was kept the same in both investigations, i.e., 1:1.62:2.44. The control strength of normal nonmodified concrete was 5,563 psi (38.36 MN/m<sup>2</sup>) in compression and 450 psi (3.10 MN/m<sup>2</sup>) in tensile splitting.
6. Stress-strain curves of the PMC's show their superior energy absorbing capacities over normal concrete. At a W/C of 0.2 and P/C of 0.4 the increase is 3.4 times over the control specimens. At a W/C of 0.045 and P/C of 0.6 the increase is maximum at six times that of the control specimen.

- C263 Bishara, A. G., et al., "Shrinkage and Creep Characteristics of Latex-Modified Concrete," American Concrete Institute Journal, Vol 75, No. 5, May 1978, pp 204-208.

An experimental investigation was conducted to study creep and shrinkage characteristics of latex-modified mortar (LMM) and concrete (LMC) used for bridge deck overlays. The test program included eight prisms of latex-modified mortar and eleven prisms of latex-modified concrete prepared to be tested for almost 8 months.

Empirical equations for predicting shrinkage strains of LMM and LMC show that shrinkage of LMM is almost double that of LMC and air-entrained normal weight concrete (AEC). Empirical equations developed for predicting creep of LMM give values of the same order of magnitude as those of AEC.

- C264 Fontana, J., and Webster, R., "Thin, Sand-Filled, Resin Overlays," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 89-103.

The use of thin, sand-filled, resin overlays to prevent the penetration of water and deicing salts into portland cement concrete (PCC) bridge decks has been investigated. The overlay, which is  $1/2 \pm 1/8$  in. ( $1.27 \pm 0.32$  cm) thick, consists of four alternating layers of a thermosetting resin and silica sand. The overlay is placed by applying a uniform coat of resin to the surface of clean, dry, sound concrete. Silica sand is immediately broadcast over the uncured resin. After the resin has cured the unbonded sand is removed and the process is repeated until four layers have been placed.

Three sand-filled, resin overlay systems have been investigated. A series of tests were performed to evaluate water permeability, chloride penetration, skid resistance, bond strength and freeze-thaw durability. Test results indicate a reduction in water permeability of over 94 percent for overlaid concrete, as opposed to nonoverlaid concrete. Chloride penetrations tests indicate the overlays significantly reduce the penetration of chlorides into concrete. Excellent bond strength, in excess of 400 psi (2.8 MPa), can be developed between the overlay and clean, dry, sound concrete.

A 14- by 90-ft (4.3- by 27.5-m) overlay has been placed in the field by bridge maintenance personnel using available highway equipment.

- C265 Izotov, V. S., Popko, V. N., Sokolova, Iu. A., and Voskresenskii, V. A., "Study of Concretes with Amine-Containing Additives," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),

Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 154, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

A study was made of the structure and physical-mechanical properties of concretes with polyethylene polyamine and carbamide resin additives.

The additives were introduced with the water for curing at 0.025 to 3 percent of the mass of the cement. The studies were performed on wet cement, mortars, and concretes. The binder used was portland cement produced by the Ul'ianov plant. The aggregates were quartz river sand, with particle-size modulus 2.7, and granite gravel of the 5- to 20-mm fraction.

The strength characteristics of the concretes with compositions of 1:1 and 1:2.86 with W/C = 0.36 to 0.4 and 0.46 to 0.5 were studied using cubic specimens 10 by 10 by 10 cm; the initial modulus of elasticity was studied using prism specimens 10 by 10 by 40 cm.

It was found that the addition of polyethylene polyamine in quantities of 0.025 to 0.1 percent of the mass of the cement increases the strength of the concrete by 10 to 17 percent. The addition of carbamide resin at 1.0 to 0.5 percent of the mass of the cement increases the strength of the concrete mortar by 10 to 19 percent. The influence of these additives on processes of hydration and formation of the structure of the cement paste was studied by the method of calorimetry, and also by measurement of pH and plastic strength.

Thus, the studies performed showed that the addition of polyethylene polyamine and carbamide resin in the optimal concentrations has a significant modifying effect on the properties of the wet cement paste, manifested as plasticizing and acceleration of hydration of the cement, as well as an increase in the strength and passivating capacity of concrete based on the cement.

C266 Lavelle, J. A., et al., "Acrylic Modifiers for Cement," Concrete Construction, Vol 23, No. 2, Feb 1978, pp 107-108.

Acrylic modifiers for portland cement impart significant application and performance advantages to the finished product. By eliminating moist curing and providing thin-section toughness, they bring immediate savings in labor and material costs. Over the long haul, the outstanding adhesion, toughness and general wear properties of acrylic-modified cement, mortar and concrete translate into superior performance, low maintenance costs and customer goodwill.

C267 Vanaskie, W. F., and Murray, M. A., "Strength of Tension Lap Splices In Polymer-Portland-Cement Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 211-228.

For the past 30 years, an area of major concern to engineers has been the strength of spliced reinforcement in reinforced concrete construction. This investigation used an epoxy emulsion to form a

polymer-portland-cement concrete (PPCC), which was cast around tension lap splices in reinforced concrete beams. The beams, with varying length of lap splice, were tested with the splice located in a constant moment zone. The results showed that the strength of the splice can be increased by as much as 50 percent in ultimate load carrying capacity by use of the PPCC. Calculations also indicate that the required development length in the PPCC is approximately one-half of that in ordinary concrete. These conclusions do not reflect, however, the physical properties of the material. Although the test beams acted favorably, the average tensile strength of the PPCC at age 7 days was 602 psi (42.3 kg/cm<sup>2</sup>), which was only a 3 percent increase over the cement concrete. However, the average bond stress was calculated to have an average increase of 200 psi (14.1 kg/cm) over the cement concrete. The PPCC exhibited a failure pattern which allowed the ductility of the member, even at short splice lengths, to be far superior to that of the control beams. The investigation indicates that this type of construction can be readily adapted to field use without additional costs in labor and with a savings in time and steel over other types of polymer modified concrete.

C267(1) *Krinkin, I. L., "Concrete Modified with Low-Molecular Polyethylene," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),* Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 161, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The Scientific Research Institute for Reinforced Concrete Products has developed formulas for concrete, modified with low-molecular polyolefins by introduction of the modifier to the zone of contact between the cement paste and the aggregate.

The studies have shown that this material has higher impermeability than that of ordinary concrete (by a factor of 2 to 4), higher strength (by 15 to 20 percent) and shows improvement in a number of other indices as well. Modification of high-strength concrete with polymers also allows improvement of its plastic properties. The use of the modified concrete for guniting of the surface of reinforced-concrete reservoirs for water and other liquids which are not highly corrosive is most promising.

#### 1979

C268 *Bishara, A. G., "Latex Modified Concrete Bridge Deck Overlays - Field Performance Analysis," Report No. FHWA/OH/79/004, Oct 1979.*

Data on field performance of 132 bridge decks overlaid by latex mortar or concrete in Ohio, Michigan, Kentucky, and West Virginia, as

well as some data from Minnesota and Vermont, were collected according to a specially designed inspection questionnaire. Common durability distress features and the factors that might influence them were identified. Statistical analysis was performed to determine the set of variables that best explain the variation in the surface distress features among the different latex projects investigated and to quantify the relationship between overlay condition and the pertinent variables through the formulation of regression models. Further assessment of available performance data was conducted to tie the obtained relationships with the limited data on effectiveness of latex overlays in providing corrosion protection to the deck rebars and to develop hypotheses on the formation and development of latex overlays' various durability deficiency features. The results obtained and the conclusions drawn explain, quantify, and delineate the interrelationship among such factors as years of service, ADT, trafficked versus untrafficked decks during placement, continuous versus simply supported decks, thickness of overlay and skid number, on the overlay durability and corrosion protection capability.

C269 *Transportation Research Board, "Durability of Concrete Bridge Decks," National Cooperative Highway Research Program Synthesis 57, May 1979, Washington, D. C.*

Over the years, bridge deck durability has continued to be a problem, especially because of deterioration resulting from corrosion of embedded reinforcing bars. This synthesis reviews recent developments in condition evaluation methods and protective systems for new and existing bridge decks.

For either new construction or as a repair technique, sealants, impregnants, overlays, membranes, or cathodic protection have been used to improve durability. Sealants are not effective in preventing corrosion damage. Polymer impregnation of bridge decks shows promise and research is continuing. Concrete overlays may be applied as the second stage of new deck construction or as preventive maintenance on an existing deck. The overlay may be low-slump concrete (the "Iowa method"), latex-modified concrete, or internally-sealed concrete (wax beads). Membranes are available in a variety of systems, but field experience has been highly variable and there is some doubt as to long-term performance. Cathodic protection has been used successfully to stop active corrosion; it is the only practical method to ensure this.

C270 *Kaeding, A. O., "15,000-psi Concrete Achieved with Polymers," Concrete Construction, Vol 24, No. 1, Jan 1979, pp 13-15.*

Formation of concretes with compressive strengths of 15,000 psi and higher is now possible by replacing or augmenting portland cement as the cementing matrix. Work completed to date shows that substantial and badly deteriorated concrete in buildings can be repaired using polymer-impregnated concrete techniques. In industrial applications, polymer concrete is an alternative.



The use of polymer concrete as an overlay to provide a waterproof membrane and a high-strength, durable wearing surface can be cost effective. Using polymer concrete and polymer-impregnated concrete techniques in conjunction with other repair and restoration methods makes possible an expanded technology for repairing concrete structures.

C271 *Civil Engineering Laboratory, "Lightweight Concrete Using Polymer-Filled Aggregate for Ocean Applications - An Exploratory Investigation," Report No. CEL-TN-1565, Dec 1979, Port Hueneme, Calif.*

A lightweight concrete specially suited for deep ocean applications was tested for its strength properties and compared to similar regular lightweight concrete. The new concrete used lightweight aggregate particles (expanded shale) which were filled with a polymeric material. The polymer-filled aggregate (PFA) was conventionally mixed with portland cement and water to make the lightweight concrete. Four concrete mixes were tested. In general, the PFA concrete, compared to regular lightweight concrete, has an equal unit weight in a seawater saturated condition and exhibited increases in compressive strength of 26 percent, split tensile strength of 4 percent, elastic moduli of 4 percent and an equal Poisson's ratio. The strongest mix for PFA concrete had a compressive strength of 6,580 psi, compared to 5,200 psi for regular lightweight concrete, at an age of 28 days under continuous fog curing. Both mixes have a weight savings of 40 percent, compared to that of normal weight concrete in a submerged, saturated condition. A discussion of cost is presented and shows that the in-place structural cost of PFA concrete would be about 30 percent greater than normal concrete.

C272 *Murray, M. A., and Schrader, E. K., "Epoxy Concrete Overlays," The Military Engineer, Jul-Aug 1979.*

Concrete deck surface deterioration in a water treatment facility was repaired using an epoxy-(polymer)modified portland cement concrete overlay. After chipping and sandblasting, loose debris was removed with compressed air. Once prepared, screed bars to control the elevation and ensure the minimum thickness (1-in.) were set in a bed of epoxy mortar or portland cement grout at regular intervals. Existing joints were extended through the epoxy-modified concrete topping.

Although the section was thin, the temperature was hot (90 to 100°F), and the humidity was low, shrinkage cracks were nonexistent. The overlay has been in service less than a year, but within a few months of application, temperatures were well below freezing and many natural wet-dry cycles had been endured. Still, the slab is in excellent condition with no evidence of debonding, crack problems, or damage. It has provided a tough, durable, and easily constructed topping that should remain watertight and maintenance free.

C273 *Srinivasa L. L., and Phelps, R., "Creep and Shrinkage of Latex Modified Versus Gap-Graded Concrete," The International Journal of Cement Composites, Vol 1, No. 3, 1979, pp 171-175.*

This study presents the results of an investigation comparing the creep and shrinkage of latex modified and gap-graded concrete. Creep and shrinkage are determined for both the latex modified and gap-graded concrete according to the standards of the American Society for Testing and Materials.

Equations based on the present data are proposed for the prediction of creep and shrinkage for both latex modified and gap-graded concrete. From the results of this investigation, shrinkage deformations and creep strains of the latex modified concrete specimens, in general, were found to be, respectively, approximately 240 and 120 percent larger than those for the gap-graded concrete specimens.

#### 1980

C275 Chandra, S., et al., "Some Effects of Polymer Addition on the Fire Resistance of Concrete," Cement and Concrete Research, Vol 10, No. 3, May 1980, pp 367-375.

Some trials have been made under this work to see the influence of small amount (1 to 1.5 percent) of polymer addition on the fire resistance of concrete. Normal concrete plates with and without polymer addition are compared. Lightweight aggregate concrete plates, slabs, and reinforced beams are also tested for fire exposure. Plates of normal and lightweight aggregate concrete have not shown any spalling effect when exposed to fire from one side. Normal concrete without polymer addition resulted in explosive spalling when exposed to fire from two sides whereas no spalling is noticed in all types of concrete tested with polymer addition. A more open structure created in cement paste by polymer addition seems to facilitate the steam transport from the specimens during heating and thus prevents creation of high vapor pressure in the concrete, responsible for explosive spalling.

SECTION D  
SULFUR CONCRETE

1924

- D1 Kobbe, W. H., "New Uses for Sulphur in Industry," *Industrial and Engineering Chemistry*, Vol 16, No. 10, Oct 1924, pp 1026-1028.

Sulfur, being of comparatively low fusibility, acid-proof, wet-resistant, of high dielectric strength and low heat conductivity, would seem to be an ideal material for many industrial purposes and even in special construction work. It is available in almost unlimited quantity and at less than 1 percent per pound. On the other hand, its flammability and extreme brittleness in the crystalline state preclude its use in the fields mentioned. In other words, pure sulfur as such is entirely unsuited for structural purposes, acid-proof tanks, or similar applications.

In general, there are two ways of utilizing the valuable characteristics of sulfur and at the same time largely modifying its flammability and brittleness. One method is to impregnate other substances with sulfur, and the other is to admix certain materials to form various sulfur compositions. In both methods advantage is taken of the comparatively low fusibility of sulfur.

Many materials have been impregnated with molten sulfur by simple immersion in a bath of this substance, and among these may be mentioned diatomaceous earth, concrete, building brick, fibrous materials, various asbestos products, sandstone, fiber board, and many others.

1926

- D2 Bates, P. H., "The Use of Sulfur in Rendering Cement Drain Tile Resistant to the Attack of Alkali," *Industrial and Engineering Chemistry*, Vol 18, No. 3, Mar 1926, pp 309-310.

The Bureau of Standards conducted a preliminary series of tests in which the tensile strength of mortar briquets was determined both before and after immersion in sulfur until the absorption of the latter was about complete. The results of these tests indicated such a marked increase in strength that it was thought advisable to carry on a more comprehensive investigation in which sulfur would be used, not only on account of the strength which it imparted, but also as an agent to reduce absorption and consequently attack by alkali or other soluble salts.

Results indicate that although the treatment of cement products such as drain tile by impregnation with molten sulfur very markedly increases their strength and decreases their absorption, it does not in any manner increase their life in alkali soils.

1934

- D3 Duecker, W. W., "Admixtures Improve Properties of Sulphur Cements," *Chemical and Metallurgical Engineering*, Vol 41, No. 11, Nov 1934, pp 583-586.

Sulphur as such or in various combinations, particularly as sulphur cements, has been used as a sealing compound or bonding agent for many years. Although such cements have been known for a long time, the technical literature reveals but little information regarding their physical characteristics and utility. In the present paper these data will be presented; and in addition, there will be given a description of a comprehensive research that had for its aim the development of a new type of sulphur cements, evolved primarily for the purpose of satisfying a wide range of industrial requirements.

1936

- D4 Payne, C. R., "Sulphur Base Cements Protect Sewage Works," Municipal Sanitation, Vol 7, 1936, pp 387-389.

The proved chemical resistance, structural strength, and resistance to erosion of a properly compounded sulphur base cement recommend its use to the sanitary engineer as a joint-ing compound for acid-proof brick or liner plates in the protection of existing concrete sewers, in the construction of new sewers, and in the construction of tanks for the storage or mixing of chemicals used in the treatment of water and sewage.

1940

- D5 Payne, C. R., and Duecker, W. W., "Construction with Sulphur Cement," Chemical and Metallurgical Engineering, Vol 47, Jan 1940, p 20.

In discussing the various industrial installations in which sulphur cement is in service, however, no mention was made of the types of construction. Types and methods of construction are well standardized and are based on the physical properties of the cement.

Sulphur cement has good adhesion to all metals and is successfully used in contact with iron, lead, and acid-resisting alloys. However, for reasons discussed in the first article, it should not be used in contact with copper. Determinations were made of the adhesion of sulphur cement to various types of acidproof brick. The best adhesion was obtained to a brick having a wire cut or scored bonding surface.

1961

- D6 Dale, J. M., "Determination of the Mechanical Properties of Elemental Sulfur," Materials Research and Standards, American Society for Testing and Materials, Vol 1, No. 1, Jan 1961, pp 23-26.

Specimens of dark, standard bright, and laboratory-grade sulfur were tested for strength in specially prepared laboratory apparatus and measurements recorded at 1, 7, and 28 days from the date of casting. It was found that elemental sulfur has an approximate ultimate tensile strength of 160 psi, and an approximate ultimate compressive strength of 3300 psi, with an approximate modulus of rupture of 200 psi. Impurities,

as found in the dark and standard bright grades of sulfur, appear to increase strength. Also, strengths were found to increase with increased age of the specimens.

Because of the high mechanical properties exhibited by elemental sulfur, it can be properly looked upon as a structural material. Thus, a great deal more research should be done in evaluating further the mechanical properties of sulfur and exploring the many possible applications where its mechanical properties can be used to advantage.

#### 1965

- D7 Dale, J. M., "Sulfur-Fibre Coatings," The Sulfur Institute Journal, Vol 1, No. 1, Fall 1965.

In work sponsored in part by The Sulphur Institute and also from internal research funds of Southwest Research Institute, a program of preliminary research was undertaken to investigate the feasibility of a system for constructing building walls utilizing a sulphur-based, fibre reinforced coating composition. Although still subject to further tests to determine its safety and reliability for general use, the method is comparatively simple. It is applicable to structures constructed of lightweight concrete blocks or any other block or block-like materials. No mortar or joining material is used between the blocks. The blocks are simply stacked dry, one upon the other, until the desired wall configuration is achieved. Over the outside and inside of the wall, a thin single coating of a molten mixture, consisting primarily of sulphur with small percentages of a physical property modifier, pigment and glass fibres, is applied. Within seconds, the molten coating cools below its solidification temperature and converts to a hard, impervious surface, which has so far proved both weatherproof and insulative in use.

- D8 Dale, J. M., and Ludwig, A. C., "Mechanical Properties of Sulfur Allotropes," Mat. Res. and Stds., Vol 5, 1965, p 411.

This paper reports the transformations and mechanical properties of the allotropes of sulfur, monoclinic sulfur, orthorhombic sulfur, and plasticized sulfur.

#### 1966

- D9 Dale, J. M., and Ludwig, A. C., "Feasibility Study for Using Sulphur-Aggregate Mixtures as a Structural Material," Technical Report No. AFWL-TR-66-57, 1966, Southwest Research Institute.

This study represents the first systematic approach ever undertaken to determine the technical feasibility of using sulphur combined with various types and sizes of natural and crushed aggregates as a structural material. In this program, the engineering properties of sulphur combined with the various single aggregate gradations were determined. Following this, the engineering properties of mixtures of sulphur and fine and coarse aggregates were determined. High early

strengths in the range of 4000 to 6500 psi in compression were obtained when using a physically poor aggregate such as limestone. The mixtures were studied for workability, and a mix design was prepared such that, in the future, by referring to this mix design, proportions of materials may be selected at will.

It was demonstrated that sulphur-aggregate concrete can indeed be looked upon as a structural material possessing a variety of outstanding characteristics including simplicity of formulation, ease of preparation, insensitivity to ambient temperature conditions, and high early strengths. In addition to this, these mixtures are low in cost and have the potential of being broken up, remelted, and used again upon completion of their useful life in a given application.

D10 Dale, J. M., and Ludwig, A. C., "Rigid Sulfur Foams," The Sulfur Institute Journal, Vol 2, No. 3, Autumn 1966, pp 6-8.

This article discusses the properties and development of sulphur foam such as those of polystyrene and urethane. It also describes a machine for producing sulphur foam.

Rigid sulphur foam is a thermoplastic mixture primarily of elemental sulphur which has been reacted above the melting point of sulphur with various viscosity improvers, surface active agents, stabilizers and blowing agents such that when it is released from a pressurized vessel a molten froth is formed which, on cooling, converts to a rigid foam material having essentially a closed cell structure and a uniform density. It does not require the use of temperature controlled molds and lends itself to the in situ placement of foam at remote sites. Unlike the rigid plastic foams, whose starting components have specific gravities on the order of one, the specific gravity of sulphur is approximately two, thus making it more difficult to achieve the extremely low densities attainable in the plastic foams.

#### 1967

D11 Dale, J. M., and Ludwig, A. C., "Sulphur-Aggregate Concrete," Civil Engineering, Vol 37, No. 12, Dec 1967, pp 66-68.

Sulphur-aggregate concrete is a thermoplastic mixture of elemental sulphur with a fine and a coarse aggregate. To be prepared it must be heated above the melting point of sulphur, 239 deg F; at this time the sulphur becomes a liquid which acts as a lubricant, wetting the aggregate and converting it into a plastic mixture. On cooling of the mixture below the melting point of sulphur, the sulphur solidifies immediately and binds the aggregate into a hard, concrete-like material.

#### 1968

D12 Dale, J. M., et al., "Investigation of Sulphur as a Structural Material," Technical Report AFAPL-TR-68 95, Aug 1968, Air Force Systems Command Aero Propulsion Laboratory.

The feasibility of using sulphur-reinforced glass fiber composites was demonstrated in the field for the construction of shelter floors and helicopter landing pads under a previous study (AFAPL-TR-66-15). The subject program was undertaken to optimize the system from the standpoint of strength, fire resistance, abrasion resistance, and economy. As a result of this program, a glass fiber mat was developed which was compatible with sulphur formulations. This mat, designated as Ferro Corporation's GP-2-oz/ft<sup>2</sup> Sulfophil III, has a terpene polymer sizing. The optimum sulphur formulation prepared during the course of this program consisted of 96 percent sulphur and 4 percent dicyclopentadiene. Flexural strengths of 4850 psi were attained with this composite which has good fire resistance and greatly improved abrasion resistance. The use of highway marking paint as a coating material was demonstrated to also aid the fire and abrasion resistance of sulphur-glass fiber composites. The feasibility of making building blocks of sulphur foam was demonstrated by the production of 80 blocks comparable in size and shape to lightweight aggregate blocks. The mechanical properties of rigid sulphur foam were determined to be sufficient for wall construction.

1970

D13 Crow, L. J., and Bates, R. C., "Strengths of Sulfur-Basalt Concretes," RI 7349, Mar 1970, U. S. Department of the Interior, Bureau of Mines.

This study advances the use of elemental sulfur in structural materials by demonstrating its value in bonding high-strength, well-graded basalt aggregates to form sulfur-basalt concretes. Sulfur is an excellent bonding agent, and the strength of a thermoplastic sulfur-aggregate mixture depends, to a large degree, on the strength and grain-size distribution of the aggregate used. A 3-cu ft, electrically powered mixer with heat applied to the barrel was used to mix the sulfur and aggregate. Sulfur content of several mixtures was varied to obtain the best workability with a minimum of sulfur in excess of that necessary to fill the voids. The average grain sizes and grain-size distributions were also varied to determine their effects on strength. Unconfined compression tests of 45 6- by 12-in. cylinders yielded average strengths of 3,348 psi to 10,398 psi. The highest strength single cylinder was 10,717 psi. The cylinders were tested from 24 hr to 6 days after pouring; after 24 hr the rise in strength was very slight. From the results obtained it appears that sulfur can be a useful construction material.

An evaluation was made of a high-vacuum application for sulfur concrete. Sulfur has a high vapor pressure at elevated temperatures, 50° to 100°C; consequently, significant losses by sublimation can be expected. At lower temperatures the losses are not significant; however, this factor will limit its use at a higher temperature.



1971

D13(1) "Fighting Corrosion with Sulphur," Sulphur Institute Journal, Fall 1971, pp 14-15.

This article describes the research work carried out by the Southwest Research Institute on the corrosion of concrete sewer pipes.

Several methods have been proposed for controlling the corrosion of sewer pipes. They include forced air ventilation of the vapor space, running the sewers full of liquid (no vapor space), controlling the pH of the sewer, using corrosion-resistant materials (plastic pipes) and treating the concrete pipes to improve corrosion resistance.

In the initial program, treated and untreated concrete samples were immersed in 10 percent sulphuric acid for 3 days. This constituted an accelerated test, as previous experiments had shown this acid concentration to be the most corrosive to concrete. The screening program indicated that both impregnating and coating materials were effective in reducing the rate of corrosion.

1972

D14 Dale, J. M., and Ludwig, A. C., "Sulfur Coatings for Mine Support," Open File Report 31-73, Nov 1972, Final Report to U. S. Department of Interior, Bureau of Mines.

Sulfur is a plentiful, low-cost, unique material whose physical properties can be altered and employed in structural applications. This program was undertaken to develop an optimum sulfur-based formulation for use as a coating to both seal and support mine walls. The initial effort in this research was devoted to a laboratory study of the physical and mechanical properties of a variety of sulfur-base coatings that were specifically formulated for this application. Concurrent with formulation development, laboratory equipment and techniques were developed for spray application of the sulfur-based coatings to the ceiling and walls of a structure that simulated the interior of a mine. One hundred parts of sulfur modified with ten parts of talc, three parts of milled glass fiber, and two parts of dicyclopentadiene was found to be a fire-retarded, low-odor, low-eye-irritation, sprayable formulation for sealing and strengthening mine walls.

D15 Meyer, B., "Future Uses of Sulfur," International Journal of Sulfur Chemistry, Part B, Vol 7, Nov 1972.

Before large-scale abatement of sulfur dioxide begins, it is worth considering briefly what the effect will be. I want to present a few short comments on the fate of sulfur after recovery of SO<sub>2</sub>. Recovery of SO<sub>2</sub> does not dispose of sulfur; it merely concentrates it, or transforms it into another chemical form. Presently tested abatement processes produce mainly calcium sulfate, sulfuric acid, ammonium sulfate, liquid SO<sub>2</sub>, or elemental sulfur. Of these, calcium sulfate is presently easiest

made, but in my mind it is clearly undesirable. It is not useful, and has no commercial value.

Clearly, the most desirable product would be elemental sulfur. It is the lightest form of sulfur, it is easiest to ship, and it is harmless and inert. Much work remains to be done before SO<sub>2</sub> can be economically converted into elemental sulfur, but, for the following, I want to assume that this can be done, and I want to consider what would happen if, as of today, all SO<sub>2</sub> emitted from power stacks would be recovered as pure, elemental sulfur, and that the recovery process would be economically competitive with other sulfur production methods.

D16 *"Sulphur Building Revisited," The Sulphur Institute Journal, Summer 1972, pp 2-4.*

This article gives a description of the performance of the Sulphur House. Back in 1957 the Southwest Research Institute demonstrated the feasibility of a system for constructing building walls using a sulphur-based, fiber-reinforced coating composition. The method is comparatively simple and applicable to structures utilizing lightweight concrete blocks or any other block or block-like materials. No mortar or joining material is used between the blocks; they are simply stacked dry, one upon the other, until the desired wall configuration is achieved. Over the outside and inside of the wall a thin single coating of a molten mixture, consisting primarily of sulphur with small percentages of a physical property modifier, pigment and glass fibers, is applied. Within seconds, the molten coating solidifies and forms a hard, impervious surface, which has proved both weather-proof and insulative in use.

#### 1974

D20 *Loov, R. E., et al., "Sulfur Concrete - A New Construction Material," Prestressed Concrete Institute Journal, Jan-Feb 1974.*

Involuntary large-scale production of sulfur as a by-product of natural gas production has resulted in rapidly increasing Canadian inventories expected to reach 22 million tons by the end of 1975. With an assurance of low sulfur prices during the foreseeable future, it is now worthwhile to consider sulfur concrete for applications where its unique properties are advantageous. This paper compares the properties of sulfur concrete with those of conventional concrete and discusses possible advantages and disadvantages of this new material. Some possible areas of application are indicated.

D21 *Malhotra, V. M., Painter, K., and Soles, J. A., "Development of High Strength Concrete at Early Ages Using a Sulphur Infiltration Technique," Report MP1(A) 74-14, Jul 1974, Department of Energy, Mines, and Resources, Ottawa, Canada.*

A new type of high-strength concrete has been developed from lean, low-strength, 48-hr-old portland cement concrete, using a sulphur

infiltration technique. The method consists of moist curing fresh concrete specimens for 24 hr, drying them at 121°C for 24 hr, immersing them in molten sulphur under vacuum for 2 hr, releasing the vacuum and soaking them for an additional half-hour, then removing them from the sulphur to cool. Testing is done 1 to 2 hr later.

Compressive strengths of the sulphur-impregnated specimens were in the range of 14,500 psi (99.5 MN/m<sup>2</sup>), about 7.5 times the strength of reference moist-cured specimens, and splitting-tensile strengths of impregnated specimens were about 1300 psi (8.9 MN/m<sup>2</sup>), almost 4.5 times the strength of reference specimens. Also, it was highly resistant to accelerated freezing and thawing, remaining in excellent condition after 513 cycles whereas the moist-cured specimens disintegrated before 40 cycles.

Petrographic and porosity studies suggest that effective infiltration of concrete by molten sulphur is highly dependent on the wettability of the hydrated cement, and on the continuity and size of capillary pores in the matrix.

D22 Malhotra, V. M., "Effect of Specimen Size on Compressive Strength of Sulphur Concrete," *Mines Branch Investigation Report IR 73-18*, Jun 1974, Department of Energy, Mines, and Resources, Ottawa.

The compressive strengths of 4- by 8-in. (102- by 203-mm) sulphur concrete cylinders are considerably higher than those of 6- by 12-in. (152- by 305-mm) cylinders. For a typical sulphur concrete mix containing about 25 percent sulphur, the 28-day compressive strengths of 4- by 8-in. cylinders range from 4785 to 6730 psi (32.8 to 46.2 MN/m<sup>2</sup>), whereas the corresponding strengths of 6- by 12-in. cylinders range from 3790 to 5005 psi (26.1 to 34.4 MN/m<sup>2</sup>).

The densities of 4- by 8-in. cylinders are generally higher than those of 6- by 12-in. cylinders. For 28-day test results, the densities of 4- by 8-in. cylinders range from 149.05 to 151.57 lb/ft<sup>3</sup> (2388 to 2428 kg/m<sup>3</sup>); the corresponding values for 6- by 12-in. cylinders range from 149.05 to 150.48 lb/ft<sup>3</sup> (2388 to 2411 kg/m<sup>3</sup>). The decrease in strength of large specimens is probably due to the combined effects of specimen size and slower rate of cooling.

D23 Mehta, H. C., and Chen, W.-F., "Structural Use of Sulfur for Impregnation of Building Materials," Report No. 390-9, 1974, Lehigh University, Fritz Engineering Laboratory.

The impregnation of building materials such as blocks and bricks with melted elemental sulphur increases the compressive strength by a factor of 2 and modulus of elasticity by a factor of 3. The permeability of sulphur impregnated materials to water and salt solutions is also greatly reduced. Due to the large surplus of sulphur and the low price, sulphur impregnation of building materials will find extensive use in tall building construction.

D24 Thaulow, N., "Sulphur-Impregnated Concrete, SIC," Cement and Concrete Research, Vol 4, Pergamon Press, 1974.

The impregnation of hardened, dry specimens of portland cement concrete with melted elemental sulphur increases the compressive strength by a factor of 2.7. The compressive strength of sulphur-impregnated concrete (SIC) with 8.4 percent sulphur by weight is  $174 \text{ MN/m}^2$  (25,300 psi). Due to the large surplus of sulphur and the low price, SIC might be a useful alternative to polymer-impregnated concrete, PIC.

1975

- D25 Currell, B. R., Williams, A. J., Mooney, A. J., and Nash, B. J., "Plasticization of Sulfur," Proceedings, Advances in Chemistry Series, Series No. 140, 1975, pp 1-17.

A method, using differential scanning calorimetry, has been developed to estimate quantitatively orthorhombic and monoclinic sulfur in sulfur materials. Sulfur cooled from the melt at  $120^\circ\text{C}$  immediately gives monoclinic sulfur which reverts to orthorhombic sulfur within 20 hr. Limonene, myrcene, alloocimene, dicyclopentadiene, cyclododeca-1,5,9-triene, cycloocta-1,3-diene, styrene, and the polymeric polysulfides, Thiokol LP-31, -32, and -33 each react with excess sulfur at  $140^\circ\text{C}$  to give a mixture of polysulfides and unreacted sulfur. In some cases substantial amounts of this unreacted sulfur may be held indefinitely in a metastable condition as monoclinic sulfur or " $\text{S}_8$  liquid." Limonene, myrcene, and dicyclopentadiene are particularly effective in retarding sulfur crystallization.

- D26 Gamble, B. R., Gillott, J. E., Jordaan, I. J., Loov, R. E., and Ward, M. A., "Civil Engineering Applications of Sulfur-Based Materials," New Uses of Sulfur, pp 154-166, 1975, Washington, J. R. West, ed.

The current surplus of elemental sulfur, principally in Western Canada, raises the possibility of using sulfur or materials using sulfur as a binder in a variety of civil engineering applications. The strength of sulfur varies indirectly with the hydrogen sulfide concentration. The creep rate of sulfur at room temperature is high and is temperature dependent. As expected, the creep rates of composites containing sulfur as a binder are also relatively high compared with conventional concretes. Depending on the mineralogical composition of the soil, and in the absence of swelling clays, sulfur has potential for soil stabilization. Lastly, a lightweight sulfur material was produced using fly ash. Other additives were used to create foams with limited success.

- D27 Limsuwan, E., and Fowler, D. W., "Sulfur-Impregnated Concrete," Apr 1975, The University of Texas at Austin, Austin, Tex.

Since impregnation techniques have been developed to produce polymer-impregnated concrete, the techniques of using sulfur instead of polymers to produce sulfur-impregnated concrete are under study.

Impregnation of concrete cylinders, slabs, bricks, and concrete blocks have been performed at Lehigh University as well as impregnation of concrete cylinders in Canada. Different techniques have been developed at the University of Texas at Austin. They are being studied in both slabs and cylinders. Included in the report are conclusions based on the study parameters.

D28 Loov, R. E., "Sulphur Concrete - State of the Art in 1974," *Second International Symposium on Concrete*, Report No. CE75-2, 1975, Monterrey, N. L., Mexico.

This report discusses sulphur concrete and its properties and characteristics. It also presents advantages and disadvantages of its use. Included in the report are the results of investigations on proportioning, mix design, strength gain, resistance to chemical attack, freeze-thaw, and creep properties of sulfur concrete.

D29 Malhotra, V. M., et al., "Development of High Strength Concrete at Early Ages Using a Sulphur Infiltration Technique," *Polymers in Concrete*, The Concrete Society, London, May 1975, pp 276-281.

This paper reports the results of an investigation in which a simple infiltration technique has been developed to produce high strength sulphur concrete at early ages from portland cement concrete of low cement content.

This new type of sulphur-impregnated concrete developed from low-strength portland cement concrete shows phenomenal improvements in its mechanical and elastic properties and durability characteristics.

The sulphur-infiltration method employed is simple, inexpensive, and can be easily adopted by the precast concrete industry. The sulphur-impregnated concrete could find wide use in the manufacture of special high-strength items such as concrete poles, pipes, and small precast units for outdoor use.

D30 Malhotra, V. M., "Sulfur-Infiltrated Concrete," *Concrete Construction*, Vol 20, No. 3, Mar 1975.

Research to produce concretes with high strength at early ages at a price competitive with conventional concrete or cheaper is described. Expensive monomers that require high pressure to impregnate the concrete were ruled out. Instead, simple and effective procedures for using cheaper materials such as sulfur were sought.

The work has resulted in a new type of high-strength concrete made from lean, 2-day-old conventional concrete, using sulfur infiltration technique. In the laboratory the method has consisted of moist-curing fresh concrete specimens for 24 hr, drying them at 250 degrees F (121 degrees C) for 24 hr, immersing them in molten sulfur under vacuum for 2 hr, releasing the vacuum and soaking them for an additional half hour, then removing them from the sulfur to cool. They are tested 1 to 2 hr later. In a simplified version of the above process, vacuum is eliminated and immersion time in molten sulfur is increased to 4 hr.

Phenomenal increases have been obtained in the mechanical and elastic properties of sulfur-infiltrated specimens. The compressive strengths increased about ninefold over those of the reference moist cured specimens, which were about 1000 psi (70 kilograms force per square centimetre). A corresponding increase was observed in the flexural strength of the infiltrated test prisms.

The sulfur-infiltrated specimens are in excellent condition after 800 cycles of freezing and thawing, whereas the relatively low-strength reference moist-cured specimens had completely disintegrated after 40 cycles.

Sulfur-infiltrated concrete should have applications in pavements, bridge decks, and many precast products.

D31 Malhotra, V. M., *Discussion of, "Sulphur Impregnated Concrete, SIC," N. Thaulow, Cement and Concrete Research, Vol 5, 1975.*

The world-wide shortage of materials has also affected sulphur and, as of July 1974, the price of sulphur is about \$25.00 (U. S.). This is an almost fourfold increase in less than 2 yr, and it is possible that the price may even go higher. Thus, the price comparison as given by the author, that sulphur is 70 times cheaper than methylmethacrylate is no longer valid. Furthermore, the projection that the inventory of elemental sulphur will accelerate to about 50 million tons by the end of 1980 has been questioned.

It should be pointed out that at elevated temperature, sulphur infiltrated concrete will suffer from the same disadvantages as the polymer impregnated concrete because sulphur melts at about 112°C. Thus, like the P.I.C., the sulphur infiltrated concrete cannot be used for load bearing members in structures where there is a possibility of exposure to high temperatures. However, like P.I.C., sulphur infiltrated concrete is ideally suited for small precast unit.

Research at the Candian Mines Branch, Ottawa, is being directed at making the impregnation procedures simple and economically competitive with conventional portland cement concrete. Preliminary results are encouraging. It appears that the impregnation cycle which normally consists of 28-day curing, drying, impregnating, and testing can be considerably shortened and high strength sulphur infiltrated specimens can be produced in less than three days after mixing concrete.

D32 Malhotra, V. M., *"Development of Sulfur-Infiltrated High-Strength Concrete," Proceedings, American Concrete Insitute Journal, Vol 72, No. 9, Sep 1975.*

Sulfur-infiltrated, high-strength concrete has been developed at early ages from 2-day-old conventional concrete containing low cement content. Two infiltration procedures have been employed, immersing both and immersing both under vacuum.

Satisfactory high-strength concretes have been produced using the above procedures, with superior results being obtained using the immersion with vacuum. Specimens exhibited higher strength and resistance to freeze-thaw cycles.

D33 "Sulphur-Impregnated Pipe," Proceedings, Journal of American Concrete Institute, Vol 72, No. 12, 1975, p N28.

Sulfur-impregnated sewer pipe is being put down in four Texas cities as part of an Environmental Protection Agency/Texas Water Quality Board study.

The program is designed to reduce the problems of corrosion and increase the strength of the pipe. One thousand feet of pipe will be put down in Dallas, 200 ft in Beaumont, and 100 ft each in Harlingen and Pecos. The pipe and transportation have been donated by Gifford Hill Pipe Co. of Dallas, and its subsidiary, Mission Concrete Pipe Co. of San Antonio. The cities' public works departments will do their own installation.

The four cities were chosen because they represent different environmental conditions which can affect the life of the pipe.

#### 1976

D34 Chen, W.-F., Mehta, H. C., and Slutter, R. G., "Sulfur- and Polymer-Impregnated Brick and Block Prisms," Journal of Testing and Evaluation, Vol 4, No. 4, Jul 1976, pp 283-292.

The objective of this paper was to demonstrate the applicability of sulfur as an attractive substitute to monomers for impregnation. It was demonstrated that sulfur impregnation of building block and brick units and prisms, carried out at atmospheric pressure using a simple process developed in the laboratory, could give equivalent relative strength increase compared to polymethyl methacrylate-impregnated units and prisms. Sulfur impregnation showed greater than 90 percent reduction in water absorption and virtually no acid attack. This suggests possible applications of treated masonry to sewage pipes and culverts, to acid treatment vessels and pump beds, and to enhance the strength and durability of low-quality masonry.

D35 Lee, D. Y., and Klaiber, R. W., "Fatigue Behavior of Sulfur Concrete," New Horizons in Construction Materials, Vol 1, 1976, pp 363-375.

Although other mechanical properties of sulfur concrete were determined in this study, the main objective was to determine the fatigue characteristics of sulfur-concrete.

Within the limited scope of this investigation with the materials studied, the experimental results indicated:

1. Sulfur concrete designed based on voids-filling and workability can be made with many combinations of aggregate type and grading, and with strength properties equivalent or superior to conventional portland cement concrete.

2. Sulfur concrete, though having other physical properties similar to that of conventional concrete, showed drastically different fatigue behavior in that: (1) it can withstand much higher flexural

stresses in terms of percent modulus of rupture, and (b) there appears to be an endurance limit.

3. There is a stress or strain hardening effect for sulfur concrete under repeated loading.

D36 Malhotra, V. M., et al., "Long-Term Strength and Durability of Sulphur-Infiltrated Concrete," International Symposium, Sep 1976.

This paper presents data on long-term strength and durability of sulphur-infiltrated concrete. The long-term data indicate that, after 18 months of storage under ambient room conditions, nonair-entrained, sulphur-infiltrated concrete with a water/cement ratio of 0.80 had compressive and splitting-tensile strengths of 12,170 and 1,235 psi (83.9 and 8.5 MPa), respectively. Corresponding strengths of the infiltrated concrete at 56 hr were 11,180 and 1,330 psi (77.1 and 9.2 MPa), respectively, indicating there was no significant change in strength with age. The compressive and splitting-tensile strengths of reference uninfiltrated concrete at 56 hr were 860 and 190 psi (5.9 and 1.3 MPa), respectively.

The sulphur-infiltrated test specimens withstood exposure to accelerated freezing and thawing remarkably well, the majority showing no significant distress after 1000 cycles. The compressive and flexural strengths remained almost unchanged compared to the reference specimens.

The sulphur loading of nonair-entrained, infiltrated concrete specimens ranges from 13 to 15 percent; the loading decreases with decreasing water/cement ratio. Corresponding values for air-entrained concrete specimens were about 18 percent.

The infiltrated concrete specimens showed excellent resistance to highly corrosive sodium sulphate solutions, both in laboratory experiments and in field studies. Their performance in alkaline solutions was poor, however, because sulphur was leached from the concrete.

D36(1) Malhotra, V. M., Soles, J. A., and Carette, G. G., "Research and Development of Sulphur-Infiltrated Concrete at CANMET, Canada," Report MRP/MSL 76-70 (OP&J), Mar 1976, Mineral Sciences Laboratories.

This paper presents research and development work being performed at CANMET on sulphur-infiltrated concrete. Two infiltration procedures are described.

The paper is divided into two parts. Part I deals primarily with long-term strength and freeze-thaw durability of sulphur-infiltrated concrete. Part II describes the performance of sulphur-infiltrated concrete in acid and alkaline solutions.

The long-term strength data indicate that the strengths achieved at 56 hr are maintained up to 540 days at least. There are no signs of retrogression in strength with ages. For a concrete mix with a water/cement ratio of 0.80, the compressive and splitting tensile strengths at 540 days were 12,170 and 1,235 psi (83.91 and 8.51 MPa), respectively;



the corresponding strengths at 56 hr were 11,180 and 1,330 psi (77.08 and 9.15 MPa).

The sulphur-infiltrated specimens have performed excellently in accelerated freeze-thaw cycling. After 1000 cycles, the length changes in prisms were only 0.08 percent, and there were no significant changes in compressive and flexural strengths of test specimens compared to the reference specimens.

Infiltration of concrete with sulphur inhibits attack by acid solutions and significantly reduces deterioration in concentrated sodium sulphate solutions.

D36(2) *Malhotra, V. M., et al., "Development of High Strength Concrete at Early Ages Using a Sulphur Infiltration Technique," Polymers in Concrete, First International Congress on Polymer Concretes, The Concrete Society, London, 1976, pp 276-281.*

This new type of sulphur-impregnated concrete developed from low-strength portland cement concrete shows phenomenal improvements in its mechanical and elastic properties and durability characteristics.

The sulphur-infiltration method employed is simple, inexpensive, and can be easily adopted by the precast concrete industry. The sulphur-impregnated concrete could find wide use in the manufacture of special high-strength items such as concrete poles, pipes, and small precast units for outdoor use.

D36(3) *Malhotra, V. M., and Winer, A., "The Use of Asbestos Fibre in Portland Cement and Sulphur Concretes," Can Min Metall Bull, Vol 69, No. 767, 1976, pp131-138.*

In recent years, attempts have been made to improve the engineering properties of concretes by the incorporation of small-diameter fibers such as nylon and steel. Favourable results have been reported. This paper describes the use of chrysotile asbestos fiber in portland cement and sulphur concretes. This type of fiber was selected because of its low cost and commercial availability in Canada.

In portland cement concretes, one grade of asbestos fiber comprising a range of lengths and diameters was used in amounts varying from 0.5 to 3 percent of the weight of cement. The addition of this fiber resulted in considerable loss of workability, with little or no gain in strength properties. It has been postulated that to successfully use asbestos fiber in portland cement concrete to improve its flexural strength, some mechanism is needed for encapsulating the fibers or making them hydrophobic.

The use of asbestos fiber in sulphur concrete (concrete that does not contain portland cement) was relatively more successful. The fiber provided nuclei for the hot sulphur, resulting in smaller crystal growth along the fiber axis on cooling, with some increase in strength.

D37 *Tashiro, C., and Kubota, H., "Sulfuric Acid Resistance of Cement Mortar Impregnated with Pulp Waste Liquid," Cement and Concrete Research, Vol 6, No. 6, 1976, pp 727-732.*

In sulfuric acid for 56 days, the corrosion rate of the mortar treated with pulp waste liquid are 52 percent in 1 percent sulfuric acid solution, 55 percent in 2 percent solution, 26 percent in 5 percent solution, 29 percent in 10 percent solution, compared to that of the mortars not treated with liquid. It is assumed that the increase of sulfuric acid resistance is due to the protective coating action by a component of waste pulp liquid and also characteristic gypsum which was formed by reaction between the mortar and sulfuric acid.

1977

D38 *Berry, E. E., et al., "Leaching of Sulphur and Calcium From Sulphur-Infiltrated Concrete by Alkaline and Neutral Aqueous Media," Cement and Concrete Research, Vol 7, No. 2, Mar 1977.*

It has been found that calcium and sulphur are leached by alkaline or neutral aqueous media from sulphur-infiltrated concrete. From chemical examinations and Raman spectroscopy it has been shown that sulphur in the leachate is present as polysulphide anions. It is postulated that homonuclear polymeric anions of sulphur are formed in the presence of moisture when molten sulphur infiltrates concrete. The soluble calcium polysulphides so formed can then be leached by water.

D39 *Sheppard, W. L., Jr., "Potential Weakness of Sulfur," Concrete Construction, Apr 1977.*

Sulfur mortars were used for a time in the early 1930's to seal joints in concrete pipe sections. These were effective for a brief period of time but after only 6 to 12 months they fell out of the joints. The problem is reported to be associated with a series of complex chemical reactions involving calcium carbonate, oxygen and sulfur whereby calcium sulfide and calcium sulfate are formed and can be leached away. The calcium sulfate can also cause expansive reaction in the concrete.

Sulfur mortars, though stable to nonoxidizing acids, can be attacked by oxidizing acids, particularly at high concentrations. They can also be attacked by alkali in the pH range above 10. Sulfur mortars withstand a number of solvents but are dissolved by others such as oils, petroleum derivatives, carbon disulfide, water solutions of ammonium polysulfide, and other polysulfide solutions. They are attacked by organic compounds related to phenol and are slowly dissolved by some aromatic compounds. In addition to these reactions, sulfur may combine with metallic salts, especially those of copper and beryllium, to form insoluble metallic sulfides which disrupt the mortar.

Sulfur coatings and sulfur mortars have a measurable fluid absorption, usually in the range of 0.2 to 0.4 percent. For this reason any liquids contained in sulfur-lined tanks will be absorbed to some extent and damage the sulfur if they happen to be reactive with it.

- D40 Shrive, N. G., et al., "Basic Properties of Some Sulphur-Bound Composite Materials," Materials Science and Engineering, Vol 30, 1977, pp 71-79.

Sulphur can be used as a cementing agent to produce composite materials with potential insulating and/or constructional applications. Six basic engineering properties of ten sulphur-cemented composites have been determined and compared with those of raw sulphur. The method of determining the properties is indicated and the different factors which affect the various properties are discussed with reference to the values obtained for the 11 materials. The properties determined were density, compressive strength, modulus of rupture, modulus of elasticity, coefficient of thermal expansion and coefficient of thermal conductivity.

- D41 Soles, J. A., Carette, G. G., and Malhotra, V. M., "The Stability of Sulfur-Infiltrated Concrete in Various Environments," Report No. MRP/MSL 77-99, Feb 1977, Canadian Center for Mineral and Energy Technology.

Experiments with sulphur-infiltrated concrete have shown it to be more durable in most environments than untreated normal portland cement concretes. Long-term maintenance of strength indicates that the condition is stable indefinitely in ambient, dry to humid conditions, and can endure extended exposure to cyclic freezing and thawing. However, sulphur is leached from the infiltrated concrete by aqueous media, which causes deterioration and may greatly affect its long-term durability in such environments. This unstable condition is apparently related to the presence of polysulphide anions formed during the infiltration process and found to be highly soluble in the alkaline pore solutions of wet concrete. The character of the products of infiltration and leaching are described and the reactions involved are discussed.

#### 1978

- D46 Ammar, R., et al., "Use of Sulfur to Repair Damaged Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 381-398.

The paper reports the results of using molten sulfur to impregnate and thereby repair portland cement concrete specimens that had been previously damaged. Concrete was damaged by the following methods: loading cylinders in uniaxial compression up to ultimate load, exposing beams to continuous cycles of freezing and thawing, and exposing specimens to elevated temperatures. The effectiveness of the repair was assessed by comparing original and repaired compressive strengths of cylinders and by comparing the resistance of the original and repaired concrete beams when subjected to cycles of freezing and thawing (indicated by measuring the resonant frequency). The results indicated that sulfur impregnation was effective in repairing concrete that had been damaged by mechanical loading, exposure to freeze-thaw cycles, and

exposure to temperatures less than 750°F (399°C). Specimens exposed to a temperature of 1000°F (538°C) regained their original compressive strengths but performed poorly when exposed to freeze-thaw cycles.

- D47 Berry, E. E., and Hope, B. B., "Preparation and Properties of Sulphur-Infiltrated Autoclaved Concrete Specimens," MRP/MSL 78-146 (OP&J), Jul 1978, CANMET, Department of Energy, Mines, and Resources, Ottawa.

Autoclaved-concrete specimens were made using combinations of portland cement, silica flour, and fly ash as cementitious binders. These were infiltrated with liquid sulphur at 150°C. The rates of ingress of sulphur, the extent of sulphur infiltration attained under simulated production conditions and the nature of the porosity of the uninfiltrated concretes were found to be profoundly influenced by the chemical composition of the cementitious binder. Mechanical properties of the infiltrated concretes were found to be related to the degree of sulphur-infiltration. The greatest strengths were attained by total infiltration of initially weak concretes.

A practical infiltration-autoclave cycle is suggested for possible use with portland cement concretes not containing additional silica flour or fly ash.

- D48 Blight, L., Currell, B. R., Merrall, R. E., Scott, R. A. M., and Stillo, C., "Aging Characteristics of Modified Sulphur Materials and of Their Composites With Polypropylene Fabrics," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 145-161.

To assist in the choice of suitable impregnants and to provide fundamental information for other applications, the aging characteristics of a wide range of sulphur materials prepared using olefin modifiers have been studied. This paper includes a progress report of these studies. A second part of the paper contains an initial report on the aging characteristics of the impregnated fabrics.

The use of olefin modifiers substantially retards the initial crystallisation of sulphur materials. However, all the materials examined show the effect of crystallisation on the mechanical properties over the total period (up to 18 months) so far examined. These results indicate that for the impregnation of polypropylene fabrics suitable impregnants may be selected to give rigid composites, but although materials prepared as indicated may initially give flexible products all these on aging may be expected to lose at least a degree of their flexibility.

- D49 Brown, T. G., and Baluch, M. H., "An Investigation Into The Strength and Durability of Sulphur Infiltrated Concrete," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 115-125.

Several authors, including Thaulow, Malhotra, and Lehair, have reported on the development of a Sulphur Infiltrated Concrete (SIC) and its evaluation in terms of strength and durability. Though several variables have already been investigated, the mix design characteristics of SIC and its resistance to hostile environmental factors peculiar to desert climates have not been reported.

Based on the aforementioned, the objective of the work in this presentation was two-fold, namely (a) identification of mix design variables and their effects on the compressive strength of SIC and (b) durability studies in the form of influence of (i) local untreated water (ii) local aggregate and (iii) elevated temperature on the compressive strength of SIC.

D50 Carette, G. G., et al., "CANMET Researches In Sulfur-Infiltrated Concrete," Second International Congress on Polymers in Concrete, Austin, Tex., Oct 1978, pp 503-518.

This paper presents a review of the researches undertaken at CANMET to develop and evaluate the strength and durability characteristics of sulfur-infiltrated concrete.

The strength of sulfur-infiltrated concrete is discussed in terms of influence of initial composition and porosity, infiltration procedures and sulfur loadings. Long-term strength data are presented and indicate that sulfur-infiltrated concrete remained indefinitely stable in relatively dry ambient conditions.

The stability of sulfur-infiltrated concrete in various environments is discussed in the light of results of laboratory and field investigations.

In acid conditions, sulfur-infiltrated concrete provides a better resistance to corrosion than uninfiltated concrete, particularly under high concentrations. However, it is shown to perform poorly when exposed to strongly alkaline media, the sulfur being rapidly leached out of the concrete, which leads to the destruction of the infiltrated matrix. It appears on the other hand, to be immune to sulfate attack. However, sulfur-infiltrated concrete is shown to be inherently unstable in aqueous media.

D51 Feldman, R. F., "The Prediction of Mechanical Properties and The Durability of Sulphur-Impregnated Portland Cement Paste Bodies," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 251-266.

This paper presents the results of sulphur impregnation of a variety of portland cement-based porous systems and porous glass. A high degree of impregnation was achieved and thus bodies approximating nonporous uniformly impregnated specimens were obtained; an attempt is made here to correlate Young's modulus and microhardness with basic properties of the impregnated body.

- D52 *Feldman, R. F., and Beaudoin, J. J., "Some Factors Affecting Durability of Sulphur-Impregnated Porous Bodies," Cement and Concrete Research, Vol 8, 1978, pp 273-282.*

The effect of impregnation on long-term durability has been investigated by exposing 1.3-mm-thick specimens of sulphur-impregnated, autoclaved, portland cement-silica mixtures, room-temperature-cured pastes, and porous glass to various liquids including water.

All impregnated bodies were permeable to vapours, and matrices with specific surface areas in excess of 20 m<sup>2</sup>/g and impregnated with sulphur were subject to high internally-generated local stresses when exposed to water and other vapours, leading to possible failure.

- D53 *Gamble, B. R., and Shrive, N. G., "Creep in Sulphur," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 503-518.*

This paper makes use of current knowledge of sulphur and other materials to suggest possible processes which may cause creep in construction materials containing elemental sulphur. As well, preliminary experimental information from creep tests on specimens containing various species of elemental sulphur is presented.

Preliminary experiments show that creep in elemental sulphur is greatly affected by the methods of preparation and curing prior to testing.

More creep occurs in specimens where larger proportions of metastable material might be expected; under some circumstances, however, an opposite trend attributed to increasingly severe stress concentrations is apparent. Hence, the experiments underline the complexity of even the elemental sulphur system.

- D54 *Groll, L., Budescu, M., Taranu, N., and Ciornei, R., "Effect of Preparation on Quality and Mechanical Behaviour of Sulphur-Infiltrated Concrete," Proceedings, International Conference on Sulphur In Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 107-113.*

The properties of sulphur-infiltrated concrete as a heterogeneous system depend on the physical and chemical characteristics of each component and also on the strength and stiffness of the interfacial layer.

Although some authors consider the infiltrated sulphur as an inert component, some research work in progress has shown that sulphur may favour the formation of calcium hydroxide from calcium carbonate. This influence, based on a certain chemical interaction between sulphur and the matrix made the interfacial layers more diffuse and assured a gradual transition from one phase to another.

- D55 *Hawkins, A. T., "Sulphur Impregnated Concrete for Large Sewers," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 217-234.*

Laboratory tests suggest that impregnating concrete with sulphur will at least double the resistance of the concrete to attack by  $H_2SO_4$  acid. Because this acid is the primary agent for corrosion of sewers in the Middle East and elsewhere, the use of sulphur impregnated concrete could double the life of the sewers in corrosive conditions. The cost of impregnating 900-mm pipes with sulphur has been estimated at 19 percent of the pipe cost, which compares favourably with coating or lining which has been variously estimated at 35 percent to 80 percent of the pipe cost.

Complete replacement of a sewer at the half life of a sulphur protected sewer would cost at least 100 percent of the original pipe and installation cost and would probably involve extra expense in disturbance to connected plant and buildings. The economic argument for using sulphur impregnated concrete sewers in corrosive conditions thus looks very promising.

D56 Hope, B. B., and Nashid, M. S., "The Physical and Mechanical Behavior of Sulphur-Impregnated Concrete Materials," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 71-89.

This investigation is concerned with the effect of various sulphur contents on the mechanical and physical properties of a wide range of concrete, mortar, and paste specimens. A number of flexural beams both plain and reinforced were impregnated and tested under two-point loading. Stress-strain characteristics, flexural and shear cracking patterns, and deflection readings were recorded to failure.

Full sulphur impregnation resulted in comparable mechanical properties regardless of the original strength or maturity. However, in the case of partial impregnation, the rate of change of strength and elastic modulus and the variation of the results were increased for the originally weak and immature mixes.

Testing of reinforced impregnated beams showed a considerable improvement in the flexural and the shear strength of concrete. Failure was caused by the fracture of all flexural steel bars while the cracking of concrete was minimal. Higher steel ratios should be investigated in order to make full use of the improved compressive and bond strength of concrete.

D57 Hynes, J. B., Roberts, B., and Turner, C., "Liquid-Solid Sulphur Phase Changes and the Role of Molecular and Allotropic Interconversion in Determining Material Properties," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 197-216.

The balance of this paper describes a series of experiments based largely on the use of differential scanning calorimetry (DSC).

The amounts of the various metastable forms generated by particular thermal regimes and the rates of their interconversion as a function of environmental conditions are examined in detail with a view to

providing some guidelines for preferred operational practice in the preparation and application of sulphur composites in construction.

- D58 *Iakashvili, T. V., and Pirozmanishvili, O. O., "Control of Surface Erosion of Stone Materials by Saturation," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii I Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 99, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

In order to increase the durability of structures, studies were performed involving saturation of stone materials with various saturating compounds: epoxy oligomer in various solvents, organosilicon silicate, methylmethacrylate, melted sulfur, etc.

In addition to the study of the physical and mechanical properties of the saturated and unsaturated materials, the influence of the saturating compound on natural porosity and biologic stability of stone materials was studied.

The preliminary observations showed that the saturating compounds which are added can significantly increase both the strength and durability of certain stones used in the construction of architectural monuments.

- D59 *Johnston, C. D., "Preparation, Proportioning, and Properties of Sulphur Concretes," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 413-432.*

This report deals with the methods and quantities required to produce economical sulfur concretes. Topics discussed include: design, workability, use of additives, strength gain, time of set factors, and types of deterioration and the materials that cause such problems.

- D60 *Jordaan, I. J., Gillott, J. E., Loov, R. E., and Shrive, N. G., "Improved Ductility of Sulphur Concretes and Its Relation to Strength," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 475-488.*

The focus of the present paper is the ductility of sulphur concretes.

It was recognized in an earlier investigation that sulphur and sulphur mortars and concretes are extremely brittle materials, far more so than portland cement mortars and concretes.

In the present work, the importance of flexibility (as against rigidity) in materials such as coatings and of ductility (as against brittleness) in construction materials will be discussed, with reference to sulphur bonded materials. Formulations have been developed which



significantly increase the flexibility and reduce the brittleness of sulphur-based materials; the formulations involve, for the most part, the use of additives which involve small additional cost in the manufacture of the materials. The additives cause a reduction in strength and elastic modulus in addition to reducing the brittleness. It is noteworthy that the additives also improve considerably the resistance to disintegration in water.

D61 Kennepohl, G. J. A., and Hass, R. G. C., "Experience With Sulphur-Asphalt Paving Binders," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 339-354.

The Gulf Canada Sulphur-Asphalt (SA) Process which replaces up to 50 percent of the asphalt in a paving mix binder with sulphur provides such an alternative for paving materials. It, therefore, offers the potential for cost savings while providing increased design flexibility and greater structural capacity. In contrast to earlier efforts to use sulphur in paving, the Gulf Canada process represents the efficient use of a by-product rather than the disposal of a waste.

The Gulf Canada SA process is based on a comprehensive, coordinated program of field and laboratory testing. The general purpose of this paper is to summarize the experiences of the research and development program.

(1) A significant portion of asphalt can be replaced in conventional paving mixes by elemental sulphur to produce a new binder for high performance, flexible paving mixes.

(2) A commercial sulphur-asphalt module (SAM) has been developed for in situ production of an intermediate SA binder as an integral part of hot mix production.

(3) Conventional equipment can be used for SA mix production, material handling, and paving procedures.

(4) An SA pavement design technology has been developed which advantageously utilizes sulphur as an additional design variable for conventional pavements, pavements with low quality aggregate, and pavements for low and high service temperatures.

(5) The SA process with its simplicity of construction requirements provides an economically sound technology with direct savings on binder and aggregate and potential benefits related to improved service life, conservation of energy, extension of asphalt supply, and utilization of surplus sulphur.

D62 Kuntsevich, O. V., and Dzhashi, N. A., "Use of Sulfur to Improve the Physical and Mechanical Properties of Fine-Grain Concretes," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978),

Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 126, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

Experiments were performed on beam specimens measuring 4 by 4 by 16 cm, made of fine-grain concrete of the following compositions: 1, 1:3; W/C = 0.45; 2, 1:4; W/C = 0.45; 3, 1:7.3; W/C = 0.8. The materials used in all three compositions were identical. The specimens were saturated as follows: When the specimens reached 28 days of age, they were immersed in melted crystalline sulfur heated to 120 to 140 C, where they were held for 2.5, 3.5, 4.5, and 24 hr.

The data presented indicate that the greatest increase in strength was observed in fine-grain concrete of the composition C:S = 1:7.3 and W/C = 0.8. The improvement in the physical and mechanical properties of the concrete achieved by sulfur impregnation can be explained by plugging of the pores and cavities with sulfur, decreasing the total pore volume, but the improvement of the physical and mechanical properties also occurs if the total porosity of treated and untreated specimens is the same, a fact which was demonstrated in other experiments we performed.

D63 Laishley, E. J., and Tyler, M. C., "Biological Oxidation of Sulphur Construction Materials," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 171-180.

Recently preliminary findings of field test studies were reported of which significant populations of Thiobacillus were found in soils surrounding buried sulphur concrete cylinders; however, none were detected in these soils at the beginning of the experiments. It is too early to comment on what affect these Thiobacillus populations are having on sulphur concrete or the soil environment surrounding them.

In this report data are presented on laboratory experiments showing biological oxidation of sulphur construction materials and the use of biocides to protect these products from microbial attack.

D64 Lee, D. Y., Klaiber, R. W., and Khosraviani, S., "Fatigue Behavior of Improved Sulphur Concrete," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 489-502.

It has been clearly established that pavements are subjected to fatigue failure and virtually all modern rigid pavement design methods are based on fatigue life to account for repeated traffic loadings during the pavement design life to prevent cracking. If sulphur concrete is to become a substitute pavement material, knowledge of its fatigue characteristics is imperative. Although other mechanical properties of sulphur concrete were determined in this study, the main objective was to determine the effect of the additives, fly ash, and dicyclopentadiene, on the fatigue strength of sulphur concrete. Another

objective was to determine the strength properties and feasibility of recycled sulphur concrete.

Within the limited scope of this investigation the experimental results indicated:

1. Sulphur concrete, though having other physical properties similar to that of conventional concrete, showed drastically different fatigue behavior in that: (a) it can withstand much higher flexural stresses in terms of percent modulus of rupture, and (b) there appears to be an endurance limit.

2. Both additives investigated (dicyclopentadiene and fly ash) increased the modulus of rupture strength, however, dicyclopentadiene decreases the compressive strength while fly ash increased the compressive strength.

3. Sulphur concrete may be recycled without changing the strength properties significantly.

4. Fly ash improved the fatigue strength of sulphur concrete, however, dicyclopentadiene decreased the fatigue strength of sulphur concrete. Both compositions had greater fatigue strength than conventional portland cement concrete.

D65 Lee, D. Y., "Mechanical Properties of Weathered Sulphur-Asphalt Mixtures," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 377-388.

This paper presents the effects of natural weathering up to 72 months on the properties of sulphur-asphalt binders and compacted sulphur-asphalt concrete mixtures.

Eight sulphur-asphalt concretes and 16 sulphur-asphalt binders were prepared and have been weathered in Iowa since 1971. The following are some of the major observations up to 72 months:

1. Sulphur-asphalt binders hardened less during natural weathering than the same asphalt without sulphur.

2. Natural weathering of sulphur-asphalt concretes up to 66 months increased the mechanical stability of the mixes with little change in flow value.

3. The stability of sulphur-asphalt concretes peaked at an "optimum" sulphur content of about 3 percent by weight of aggregate (sulphur/asphalt ratio of 0.6).

4. The resilient modulus and tensile strength of sulphur-asphalt concretes increased with weathering; however, both resilient modulus and tensile strength of the weathered sulphur-asphalt concretes were lower than those of asphalt concrete without sulphur.

5. There were no significant differences in weight loss during weathering between compacted mixes with sulphur and without sulphur.

D66 Majidzadeh, K., and El-Mitiny, R., "The Feasibility of Using Sulfur in Bituminous Mixtures With Power Plant Bottom Ash Aggregates," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 389-412.

The scope of this investigation is to develop optimum mix designs for sulphur-ash mixtures with consideration to the specific physical and engineering properties of ash-asphalt-aggregate systems.

In this investigation, the results of the laboratory performance of bottom ash aggregate mixtures using sulfur-modified asphaltic binder are documented. The research investigation included two bottom ash aggregates and a uniform sand from Texas. The bottom ashes were also combined with limestone at a 60/40 ratio to obtain the same gradation.

D67 Malhotra, V. M., Carette, G. G., and Soles, J. A., "Long-Term Strength and Durability of Sulfur-Infiltrated Concrete," Polymers in Concrete - International Symposium, SP-58, pp 367-398, 1978, American Concrete Institute, Detroit, Mich.

This paper presents data on long-term strength and durability of sulfur-infiltrated concrete. The infiltration procedure consists of moist-curing fresh concrete specimens for 24 hr, drying them at 130 C (266 F) for 24 hr, immersing them in molten sulfur under vacuum for 2 hr, releasing the vacuum and soaking them for an additional 0.5 hr, and then removing them from the sulfur to cool. Strength testing is done 1 to 2 hr later.

The long-term data indicate that, after 18 months of storage under ambient room conditions, nonair-entrained, sulfur-infiltrated concrete with a water-cement ratio of 0.80 had compressive and splitting tensile strengths of 12,170 and 1,235 psi (83.9 and 8.5 MPa), respectively. Corresponding strengths of the infiltrated concrete at 56 hr were 11,180 and 1,330 psi (77.1 and 9.2 MPa), respectively, indicating there was no significant change in strength with age. The compressive and splitting tensile strengths of reference uninfiltrated concrete at 56 hr were 860 and 190 psi (5.9 and 1.3 MPa), respectively.

The sulfur-infiltrated test specimens withstood exposure to accelerated freezing and thawing remarkably well, the majority showing no significant distress after 1000 cycles.

Infiltration of portland cement concrete with sulfur makes it more durable in acidic environments.

The infiltrated concrete specimens showed excellent resistance to highly corrosive sodium sulfate solutions, both in laboratory experiments and in field studies. Their performance in alkaline solutions was poor, however, because sulfur was leached from the concrete.

D68 Malhotra, V. M., "Mechanical Properties and Freeze-Thaw Resistance of Sulphur Concrete," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 433-452.

This investigation was undertaken to develop satisfactory mixing procedures for making sulphur concrete and to determine its mechanical properties and its resistance to freezing and thawing.

Elemental sulphur can be combined with mineral aggregates to produce high-strength concrete. The best content of sulphur in the

mixes studied seems to be between 23 and 25 percent by weight of aggregates.

The most satisfactory way to make sulphur concrete in a laboratory is to add sulphur to ovenheated aggregates. External application of heat to the drum of the concrete mixer is neither desirable nor practical.

The test specimens of sulphur concrete had high compressive and flexural strengths. However, there were indications of retrogression in strength with age.

The high within-batch and between-batch variations in compressive strength stem from the mixing and casting difficulties.

Sulphur concrete has poor resistance to repeated cycles of freezing and thawing. This would discourage its use as a structural concrete. However, this should not preclude its applications where sulphur concrete is not exposed to freeze-thaw conditions.

D69 *McBee, W. C., and Sullivan, T. A., "Development of Specialized Sulfur Concrete," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 453-473.*

This report concerns the development and testing of specialized sulfur concretes, designed for use in environments where resistance to corrosion by acidic or salt solutions is desired. Previous research had shown that the type of aggregate used in making sulfur concretes had an effect on the properties and performance of the material. It was found that basic aggregates such as limestone formed higher strength materials, possibly owing to the formation of a chemical bond between the sulfur and the aggregate. With acidic aggregates, composed primarily of silica, lower strengths were developed, and there was less evidence of chemical bonding between the sulfur and aggregate. Because the mineral aggregates also come into contact with the corrosive media, the present study was designed utilizing two different homogeneous aggregates, limestone and quartz, to develop materials for testing in the various corrosive environments. The concretes were characterized for mechanical properties, freeze-thaw durability, and corrosion resistance in acid and salt solutions.

D70 *McBee, W. C., Sullivan, T. A., and Saylak, D., "Recycling Old Asphaltic Pavements With Sulfur," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 355-375.*

The feasibility of using sulfur to soften or reduce the viscosity of the oxidized asphalt binder in old asphaltic pavements by recycling such materials was demonstrated on a laboratory scale. Three sources of discarded, oxidized pavements were investigated. One contained a volcanic type aggregate, one a limestone aggregate, and the third a combination of volcanic and limestone aggregate. The aggregates in all three met Type IVb asphalt Institute specifications for aggregate grading. With all three materials, a mix design incorporating the addition of 1.25 wt-pct sulfur (16 to 26 wt-pct of the binder) to the

reheated material for recycle and remixing was successful in reducing the hardening effect of aging. Additional asphalt was also added to coat any bare aggregate materials and give a compacted product with approximately 3 pct voids. Products were prepared with properties similar to those of virgin asphaltic concretes.

D71 Mehta, P. C., and Chen, S.-S., "Studies on Improving Moisture Resistance of Sulfur-Infiltrated Mortars," Dec 1978, University of California, Civil Engineering Department, Berkeley, Calif.

High-strength products can be made by sulfur infiltration of dried portland cement mortars or concretes. However, on exposure to moisture, strength deterioration takes place due to complex chemical reactions involving  $\text{Ca}(\text{OH})_2$  and sulfur.

This paper presents the results of two series of tests. In the first series an attempt was made to inhibit the reaction between sulfur and  $\text{Ca}(\text{OH})_2$  by coating the  $\text{Ca}(\text{OH})_2$  with a film of insoluble calcium salts. In the second series, cements which did not contain  $\text{Ca}(\text{OH})_2$  in hydration products were investigated for sulfur infiltration. Both the approaches gave encouraging results in improving moisture resistance of sulfur-infiltrated mortars.

D72 Mirkovich, V. V., "Thermal Conductivity of Sulphur-Infiltrated Concrete," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 547-555.

In this study thermal conductivities of three partially and fully sulphur-infiltrated concrete specimens were measured and the results compared with the values available in literature for noninfiltrated concrete.

The specimens used for thermal conductivity measurements were cast as cylinders, 4 in. in diameter, 8 in. long. After being moist cured under standard CSA A23 conditions for 24 hr, they were oven-dried at approximately 275°F and then infiltrated with sulphur. Infiltration of sulphur in dry specimens was performed either in vacuum or at atmospheric pressure. In the latter case the infiltration procedure lasted 24 hr. Specimens 110 and 117, used for this study, were vacuum-infiltrated, whereas specimen 163 was infiltrated at atmospheric pressure.

For thermal conductivity measurements discs 1 in. thick and 4 in. in diameter were cut from the original 4- by 8-in. cylinders. However, after the specimens were ground to the required dimensions, it became evident that the sulphur infiltration was not complete. The thermal conductivity measurements were nevertheless performed on these partially infiltrated specimens. After the measurements were completed, the specimens were once again infiltrated using the vacuum method developed by Malhotra et al.

D73 Muir, D. R., "Sulphur Supply/Demand and its Relevance to New Sulphur Products: An Examination of Their Economic Viability," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 1-16.

The purpose of this paper is to discuss the economic competitiveness of sulphur asphalts and concretes, under both present and expected market conditions. General price trends for sulphur can be examined in the context of supply/demand forecasts to determine whether any major price disruptions might be expected due to imbalanced supply and demand. With price trends for sulphur and for raw materials used in competing products (asphalt, portland cement, etc.), material price indices can be developed. By applying these indices to current product economics, the cost competitiveness of sulphur and conventional products can be projected. As with any forecast, the degree of accuracy cannot be great; however, a trend can be established.

D74 Neville, A. M., "Essentials of Strength and Durability of Various Types of Concrete With Special Reference to Sulphur," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 17-44.

The title of the paper refers to the essentials of strength and durability of concrete, which is about all there is to say about concrete. However, it is not suggested that the issue is good concrete but concrete which is good for the job in hand. The distinction is clear: it is uneconomical to seek perfection, to produce the best that money can buy; engineers should seek what is good enough for the given purpose at the lowest cost.

It is proposed, therefore, to consider first the fundamental factors influencing strength of concrete, volume of pores, types of pores, and flaws. The paper will then review composites in a slightly broader way, considering the role of an additive like a polymer on the volume of pores and on the interface bonds, but stopping short of consideration of fibres, with their especial crack-arresting function. In all this, reference will be made to sulphur, very much a Canadian contribution, not to say specialty.

In addition to strength, it is proposed to consider elasticity, stress-strain curve and strain at failure, and finally durability.

D75 Orlovskii, Iu. I., "Study of Technology of Manufacture and Properties of Concrete Using Sulfur and Wastes from the Production of Sulfur," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 127, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.

The L'vov affiliate of UkrNistromproekt, in cooperation with the Polymer Concrete Laboratory of the Scientific Research Institute for Reinforced Concrete Products, USSR State Planning Commission, is developing manufacturing technologies and studying the properties of heavy and light concretes made by two methods: saturation of dried

concrete with a sulfur melt (under normal conditions and under a vacuum) and with subsequent melting of the sulfur, distributed in the mass of the freshly formed concrete with gradual drying to a temperature of 145 to 150 C.

The strength of the concrete after sulfur impregnation depends on the quantity of sulfur absorbed, the method and time of impregnation. Impregnation of concretes improves all of their strength and deformation characteristics by several times, decreases water absorption by a factor of 15 to 20, significantly increases resistance to cold and corrosive media, and improves the heat-physical properties.

D76 Patureov, V. V., Volgushev, A. N., and Orlovsky, Yu. I., "Application Potentialities and Technology Peculiarities for Impregnation of Porous Space in Building Materials by Sulphur Melt," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 45-52.

Discovering possibilities for impregnating with less expensive and available materials has always been an important problem. Sulphur may with good reason be considered one of these materials.

The tests conducted have shown that one can change considerably the physicomechanical properties of initial building materials such as sand concretes, heavy concretes, ash-concretes, concretes of water-soluble glass, asbestos cement and building ceramics by impregnating the porous space with molten sulphur.

Different depths of sulphur penetration can be obtained depending on regime. With surficial impregnation the protective coating of the structure acquires an increased density and resistance to different actions. With deep or complete impregnation, not only is the resistance of the structure to external effects of environment increased, but also its bearing capacity.

Sulphur impregnation in this case should be considered as a continuation of a main technological process for manufacturing products with improved anticorrosive properties. With proper organization, the consumer specifies the products requiring impregnation by sulphur and receives them at higher prices, with due regard for impregnation expenses.

D77 Patureov, V. V., and Volgushev, A. N., "Main Characteristics of Polymer Concretes Impregnated with Sulfur," VIII International Congress of the Federation Internationale de la Precontrainte, 1978; Translated from Russian.

The most important problems of compacting porous space of building materials by impregnating them with sulfur are discussed. Physico-mechanical properties of cement concretes were mainly studied. The impregnation is shown to increase strength of concretes to a high degree. The subject of research was also the influence of the impregnation on water absorption, resistance to aggressive environment, and frost resistance.



The possibility of impregnating such materials as asbestos cement, sodium silicate concrete, acid-resistant ceramics is shown.

Experiments have proved a great increase in durability of concretes impregnated with sulfur. Comparisons with polymer-impregnated concretes are made.

Basic operations for impregnating building components in melted sulfur are described. Main parameters of the process are presented.

The most promising applications of concretes and other building materials impregnated with sulfur are indicated.

D78 Paulson, J. E., Campbell, R. W., and Simic, M., "Sulfur-Based Composites In The Construction Industry," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 127-143.

This paper will focus on the use of sulfur composites as protective coatings for portland cement concrete. Today this is one of the most commercially advanced uses for sulfur in construction.

D79 Pronk, F. E., and Soderberg, A. F., "Sulphur in Asphalt Paving," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 299-319.

A complete system for the production of sulphur modified asphalt hot-mix has been developed and successfully demonstrated with full-scale production facilities and conventional paving equipment.

Plant modification with the system developed is simple, relatively inexpensive and does not interfere with conventional hot-mix production. Furthermore, plant production is routine with no loss of capacity and is carried out with a minimum of fumes.

S/A emulsion composition needs to be optimized on the basis of anticipated project conditions, particularly with regard to low temperature performance. Provided field performance confirms the encouraging laboratory findings obtained by several research groups, sulphur modified asphaltic concrete will probably find acceptance in Canada and abroad.

D80 Remillon, A., Carpentier, A., and Dulout, C., "'Sodovia' - A Sulphur-Infiltrated Fabric: Manufacture and Application," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 163-170.

This study concerns a compound which consists of a nonwoven fabric impregnated with a direct distillation asphalt modified by sulphur.

D81 Samarai, M. A., "Sulphur as a Partial Substitute for Asphalt in Pavement Used Under Hot Weather Conditions," Proceedings, International Conference on Sulphur in Concrete, Ottawa, Ontario, 12-15 Sep 1978, pp 321-337.

Sulphur/asphalt mixture has been considered as a possible substitute for asphalt in road construction since 1936. Various studies since then have been conducted on the sulphur/asphalt mixes in France, U.S.A., and Canada. Frasch sulphur deposits in Iraq are available in large quantities while there is a shortage of asphalt which is needed for the vast number of roads under construction. One should also consider the diminishing reserves of petroleum and therefore to reduce the consumption of petroleum based products such as asphalt might be very desirable. On the other hand the availability of sulphur is increasing because of exploitation of natural deposits and because of sulphur being recovered from coal and natural gas. Therefore, it was decided to try the use of sulphur as a part-substitute for asphalt in pavement construction under hot weather. The results of these experiments are presented in this paper.

Experimental work shows that using sulphur asphalt binder ratio equivalent to the ratio obtained from the job mix using asphalt alone is the most suitable ratio from quality and economical point of view.

The sulphur/asphalt ratio of 30/70 can be considered as the most suitable ratio for both surface and base courses.

The quality of roads paved with S/A improves with time as the result of compaction caused by traffic.

The S/A binder gives wider tolerance to the percentage of binder recommended without causing an appreciable decrease in the serviceability of roads.

In spite of the difference in temperature between the two sites of the experiment, it seems that quality of the binder is not materially affected.

D82 Shah, S. P., Naaman, A. E., and Smith, R. H., "Investigation of Concrete Impregnated with Sulfur at Atmospheric Pressure," Polymers in Concrete - International Symposium, SP-58, pp 399-417, 1978, American Concrete Institute, Detroit, Mich.

The primary purpose of this investigation was to study the feasibility and effects of sulfur impregnation of concrete carried out at atmospheric pressure. The investigation had three parts: to study the effects of process technology parameters (mix proportions, time of curing, temperature of drying and time of immersion in molten sulfur bath), to analyze the effects of high temperature and temperature cycling on properties of impregnated concrete, and to explore the possibility of improving strength and ductility of SIC by addition of steel fibers. It was observed that sulfur impregnation can increase flexural and compressive strengths, and elastic moduli from about 2 to 5 times depending upon the various process technology parameters. Near optimum improvement was attained for the types and sizes of concrete specimens used in this investigation when they were moist cured for 24 hr, dried for 24 hr, and immersed in molten sulfur for 24 hr. Sulfur impregnated fiber reinforced specimens showed high flexural strength (up to 4000 psi) and substantially improved ductility.

D83 Soles, J. A., Carette, G. G., and Lessard, J. R., "Stability of Sulphur-Infiltrated Concrete in Silage Environments," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 235-249.

This paper gives the results of an investigation of the behaviour of sulphur-infiltrated portland cement concrete under conditions encountered in or near silos, to assess its durability and potential usefulness in such environments.

A long-term immersion experiment has revealed that, besides leaching, a slow, steady expansion of infiltrated concrete occurs in anaerobic aqueous environments, and associated tension fractures develop and propagate inward as leaching and alteration progresses. This is an inexorable, destructive process which may be related to adsorption of water on an exceedingly large surface area developed during or after infiltration of the matrix of portland cement concrete with sulphur. It will decrease the long-term durability of sulphur-infiltrated concrete in moist environments, particularly in freezing-thawing conditions.

D84 Suparinayok, B., and Fowler, D. W., "Behaviour of Reinforced Sulfur-Infiltrated Concrete Beams," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 181-190.

The objective of this study was to determine the load-deflection responses, the ultimate strength, and the compressive stress-strain relationship of reinforced SIC beams.

D85 Terrel, R. L., and Babaei, K., "Mortarless Sulphur Concrete Block," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 519-546.

This paper is a result of a project which was initiated to provide a practical means for the manufacture of mortarless sulphur-concrete block units, as well as to evaluate the physical properties of the units. The approach in this study was to completely replace portland cement with sulphur.

Sulphur-concrete block exhibits numerous advantages in the construction field such as resistance to attack by those acids and salts which are deleterious to portland cement concrete, low coefficient of thermal conductivity, and high insulation value. It has also potential for recycling as fabricated or remelting.

The conventional method to prepare sulphur-concrete block is generally by heating sand to about 160°C and mixing it with sulphur until all the sulphur is melted. The mix is then poured into a mold and left to harden.

Initially, this conventional method was employed to construct mortarless sulphur-concrete block in the current study. Although a high compressive strength was achieved, there were some problems regarding the preparation of the material by this method. For example, segregation of the material occurred for compositions with high sulphur content while

pouring the material into the mold. Usually sand tends to settle while the sulphur is molten. Excessive shrinkage of the sulphur-concrete occurred during the cooling/curing process in the mold. This shrinkage has to be overcome by addition of material to the top surface of the mix. Blocks used in a mortarless building system must be dimensionally accurate and shrinkage cannot be tolerated. Finally, the mold had to be cleaned before making each block, since part of the material usually would stick to it after extrusion.

To eliminate the conventional method's problems and to fabricate sulphur-concrete block by practical means, a dry mix procedure was developed to fabricate the blocks. This method essentially consists of mixing moist sand and clay with powdered sulphur at ambient temperature. Using the same procedure as utilized for portland cement concrete blocks, the sample mixture is then compressed into its final shape under high pressure in a die-type mold. The mixture is then strong enough to be extruded from the mold and to be dried. At this point the block is dried at ambient temperature or in a low temperature oven until the moisture is driven off, resulting in a relatively rigid structure with the sulphur (20 to 25 percent by weight) acting as a mineral filler. The block is then heated sufficiently to melt the sulphur, which bonds the clay and sand particles to form a continuous matrix. The molded shape mixture has no tendency for deformation and shrinkage during the heating and curing process and attains 2000 psi strength with little reduction after soaking.

D86 *Volgushev, A. N., and Turapov, M. T., "Study of Water Absorption and Water Impermeability of Ash Concrete Treated with Sulfur," Increase in the Service Life of Industrial Buildings and Structures by Using Polymer Concretes, Summaries of Papers Presented at Tashkent, September 1978, (Povyshenie Dolgovechnosti Promyshlennykh Zdanii i Sooruzhenii, Za Chet Primeneniia Polimerbetonov Tezisy Dokladov, Tashkent, Sentiabr' 1978), Iu. M. Bazhenov, ed., Book No. 7220 (C-92), Paper No. 125, Jan 1979; Translated from the Russian by Engineering Services Branch, U. S. Bureau of Reclamation Translation Group, Denver, Colo.*

Sulfur treatment can be used to produce a significant increase in the strength and density of concrete. Studies were performed using compositions with various contents of ash (as a percent of the mass of the cement). The specimens were treated at +140 C for 24 hr at normal pressure. The specimens were first dried to constant mass. The compositions and basic properties of saturated and unsaturated specimens are presented.

The tests showed that saturation of the pore structure with sulfur is quite effective as a means of increasing such important properties of concretes as density, water resistance, and impermeability, which increases by a factor of 4 to 5. The greatest effect of practical utilization of the technology of saturation of the concretes with sulfur will probably be achieved in compositions containing ash at up to 50 percent of the weight of the cement.

- D87 Volgushev, A. N., Kasymov, N. K., and Turapov, M. T., "Development of Technology and Study of Physicomechanical Properties of Ash Concrete Impregnated by Sulphur," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 191-196.

The main purpose of this investigation is the improvement of the physicomechanical properties of ash-concrete by impregnation of the porous space by molten sulphur. For this purpose the possibility was studied of using ash concrete with up to 80 percent ash for impregnation.

- D88 Yuan, R. L., and Chen, W.-F., "Study of Sulphur-Impregnated Brick, Block Prisms and Concrete Pipes," Proceedings, International Conference on Sulphur in Construction, Ottawa, Ontario, 12-15 Sep 1978, pp 91-106.

The objectives of this investigation were twofold:

1. To evaluate the strength and modulus of sulphur-impregnated brick and block units, brick and block prisms, and concrete pipes.
2. To determine water absorption, acid resistance, freeze-thaw resistance and abrasion resistance of sulphur-impregnated brick units, block units, and concrete pipes.

The testing program consisted of obtaining the ultimate strength and modulus of elasticity in compression of brick and block units, brick and block prisms. The testing program also included determining the water absorption, acid resistance and abrasion resistance of sulfur-impregnated brick units, block units, and concrete pipes.

The experimental investigation included four types of bricks, one type of masonry block, and one type of concrete pipe.

#### 1979

- D89 Berry, E. E., and Hope, B. B., "Preparation and Properties of Sulphur-Impregnated Autoclaved Concrete," Cement and Concrete Research, Vol 9, No. 6, Nov 1979, pp 667-676.

Autoclaved concrete specimens were infiltrated with liquid sulphur at 150°C. The rates of sulphur infiltration, the mechanical properties, and the durability of the infiltrated specimens were all found to be greatly influenced by the nature of the porosity of the uninfiltrated parent concretes. The size distributions of pores in the specimens were found to be controlled by the CaO/SiO<sub>2</sub> (mole) ratio of the binder.

- D90 Hope, B. B., and Nashid, M., "Sulphur-Impregnated Concrete Materials," The International Journal of Cement Composites, Vol 1, No. 1, May 1979.

Various types of hardened cement paste, mortar and plain and reinforced concrete specimens were impregnated with elemental sulphur. The physical and mechanical properties of each type of specimen were extensively examined. The elastic modulus and the stress-strain

characteristics of the impregnated materials reflected a significant improvement in its behaviour and emphasized the important role of the final porosity. The mechanical properties of the impregnated cement paste and mortar composites were determined from the properties of the constituent materials by means of an analytical finite element technique.

D91 Volgushev, A. N., and Patureov, V. V., "Use of Sulfur to Fill the Pore Space of Construction Materials," Summaries of Papers of the Republican Conference Physical and Mechanical Properties of Concretes Made with Polymers, Apr 1978, N. Gilite, ed., Translated from Russian by U. S. Bureau of Reclamation Translation Group, Denver, Colo., Jan 1979.

In the planning of many construction structures, the determining factor consists of such properties as density, impermeability to water, resistance to cold, and stability in corrosive media. One effective means of improving these properties for traditional construction materials is to fill the pore space with liquid compositions capable of curing after treatment. As tests have shown, fused sulfur can be used for treatment of this type.

Studies performed at the Scientific Research Institute for Reinforced Concrete's Laboratory of Polymer-Treated Concrete have shown that treatment causes a significant improvement in the strength characteristics (compressive strength, bending strength, tensile strength), a decrease in deformation properties, and an increase in modulus of elasticity by a factor of 1.5 to 2.5. After treatment, water absorption is greatly decreased (to 0.1 to 0.3 percent), cold resistance and resistance to corrosive effects are significantly increased.

Based on the experimental data, technological systems have been developed for treating construction materials with sulfur, including: drying of the product, treatment at a melt temperature of 140 C (at normal pressure, under a vacuum, under excess pressure) and cooling. The treatment mode is determined as a function of the type of treatment material and the depth of treatment. The possibility has been experimentally demonstrated of using this technology for such construction materials as concrete, asbestos cement, ceramics, liquid-glass-based concrete, etc.

D92 Mehta, P. K., and Chen, S.-S., "Studies on Improving Moisture Resistance of Sulphur-Infiltrated Mortars," Cement and Concrete Research, Vol 9, No. 2, Mar 1979, pp 189-196.

High-strength products can be made by sulfur infiltration of dried portland cement mortars or concretes. However, on exposure to moisture, strength deterioration takes place due to complex chemical reactions involving  $\text{Ca(OH)}_2$  and sulfur.

This paper presents the results of two series of tests. In the first series, an attempt was made to inhibit the reaction between sulfur and  $\text{Ca(OH)}_2$  by coating the  $\text{Ca(OH)}_2$  with a film of insoluble calcium salts. In the second series, cements which did not contain  $\text{Ca(OH)}_2$  in hydration products were investigated for sulfur infiltration. Both the

approaches gave encouraging results in improving moisture resistance of sulfur-infiltrated mortars.

D93 Neville, A. M., "Essentials of Strength and Durability of Various Types of Concrete with Special Reference to Sulfur," American Concrete Institute Journal, Sep 1979.

Criteria of strength of concrete and other solids are discussed with reference to the behavior of neat  $C_3S$  pastes, porosity, pore-size distribution, and Griffith flaws. This is followed by a consideration of bonds within the cement paste; the absence of their influence on its modulus of elasticity is noted.

The two-phase nature of concrete is reviewed in some detail.

In considering impregnated concrete, attention is drawn to the disparity between the coefficients of thermal expansion of sulfur and of other concrete materials. A proper basis for evaluation of polymer-impregnated concretes is discussed, with special consideration of the effects of impregnation on the compressive and tensile strengths and on the modulus of elasticity.

Consideration of the durability of sulfur-impregnated concrete with respect to freezing-and-thawing and to chemical attack leads to a positive evaluation of this material for many purposes.

D94 Vroom, A. H., "Sulfurcrete - Another Option in the Energy/Materials Picture," The Military Engineer, Jul-Aug 1979.

During the last 4 years, more than 3000 tons of Sulfurcrete, largely in the form of precast products, have been produced and marketed.

The energy required to produce 1 ton of Sulfurcrete is substantially less than that required for 1 ton of portland cement concrete or for 1 ton of asphaltic concrete if the energy in the production of the portland cement or the energy value of the asphalt bitumen is taken into account. For this reason, as energy prices escalate, the economics of Sulfurcrete production become more attractive in relation to both portland cement concrete and asphaltic concrete.

It appears that sulfur will remain abundant and that the world surplus will increase in years to come. Alberta has close to 25 million tons of unsold production in stockpiles and the U. S. Department of Energy is reported to anticipate involuntary production by the late 1980's of some 50 million tons per year as a by-product from the processing of coal. In view of these large surpluses, it seems safe to assume that sulfur prices will not rise at the same rate as most other materials and that sulfur concrete can be expected to be an even more economical construction material in the future.

D95 Bretz, T. E., Jr., Properties of Sulfur Concrete, M.S. Thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, Report No. AFIT-CI-79-170T, July 1979.

This report summarizes the state of the art of sulfur concrete. Sulfur concrete is created by mixing molten sulfur with aggregate and

allowing the mixture to solidify. Ultimate strength is reached in a short time. It exhibits favorable fatigue properties and has excellent resistance to acids, salts, and many organic compounds. It works well as a rapid runway repair material. Sulfur concrete also has unfavorable properties. It has poor durability when exposed to large temperature change and to wet curing conditions. The material is also brittle. All of these properties are examined in some detail and modifications (dicyclopentadiene and sulfurcrete) are proposed to overcome the unfavorable properties. (Author)



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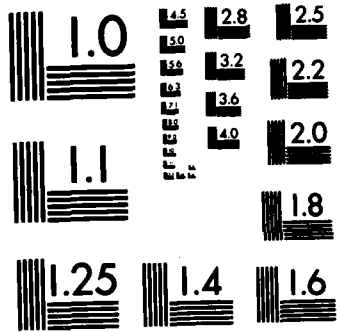
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