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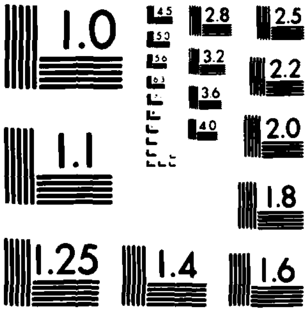

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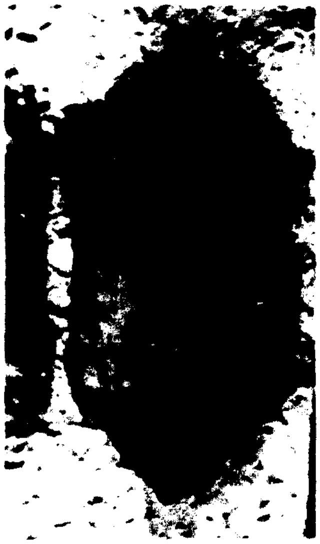

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-3

LATEX ADMIXTURES FOR PORTLAND CEMENT CONCRETE AND MORTAR

by

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Final Report

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The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

For example, Technical Report REMR-CS-3 is the third report published under the Concrete and Steel Structures problem area.

COVER PHOTOS:

TOP — Specimen after testing for resistance to freezing and thawing.

BOTTOM — Application of mortar to vertical surface of test specimen.

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19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Concrete overlay	Polymer
Concrete repair material	REMR (Repair, Evaluation, Maintainance, and Rehabilitation) Research Program
Latex modifiers	

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A latex used as an admixture in portland cement concrete or mortar is a water-emulsion organic polymer. This polymer emulsion will coalesce to form a continuous film within the matrix of the paste and around the aggregate, thus producing greater tensile and flexural strength and a more durable material (because it acts as a moisture barrier to the entry of liquid water but allows water vapor to migrate out). A literature search was conducted to collect information about latex admixtures and some minor laboratory testing was performed to corroborate some of the literature findings.

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PREFACE

The investigation described in this report was conducted by the Concrete Technology Division (CTD) of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES). Publication of the report was funded under Civil Works Research Work Unit 32303, "Application of New Technology to Maintenance and Minor Repair," for which Mr. James E. McDonald is principal investigator. This work unit is part of the Concrete and Steel Stuctures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). The Overview Committee of HQUSACE for the REMR Research Program consists of Mr. John R. Mikel, Mr. Bruce L. McCartney, and Dr. Tony C. Liu. Technical Monitor for this study was Dr. Liu.

The investigation was performed under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John M. Scanlon, Chief, CTD, and under the direct supervision of Mr. Richard L. Stowe, Chief, Materials and Concrete Analysis Group, CTD. Program Manager for REMR is Mr. William F. McCleese, CTD. Problem area leader for the Concrete and Steel Structures Problem Area is Mr. McDonald. This report was prepared by Messrs. Dennis L. Bean and Tony B. Husbands and was edited by Ms. Janean Shirley, Publications and Graphic Arts Division.

COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
centipoises	0.001	pascal-seconds
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
inches	2.54	centimetres
inch-pounds (force)	0.1129848	metre-newtons
kips (force) per square inch	6.894757	megapascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic foot	16.01846 or 0.01601846	kilograms per cubic metre or megagrams per cubic metre
tons (2,000 pounds, mass)	907.1847	kilograms

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

LATEX ADMIXTURES FOR PORTLAND CEMENT CONCRETE AND MORTAR

PART I: INTRODUCTION

Purpose and Scope

1. This report documents a literature search which was conducted to gather information about latex admixtures. Laboratory testing was conducted to verify the information obtained in the literature search, and the results of this testing are documented herein.

2. A latex admixture is an emulsion in which a polymer is dispersed in water. Thus, a latex-modified concrete (LMC) is a portland cement concrete which includes an emulsion of water and polymer.

3. "A polymer latex consists of small (0.05- to 1.0-μm-diameter) spherical particles held in suspension by the use of surface-active agents. Polymer latexes are generally copolymer systems of two or more polymers with the possible addition of plasticizers or other modifiers, and typically contain around 50 percent solids by weight" (New Zealand Concrete Research Association 1983).

Background

4. In the 1950's, Dow Chemical was the first to try to improve both strength and durability of portland cement concrete by means of a polymer admixture.* The first polymer type that was studied was polyvinyl acetate (PVA) which is susceptible to alkaline degradation. This type of polymer changes to acetic acid and polyvinyl alcohol (ACI Committee 584 1977). LMC which contained PVA had improved flexural, shear, and bond strength when dry but rapidly lost strength when wet because of the water solubility of polyvinyl alcohol.

5. Elastomeric latexes, particularly natural rubber latex, were also investigated to modify portland cement concrete. However, the resulting

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* An admixture to concrete or mortar is any material other than hydraulic cement, aggregates, water, or reinforcing that is added to the concrete batch during mixing.

relatively poor mechanical properties led to the development of the use of synthetic polymers, with styrene-butadiene being the most important.

6. The first report that dealt with polymer-modified mortar and concrete in Japan was published in 1953 (Okada 1979). This report was also concerned with PVA-modified concrete. Some of the types of latexes produced in Japan and their properties are shown in Table 1.

PART II: LITERATURE FINDINGS

Classification of Latex Admixtures

7. Examples of polymers used as latex admixtures for concrete and mortar in the United States are PVA, styrene-butadiene, polyacrylates (acrylics), and natural rubber. Some of the structures of these polymers are shown in Figure 1.

8. Some commercial polymer latexes developed for use as admixtures for portland cement concrete are shown in Table 2 (Mindness 1981) and suppliers of latex admixtures are listed in Table 3, along with their trade names. Most commercial latexes are based on thermoplastic (vinyl compounds) or elastomeric (polymers similar to rubber) polymers which form a coherent film when the latex dries. A thermoplastic material is a substance that becomes plastic and even flowable when the temperature exceeds the glass-transition temperatures (tg) for that material. Therefore, concrete made with a thermoplastic latex will become weaker as the temperature increases.

9. Typical properties of polymer latex modifiers for concrete and mortar are shown in Table 4.

Mechanism of Latex Admixtures

10. When properly mixed, the spheres of polymer in a latex admixture will coalesce to form a continuous polymer matrix which coats the hydrating cement grains and aggregates. This polymer matrix acts as a barrier which helps to maintain high levels of internal moisture (prevents moisture loss due to evaporation) for improved hydration of the cement and also provides a polymeric network which enhances the toughness and durability of the finished product.

11. The optimum procedure for curing LMC is different from that used for ordinary concrete (Iyer 1979). For thin and normal applications (<2 in.*) LMC achieves maximum properties when cured in air at room temperature and ambient relative humidities. The optimum properties of LMC are achieved when the dispersed latex is converted to a continuous polymer film within the

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

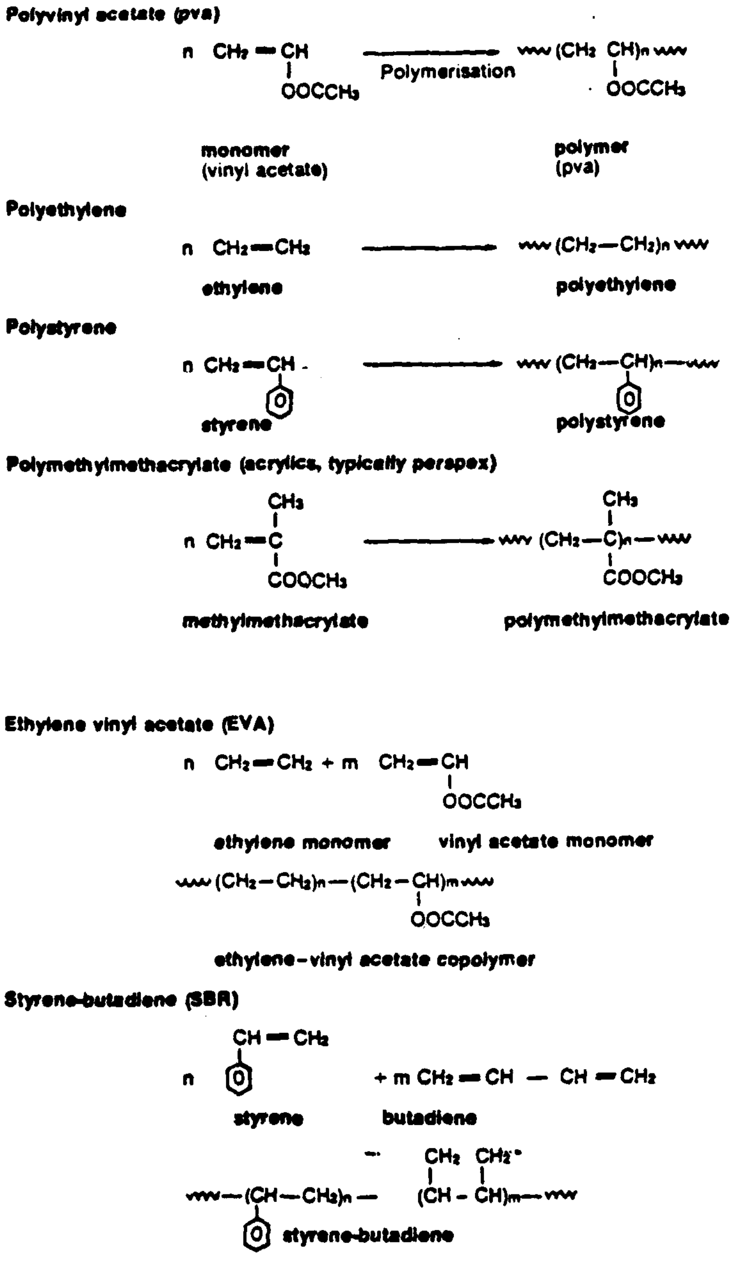

Figure 1. Structures of some polymers used for latex admixtures (Okada 1979)

concrete. This continuous film is formed by the removal of water, by either evaporation or hydration of the cement paste. Under most circumstances, initial moist curing or steam curing is not recommended because it retards the film formation of the polymer. For some polymers (e.g., PVA and some polyacrylates) the prolonged exposure to the moist, alkaline environment of the saturated concrete can cause hydrolysis (chemical breakdown) of the polymer, resulting in a loss of strength. The mechanism of formation of the initial film coalescence can be used to advantage in the curing of the LMC. As the latex dries, a plastic or rubber film is formed. This film then acts as a moisture barrier, reducing the rate of loss of water from within the concrete. Consequently, below the surface of the concrete a moist condition exists in which hydration of the cement can continue. The effectiveness of the latex in achieving such conditions depends on the moisture transmission of the dried polymer film, and acrylics are generally the most effective. However, with very thick sections of LMC (>2 in.) and for thinner sections placed at high temperatures and low relative humidities, an initial 24-hr period of moist curing was found useful in reducing surface cracking by retarding the surface film effect and allowing the surface and interior to cure at more uniform rates. This initial moist curing period should be followed by exposure to air at reduced relative humidity for 3 to 5 days depending on the thickness placed.

12. All latex admixtures have a minimum film formation temperature (MFT) below which the polymer spheres will not coalesce to form a film. Application temperature must be maintained above the MFT until the film formation process is complete. For sections of mortar less than 1/2 in. thick, the application temperature should remain at or above 55° F for approximately 24 hr. For thicker sections, the application temperature should be maintained at or above 55° F for 3 to 5 days. This is because the mortar thickness and the tendency for the polymer to form a surface film will retard moisture loss and slow the film-formation process. In any case, higher application temperatures will accelerate film formation and cause mechanical strength and resistance properties to develop more rapidly.

Properties of LMC and Latex-Modified Mortars (LMM)

13. Improvements in compressive, tensile, and flexural strength occur

with the addition of latex admixtures to concrete, but are proportionally greater for tensile and flexural strength. It is thought that the polymer film inhibits the propagation of microcracks under tensile stress because the high flexibility of the polymer will relieve the stress at the crack tip. Thus, LMC will have a high strain to failure, as is reflected in a lower modulus of elasticity.

14. The commercial success of latex admixtures is most likely due to the fact that they can improve the properties of ordinary concrete and mortar without requiring any significant changes in process technology. A portland cement concrete containing a polymer can be made using conventional concrete technology and equipment. Some improvements in mortar and concrete that have been claimed with the addition of a polymer are:

a. Increased bond strength to a variety of substrates, including concrete, masonry, brick, glass, metal, wood, and polymeric foam.

b. Increased tensile strength, flexural strength, and impact strength.

c. Increased resistance to abrasion.

d. Increased resistance to freezing and thawing.

e. Increased chemical resistance.

f. Improved workability.

15. All LMC shows improved adhesion to most substrates, a characteristic useful in overlays and toppings. Bond strengths of LMC exceed those of concrete without polymer; therefore, when an LMC is used to repair deteriorated concrete, shear failure goes through the concrete rather than through the interface. Since the composite of polymer and cement provides improved adhesion for most substrates, there is no need for a special bond coat or primer application. Some manufacturers nevertheless recommend priming the substrate with a 1:1 ratio of polymer emulsion and water or a slurry coat made from sand, cement, and the latex. Since a latex polymer bonds well to most materials, removal of formwork from LMC or LMM will be difficult unless the forms have been coated with an efficient debonding agent, such as silicone grease.

16. A comparison of the mechanical properties of plain concrete and various types of LMM is shown in Table 5. A major effect of the use of a polymer latex admixture is to improve the ductility, i.e., to lower the modulus of elasticity of the cement paste in concrete. This may be reflected in

higher tensile and flexural strengths in the concrete. The elastic nature of the polymer film can offset the brittle nature of the paste. Polymer portland cement concretes (PPCC) have been used to make piles. Bhargava (1977) reported that LMC showed 30 to 35 percent higher dynamic strength and significantly higher energy transmission capacity.

17. In order for a cured mortar or concrete to achieve optimum strength properties, it must have a high density. LMC shows improvement in abrasion resistance over plain concrete. This is a result of a lower water-to-cement ratio and a partial filling of capillary pores by the polymer. The lower water-to-cement ratio results in a denser mortar with more strength. A comparison of abrasion and impact resistance for LMM and portland cement mortar is shown in Table 6.

18. LMC is reported to have improved resistance to weathering over conventional concrete. This may be due in part to the increased resistance to tensile cracking. When cracks form, they are held together by microfibers of polymer. This tends to reduce the area of entry accessible for aggressive elements. It is believed that a polymer film coats the walls of the capillary pores, reducing the permeability and water absorption. This could also reduce the flow of aggressive chemicals. The air-entraining properties of the latex might enhance frost resistance. A comparison of tensile strength properties for some polymer-modified portland cements exposed to weathering is shown in Figure 2. The poor performance of the PVA is a result of hydrolysis (chemical breakdown) of the polymer in the moist alkaline condition in the wet concrete.

19. Portland cement mortars, with and without admixtures, are used in applications where they may be exposed to industrial chemicals. Some industrial chemicals attack portland cement mortar and cause disintegration. The rate of attack depends upon the ability of the chemical to penetrate into the mortar and the rate at which the reaction products are removed from the surface. Polymer modification does not substantially alter the chemical resistance of mortar; however, because the polymers result in a denser paste, the penetration of the chemical into the mortar and the rate of disintegration may be reduced. LMM is less resistant to some chemicals, such as strong solvents, due to the solubility of the polymer in the solvent. PVA is particular susceptible to acids or alkalies.

20. Workability is improved in LMC and LMM because the small spherical polymer particles act to improve workability and decrease bleeding in the

paste. Since the latex generally acts as a water reducer, adjustments in the water content must be made to obtain the required workability. To avoid overly fluid mixtures, a portion of the water should be withheld and added gradually until the desired consistency is obtained. When mixing, the latex polymer entrains considerable amounts of air due to the action of the emulsifying surface-active agent that stabilizes the latex. Additional air-entraining admixture should not be used unless needed to bring the air content up to the level specified. It may be necessary to suppress the air entrainment in some latexes by the addition of antifoaming or air-detraining admixtures. With acrylic latex such an admixture is almost essential. Concrete with excessive air entrainment will be difficult to place and will have reduced strength at the rate of about 5 percent per percent of air. With LMC good workability is achieved at lower water contents, resulting in higher density with a reduced tendency toward shrinkage.

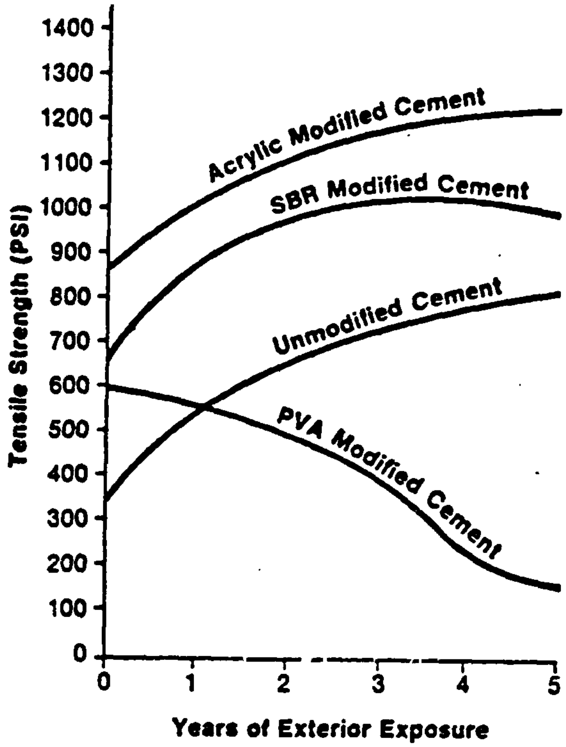

Figure 2. Comparative durability of polymer-modified cements (Rohm and Haas Company 1982)

21. The amount of drying shrinkage of cement-based mortars containing a latex admixture is lower than that of mortars without such admixture because of the reduction in the water-cement ratio of the mortar. However, many factors will affect the drying shrinkage, such as water-cement ratio, cement content, polymer content, and water evaporation rate. When cured at 50 percent relative humidity and 20° C, Lavelle and Wright (1974) stated that the moisture retention capabilities of the polymer film will determine the amount of drying shrinkage. The moisture retention capabilities of the polymer film are dependent on the type and quality of the polymer. Acrylics appear to form the most effective water retention membrane.

22. The presence of a polymer in a concrete or mortar may tend to increase creep, but this is significant only at high temperatures. In most applications, creep is of little consequence and the high flexibility of portland cement concrete prevents shrinkage cracking.

23. LMM's are more susceptible to damage by exposure to high temperatures than mortar without such admixture. At high temperatures creep increases while flexural strength and flexural modulus decrease. These effects occur both for elastometric polymers (SBR) and thermoplastic polymers (acrylic and PVA) but the effect is more noticeable for thermoplastic latex since the thermoplastic polymer has a glass transition (tg) temperature just above room temperature (typical tg's for PVA and acrylics used in concrete being in the range 27° to 30° C) (Rohm and Haas Company 1982). A thermoplastic polymer softens rapidly when its tg is reached, whereas the elastomers are already "softened." Typically, the modulus of elasticity and flexural strength of mortar modified with a thermoplastic latex will decrease by about 50 percent at around 45° C (Rohm and Haas Company 1982). This temperature can be reached under natural conditions by the sun, or under hot water cleaning conditions. However, it should be noted that although the effect of the added latex is reduced at elevated temperatures, the basic strength characteristics of the mortar are retained. Since LMM's are often produced at a reduced water-cement ratio, the strengths are often adequate for such conditions of elevated temperatures.

24. The linear coefficient of thermal expansion of LMM's is similar to comparable portland cement mortars without admixture. The low elastic modulus of the polymer material within the mortar will not restrain any thermal or other movement of the mortar.

25. The working time (amount of time after mixing before the material becomes too stiff to be useful) and set time of a typical modified sand-cement mortar mixture can be 0.2 to 2 hr and 4 to 6 hr, respectively, under ambient temperatures and humidities. Working time will decrease at higher temperatures. Setting time will also decrease at higher temperatures and under conditions of low humidity or rapid air movement, or both.

Materials Proportioning

26. The selection of mixture proportions for latex-modified mortars

and concretes will involve the same factors as the selection of mortars and concrete without a latex admixture, depending upon the end-use application. Some typical mixtures developed by the New Zealand Concrete Research Association (1983) for latex-modified mortars and concretes are shown in Table 7. Avoid "overextended" mixtures where the quantity of cement is less than the amount needed to adequately bind all of the aggregate.

27. Choose materials based upon the requirements of the application. The type and particle size distribution are selected for reasons such as cost, density, color, texture of the final product, chemical resistance, and workability. Very fine aggregates such as silica flour or marble dust will have a higher water and cement requirement because of the high ratio of surface area to volume. The polymer requirements also increase at high cement levels. If possible, the aggregate should be prewashed and dried to reduce the quantity of inorganic salts which contribute to the development of efflorescence. This is especially important in coating applications.

28. An optimum balance of mortar properties is generally obtained by incorporating approximately 15 percent polymer solids by weight of portland cement. The correlation between polymer and performance properties is shown in Figure 3.

Mixing and Application

29. Mixing of LMM can be performed in the same manner as conventional mortar. If an antifoaming agent is to be added, it should be added as instructed. Follow the manufacturer's mixing and proportioning instructions. If the system contains a liquid component, it may or may not contain all of the water needed for the mixture; again check the manufacturer's literature.

30. LMM will not possess as much working time as mortar without a latex admixture. Once LMM begins its initial setting, it cannot be worked to retain its workability as mortar not containing a polymer can. Water should never be added; it will weaken the matrix.

31. Once the liquid component is added to the solids, the LMM is as easy to work as a conventional mortar. Most suppliers of latex admixtures recommend that the concrete surface first be primed with the latex or a slurry coat made from portland cement and latex before placing LMM. The thickness of the repair material applied can be a limiting factor. If the material is

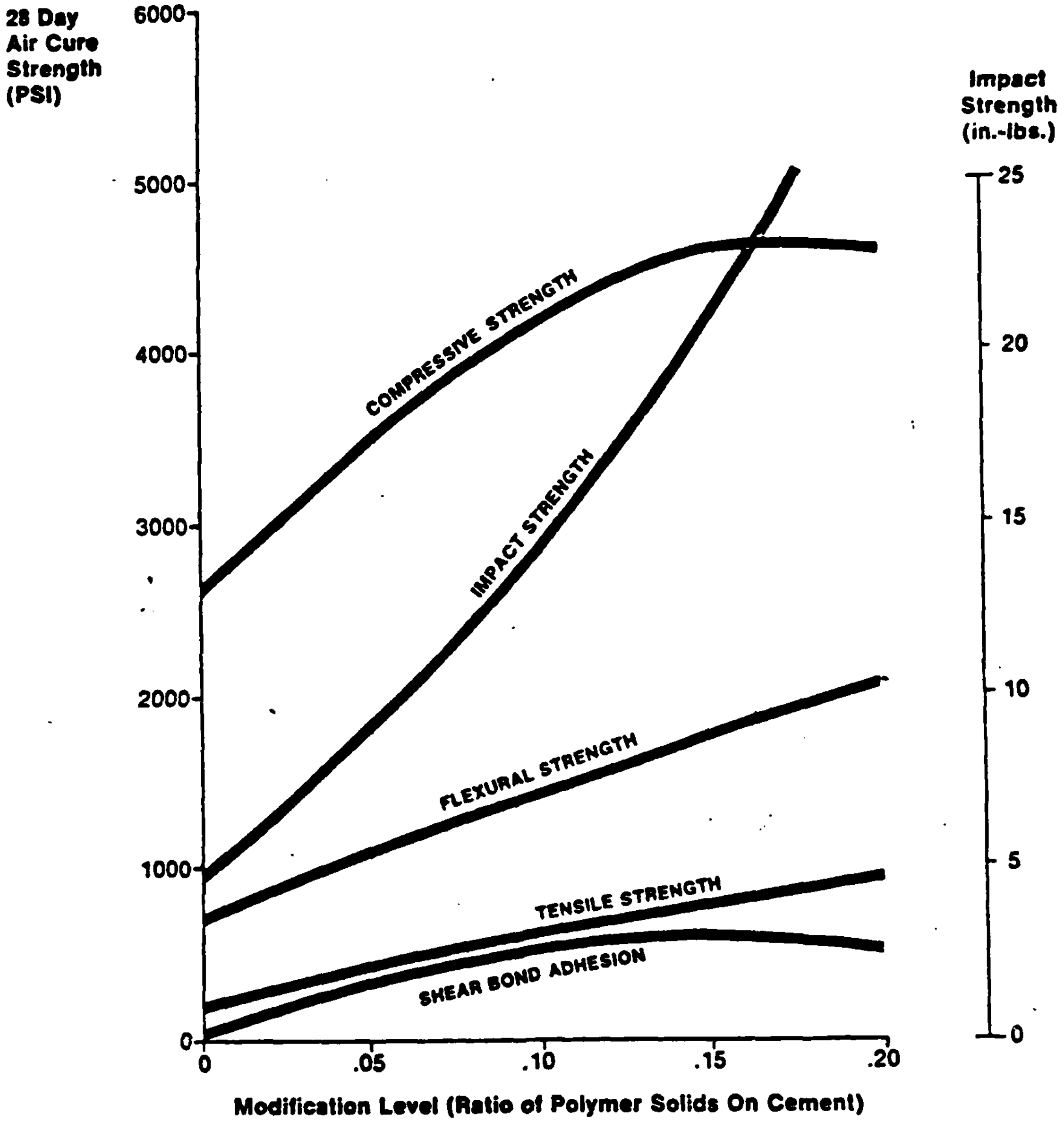

Figure 3. Performance properties versus level of polymer modification (Rohm and Haas Company 1982)

placed with too great a thickness, equal moisture distribution cannot be achieved, resulting in shrinkage cracks in the repair material. Also, applying the material too thickly on a vertical surface will result in sagging of the LMM. The manufacturer's literature should give the maximum thickness at which the material can be placed.

32. As a general rule, an unsound substrate should not be covered with

repair materials; it will only continue to deteriorate regardless of the quality of the repair material. Prepare the substrate by removing all loose and disintegrating material. Oil, grease, or other chemicals should be removed with a detergent, and the detergent should be removed by several washings with water. Because of the surface film characteristics of a latex mixture, the mortar should be placed as quickly as possible and in the same manner as an unmodified mortar. Avoid overtroweling as this may result in floating polymer to the surface or in tearing the surface film.

33. Shotcrete can be made using LMM with strands of fiberglass for reinforcement (Schrader 1981). When these materials are properly applied, a durable, high-strength, high-impact-resistant, low-permeability coating is obtained.

Curing

34. Curing of LMM and LMC is the process of aiding the natural reaction by keeping the reactants confined until they react. When latex admixtures are used, the dispersed latex is converted to a continuous polymer film within the paste. This film acts as moisture barrier to retain enough water to permit hydration of the portland cement. When a system is said to be "air cured," it means that no moisture barrier was applied externally. Although LMM's have been called "self-curing," they do have limitations. On hot windy days, the combination of high temperatures and moving air will cause excessive moisture loss. Placing a polyethylene sheet over the freshly placed material for 24 hr will allow enough of a polymer film to form to retain sufficient moisture for proper curing.

35. Moist curing of LMM or LMC should be avoided. The polymerization of the latex polymer is achieved by the removal of water from the mortar (principally by evaporation). If moist curing is used, enough water cannot be removed to completely polymerize the polymer. Although the cement will continue to hydrate, the grains will be incorporated with a weakened polymer, resulting in a lower strength material. If the moisture is removed later, then the polymerization of latex modifier will continue. After the polymerization is completed, moisture will not significantly weaken most properly produced LMM. However, there are some exceptions, such as LMM or LMC made with a PVA latex admixture.

PART III: TEST PROCEDURES AND RESULTS

36. The results of the testing and evaluation of latex admixtures reported in this section were accumulated from several different testing programs at the US Army Engineer Waterways Experiment Station (WES). There was never a planning phase or overall plan to test latex admixtures. The results of the different testing programs were compiled to verify the information obtained in the literature search. The evaluation and testing performed at WES were done with LMM only. Some of the LMM's were made using prepackaged kits in which the manufacturer had proportioned the percentages of the ingredients. Some of the LMM's were made by adding the latex admixture to cement and sand obtained locally. For these mortars the sand-to-cement ratio was 3:1 by weight and the water-to-cement ratio was 0.5 for all the nonprepackaged mortars. LMC's were not considered because it was felt that LMM would facilitate the production of specimens and would give sufficient information on the properties of the matrix.

Addition of Antifoaming Agents

Background

37. Some manufacturers of the latex admixtures evaluated recommend that an antifoaming agent be added to the material to reduce the entrapment of air while mixing. Air that is trapped in the material will cause a reduction in compressive and tensile strengths in the cured material. The admixtures that use an antifoam are identified in Table 3. Some of the prepackaged latex systems have the antifoaming agent in one of their packaged components. If the strength of a material is of concern, the manufacturer's literature should have these values listed in the specifications sheets.

38. If an antifoaming agent is used, it should be added after the other materials have been thoroughly mixed. The reason for this is that the entrapped air will aid in the mixing process. The amount of antifoaming agent added should be in accordance with the manufacturer's instructions. After the agent is added, the mixing operation should be continued to ensure that the agent is evenly dispersed. When the agent is added and incorporated into the mixture by the mixer, the mixture will change from being fluffy to nonfluffy.

Test procedure

39. To verify the effect of antifoaming agent on compressive strength, 2-in. LMM cubes were made using one of the acrylic polymers. An antifoaming agent (silicone emulsion) was added to the latex before mixing the LMM when preparing the test specimens. Antifoaming agent was not added to the latex when preparing control test specimens. Both types of specimens were cast and cured in air for 28 days before testing in compression in accordance with ASTM C 109-80 (American Society for Testing and Materials 1984).

Test results

40. The specimens with antifoaming agent had an average compressive strength of 5,160 psi. The specimen with no antifoaming agent had an average compressive strength of 3,560 psi, a 45-percent lower strength.

41. The 2-in. compressive strength test cubes with the antifoaming agent had a density of 2.11 Mg/m^3 (132 pcf), while the control cubes had a density of 1.69 Mg/m^3 (106 pcf).

Application to Vertical Surfaces

Test procedures

42. Three prepackaged commercial LMM's marketed for vertical and overhead repairs (ACR-1, ACR-2, and ACR-6) were applied to test panels placed in a vertical position to evaluate ease, thickness, and finished appearance of application to vertical surfaces. Test panels were prepared by casting voids into concrete panels. The voids, which simulated areas of concrete spalling, had dimensions of 14 by 8 by 2 in. A test panel is shown in Figure 4.

43. All of the LMM's were mixed and applied following the manufacturer's instructions. The voids were filled using two applications of the LMM, each approximately 1 in. in depth. The surface of the first layer of LMM was scored with the edge of a trowel to roughen the surface before applying the second layer.

Test results

44. Laboratory personnel placing the mortars observed a difference in the thickness of the three latex-modified mortars that could be applied in one application and a difference in the initial setting times. One of the LMM's, ACR-2, developed some surface cracking after the application. This was not observed when applying this material to other vertical surfaces at depths of

Figure 4. Application to vertical surfaces

1/2 to 1 in. ACR-1 could be applied in thicker layers than the other two LMM's without sagging.

45. Two of these LMM's (ACR-1 and ACR-6) were used to repair vertical and overhead spalls located on concrete balconies and support columns of a multistory barracks building at Fort Bragg, N.C. ACR-1 was used to repair the shallow overhead spalls and ACR-6 was used to repair the deeper vertical spalls (up to 3 in.) located on the support columns. All repairs were finished with a trowel followed by floating the surface with a damp sponge. No appreciable sagging of the LMM was observed, and the finished appearance was satisfactory. Unsound concrete around spalls was removed. The application of a primer to the prepared area on one of the support columns and the finished repair can be seen in Figures 5 and 6, respectively.

Figure 5. Spalled area, primer being applied

Figure 6. Repair of spalled area

Compressive Strength

Test procedure

46. Two-inch cube specimens were cast and consolidated using some of the materials. The prepackaged mortars were prepared as instructed in the manufacturer's mixing and proportioning instructions. The nonprepackaged mortars were made by varying the percentage of polymer added. This was done to determine the effects of the amount of polymer in the mortar. The water-to-cement ratio remained constant (0.5) so that any differences could be attributed to the percentage of polymer. The specimens were allowed to air cure in the molds for 1 day before being unmolded. Then they were cured at ambient room conditions for an additional 27 days. At 28 days age, the specimens were tested in compression in accordance with the requirements of ASTM C 109-80.

Test results

47. There were significant differences in the compressive strengths of the cubes made with latexes from different manufacturers. As expected, the compressive strengths of the mortar cubes increased with higher percentages of one manufacturer's polymer. The compressive strength values are shown in Table 8.

Tensile Strength

Test procedure

48. To determine the effect that percentage of polymer in the mortar has on the tensile strength of the LMM, latex-modified with two different percentages of polymer were cast into tensile briquet specimens.

49. The specimens were cast and consolidated in the molds. The specimens were allowed to air-cure in the molds for 1 day, then for 27 days in ambient laboratory conditions before testing in tension. The specimens were cast into molds specified by ASTM C 190-82 and also tested in accordance with the requirements of the same specifications.

Test results

50. Specimens made with different latexes showed variations in their tensile strengths; the percentage of latex in the specimens also affected the tensile strength. The tensile strength values obtained are shown in Table 9.

LMM Bond Strength to Concrete

51. The primary concern for patching materials is how well they bond to concrete. The bond strength test (ASTM C 882-78) was used to obtain a bond strength value. Although the bond strength test may not be identical to loading in an actual structure, the values obtained are relative and good indications of the bonding ability. The method specifies that one-half of a 3- by 6-in. mortar cylinder be cut or molded 30 deg along the height of the cylinder. The repair material is applied to the diagonal surface after the mortar has gained strength; the composite cylinder is tested in compression to determine the force required to separate each half of the cylinder. One matter of concern is whether the surface needs to be primed. The test was performed using primed and unprimed surfaces. Test results are listed in Table 10.

Bond to Hardened LMM and LMC

52. Another concern of a patching material is how well it bonds to itself. An LMM cannot be applied in too thick a section because of problems discussed in paragraph 31; therefore, if a thick section is required, the material must be placed in lifts. The fresh material must bond to cured material. To test the bond of a material to itself, the bond strength test (ASTM C 882-78) was used. One-half of a cylinder was cast with an LMM and allowed to air-cure for a minimum of 16 hr. Fresh material was placed over the half cylinder to make a 3- by 6-in. LMM cylinder which was air-cured for 28 days. Then this cylinder was tested in compression to determine the bond strength. To determine if primer was needed, the materials were tested using primed and unprimed surfaces. Test results are listed in Table 10.

Effects of Underwater Submersion

Test procedure

53. Compressive-strength and tensile-strength specimens for underwater submersion were made in the same manner as the other compressive- and tensile-strength specimens. To determine the effects of continuous submersion, ACR-3 (with 0.10 polymer/cement ratio) specimens were placed in tap water after they were air-cured at ambient room conditions for 28 days. Periodically,

specimens were removed from the water and tested in compression and tension while they were still wet.

54. To determine if the dry strength was affected by submersion, tensile and compression specimens that were submerged for 5 months were allowed to dry at ambient room conditions for 28 days. Then the specimens were tested in compression and tension.

Test results

55. The results of the effects of underwater submersion are shown in Table 11. Similar values were obtained from testing a specimen that was air-cured for 6 months and a specimen that was immersed for 5 months and then air-dried for 1 month. This indicates that submersion did not affect the long-term strength of the specimen made with this particular latex when it was allowed to air dry sufficiently before testing.

Water Vapor Transmittance

Test procedure

56. To determine the breathability of the material, a vapor transmittance test was devised. ACR was used in making 1/2- by 3-1/2-in. mortar disks of varied polymer ratio which were cast and allowed to air-cure for 28 days. These disks were bonded and sealed (using an epoxy with a 5-min gel time) to the top of a 1-1/8- by 3-in. reservoir to prevent any moisture loss around the edges. The reservoir was a commercially available metal container with a metal lid. The lid was used as a form to cast the LMM disk. A 1/16-in.-diam hole was drilled into the container to allow water to be added after the specimen was sealed onto the container. A specimen and reservoir are shown in Figure 7. A known amount of water was injected into the reservoir, then the injection hole in the reservoir was sealed with a 5-min epoxy. The specimen and sealed reservoir were placed in a forced-air oven set at 105° F. The specimen was removed and weighed daily to determine the water loss.

Test results

57. The amount of water that evaporated from the reservoir is controlled by the water vapor transmittance of the specimen. The amount of water evaporated, shown in Table 12, is inversely proportional to the polymer/cement ratio of the specimen.

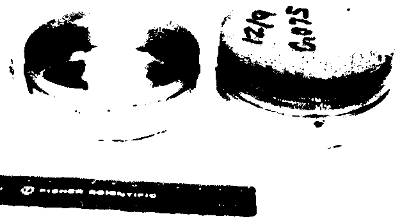

Figure 7. LMM disk, container, and sealed disk on container

Freezing and Thawing Resistance

Test procedure

58. To determine how well LMM adheres to concrete exposed to cycles of freezing and thawing, different LMM's were applied to air-entrained concrete panels that contained a cast-in void (Figure 8). The LMM was applied in the void while the panels were in a vertical position; this was to simulate applying patching material to a vertical surface. After curing, 3-1/2- by 4-1/2- by 16-in. beams were sawed from the panels and the LMM patched concrete specimens were tested for resistance to rapid freezing and thawing in accordance with CRD-C 20-79 (US Army Engineer Waterways Experiment Station 1949). The specimens were removed from the testing apparatus periodically to be tested for relative dynamic modulus of elasticity.

Test results

59. The values of the relative dynamic modulus of elasticity (E) for five specimens are shown in Figure 9. The reduction in percent relative E is attributed to debonding of the LMM patch from the concrete panel. This is an

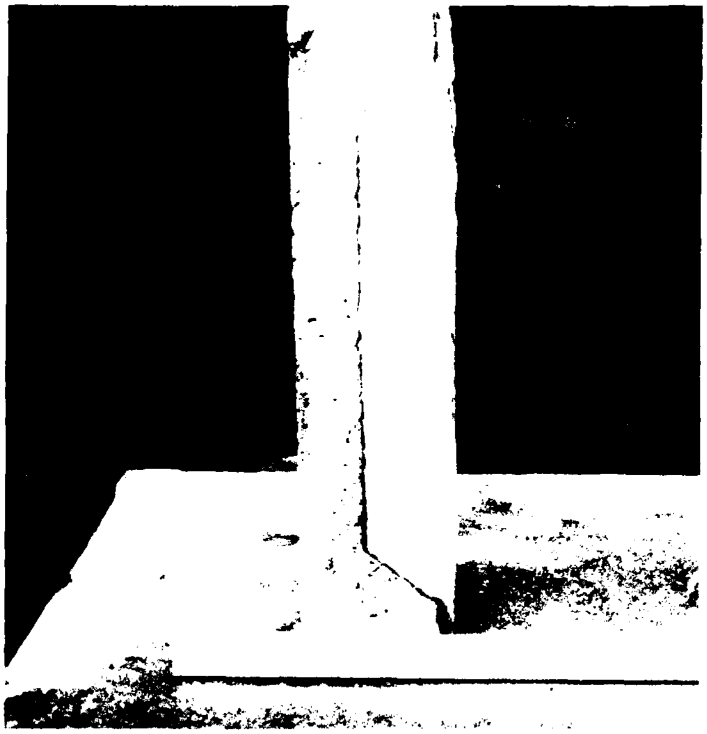

Figure 8. Freezing and thawing specimen (note the separation between concrete and LMM)

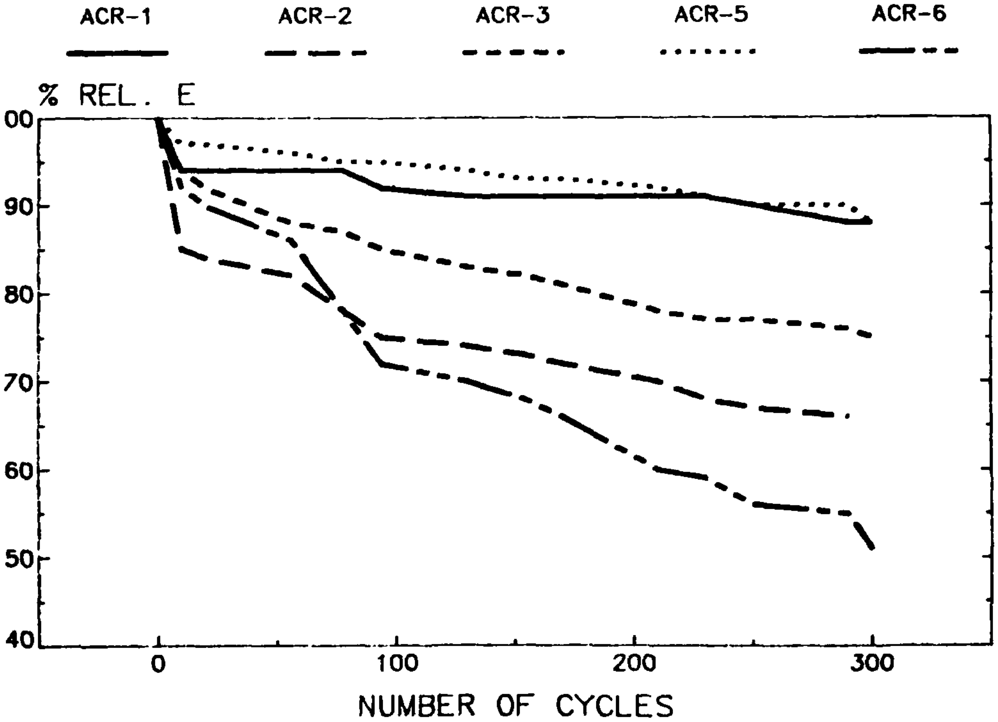

Figure 9. Relative dynamic modules of elasticity for five test specimens

assumption made because the concrete and the LMM appeared to be in good condition and the separation of concrete and LMM could be seen as shown in Figure 8. The separation is assumed to be a result of small differences in the linear thermal coefficient of expansion for the two materials or a result of placement problems. A typical air-entrained concrete would have a percent relative E of about 95 percent after 300 cycles.

60. Specimens made with ACR-1 and ACR-5 had a higher percent of relative E after exposure to freezing and thawing conditions. This is probably a property of the material; however, application methods could affect the durability of some materials.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

61. The results of limited testing of different latex modifiers in the WES laboratory basically agreed with the literature findings. The strengths of the LMM's tested at WES generally agreed with the values shown in Figure 3. The results of the bond test indicate that the surface of concrete or hardened LMM does not need to be primed to obtain good adhesion. The percentage of polymer in the LMM does affect the water vapor transmittance (breathability) of the specimen. A higher percentage of polymer will reduce the vapor transmittance of the hardened mortar.

62. The underwater submersion data revealed that immersion did not weaken the mortar tested at WES when allowed to air-dry sufficiently before testing. If the absorbed moisture in the LMM could evaporate after the specimen was removed from the water, the strengths were returned to their expected values. However, this may not be true for all acrylic latex modifiers; some may contain ethyl or methyl acrylates which are hydrolized when submerged in water. Further testing and evaluation are needed for various types of modifiers.

63. The results of the freezing and thawing testing of mortar patches showed that some latex mortars performed much better than others. Visual examination of the patches indicated that the principal cause of degradation was separation of the patches from the test panels.

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Table 1

Properties of Typical Japanese Polymer-Modified Mortars

Type of Modified Mortar	Polymer-Cement Ratio, %	Strength, psi		Adhesion in Flexure psi	Water Absorption %	Drying Shrinkage × 10^{-4}
		Flexural	Compressive			
Plain (unmodified)	0	450- 730	2,610-2,900	150- 290	10-15	10-15
Natural rubber latex	10	580- 870	2,180-2,470	220- 360	10-15	14-16
	20	290- 440	580- 730	360- 440	10-15	18-20
Chloroprene latex	10	730- 870	2,610-2,760	220- 360	10-15	13-15
	20	1,310-1,450	4,500-4,930	360- 440	5- 7	7- 9
Styrene-butadiene rubber	10	870-1,450	2,180-4,210	360-1,020	4-10	8-17
	20	1,020-1,740	2,470-4,640	290-1,020	2- 5	5-17
Polyacrylic ester emulsion	10	870-1,160	2,320-2,610	650-1,160	4-10	8-11
	20	870-1,310	2,030-2,900	1,020-1,160	4- 7	6-10
Polyvinyl acetate emulsion	10	870-1,020	2,320-2,470	220- 360	10-15	9-11
	20	870-1,020	2,180-2,320	360- 510	10-15	8-10
Ethylene vinyl acetate	10	870-1,310	2,610-4,210	220- 940	6-13	9-12
	20	870-1,600	2,760-4,640	400-1,020	3-13	8-16

Table 2

Some Commercial Polymer Latexes Developed for Use as Admixtures*

Chemical Name	Type	Use	Wet Strength
Polyvinyl acetate	Thermoplastic	Bonding aid	Low
Polyvinylidene chloride-polyvinyl chloride-copolymer (Saran)	Thermoplastic	Overlays and patching	Good
Styrene-butadiene copolymer	Elastomer	Overlays and patching	Moderate
Polyacrylate copolymer	Thermoplastic	Patching	Moderate
Epoxy	Thermosetting	Overlays and patching	Good

* Mindness (1981).

Table 3

Commercially Available Latexes

Polymer Type	Supplier	Trade Name	Solids, %
Acrylic	Rohm and Haas Company	Rhoplex E-330 Rhoplex MC-76	47 47
	Reichold	Synthemul 97-629	47
	Beatrice Chemical Co.	NeoCryl A-1055	47
	Set Products	Acryl-Set*	25
	Thoro Systems Product	Acryl-60*	28
	Tamms Ind.	Akkro 7-T	28
Styrene-butadiene	Polysar Latex	Dylex Latex 1186	47
	Reichold	Tylac 97-314	47
	Dow Chemical	Dow Modifier A	47-49
	General Polymers	Deco-Rez Polymer 4776	46-49

* Antifoaming agent included in the admixture by manufacturer.

Table 4

Typical Properties of Polymer Latex Admixtures for Concrete and Mortar*

Polymer Type	PVA	SBR	Acrylic	Saran
Solids, %	50	48	46	50
Density, Mg/m^3	1.09	1.01	1.05	1.23
pH	5.0	10.5	9.5	2.0
Particle Size, µm		0.20	0.2	0.14
Shelf Life, yr		Over 2	Excellent	
Viscosity, centipoises at 20° C	14	24	250	

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* Bentur 1982.

Table 5

Mechanical Properties of Latex-Modified Mortars*

(from Mindness 1981)

	Control		Styrene-butadiene	Saran**	Acrylic	PVAc	Epoxy
Compressive strength							
MPa	31	41†	33	61	32	26	52
psi	4,500	5,800†	4,800	8,400	4,700	3,700	7,500
Tensile strength							
MPa	2.2	3.7†	4.3	6.3	5.8	4.8	5.0
psi	310	535†	620	910	835	700	730
Flexural strength							
MPa	4.2	7.4†	9.9	12.9	12.7	12.7	11.3
psi	610	1,070†	1,430†	1,820	1,835	1,840	1,640
Modulus of elasticity							
GPa	23	--	10.8	15.5	--	--	18
millions of psi	3.40	--	1.56	2.25	--	--	2.7
Shear bond strength							
MPa	0.35-1.4	--	>4.5††	>4.5††	>4.5††	>4.5††	
psi	50-200	--	>650††	>650††	>650††	>650††	
Impact strength							
m·kg	0.07	0.08†	0.22	--	0.25	0.18	--
in.-lb	6	7†	19	--	22	16	--
Abrasion resistance (% Wear)	24	5†	2.5	--	1.7	5	--

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* Sand/cement = 3; polymer/cement = 0.20; dry-cured 28 days at 50 percent RH.

** Vinyl chloride-vinylidene chloride copolymer.

† Moist-cured 28 days.

†† Failure occurred through mortar rather than at the interface.

Table 6

Impact and Abrasion Resistance of Latex-Modified Mortars*

(Sand/Cement = 3; Polymer/Cement = 0.10; Dry-Cured
28 Days at 50-Percent Relative Humidity)

	Control**	Styrene-butadiene	Acrylic	PVA
Impact resistance, in.-lb	6.2 (7.1)	11.5	12.6	11.5
Abrasion resistance, % loss in mass	24 (5)	2.5	1.7	5

* New Zealand Concrete Research Association 1983.

** Figures in parentheses indicate control values appropriate to 28-day moist cure.

Table 7

Typical Mixture Proportions for Latex-Modified Mortars and Concretes*

Plaster Mix (3/1)	kg
Sand	1,390
Cement	500
Latex solids	50
Water**	200
Antifoam	0.75
Floor Topping (4/1)	
Sand	1,540
Cement	400
Latex solids	40
Water**	160
Antifoam	0.60
Concrete	
3/4-in. aggregate	740
3/8-in. aggregate	490
Sand	650
Cement	320
Latex solids	32
Water**	130
Antifoam	0.48

* New Zealand Concrete Research Association 1983.

** Includes water from latex.

Table 8
Compressive Strength

System	28-Day Strength, psi
ACR-3	
(0.05 polymer/cement)	5,870
(0.075 polymer/cement)	6,030
(0.10)*	~6,500
ACR-7**	4,410
SBR-1 (0.12 polymer/cement)	5,570
ACR-5**	5,220
ACR-2**	4,730

* Obtained from Table 11.

** Prepackaged kit; recommended proportions were used and polymer/cement ratio was not given.

Table 9
Tensile Strength

System	28-Day Strength, psi
ACR-1*	620
ACR-2*	680
ACR-4 (0.20 polymer/cement)	~1,000
ACR-5*	1,100
ACR-6*	840
ACR-8*	830
SBR-1 (0.12 polymer/cement)	770
ACR-1 (0.16 polymer/cement)	1,150
ACR-1 (0.12 polymer/cement)	810

* Prepackaged kit; recommended proportions were used and polymer/cement ratio was not given.

Table 10
Bond Strength

Type of Interface	Bond Coat**	Bond Strength, psi	Type of failure
ACR-1/mortar	No	1,140	Bond
ACR-1/mortar	Yes	1,490	Bond
ACR-2/mortar	Yes	2,220	Bond
ACR-5/mortar	No	3,270	Mortar
ACR-5/mortar	Yes	2,590	Bond
ACR-8/mortar	No	2,220	Bond and Mortar
ACR-8/mortar	Yes	1,950	Bond
SBR-2/mortar	Yes	2,440	Bond
SBR-3/mortar	Yes	1,210	Bond
ACR-2/ACR-2 (16 hr)*		1,930	Bond and Mortar
ACR-2/ACR-2 (16 hr)*		1,450	Bond
ACR-6/ACR-6 (24 hr)*	No	2,767	Bond
	Yes	2,017	Bond
ACR-3/ACR-3 (24 hr)*	No	1,840	Bond
ACR-4/ACR-4 (24 hr)*		2,890	Bond
		2,190	Bond

* Time lapsed between application of second half of cylinder.

** Bond coat indicates if the surface was primed with the latex admixture.

Table 11
Effects of Underwater Submersion on ACR-3 Specimens
(0.10 polymer/cement ratio)

Condition	Compressive Strength, psi	Tensile Strength, psi
6-month air-cured	6,520	--
12-month air-cured	6,870	830
6-month immersed*	5,560	--
12-month immersed*	5,680	570
5-month immersed, then 1-month air dried*	6,840	930

* Test specimens were air-cured for 28 days prior to immersion.

Table 12

Water Vapor Transmission on ACR-3 Specimens

Time days	Grams of Water Evaporated Polymer/Cement Weight Ratio Control*	0.05	0.075	0.10	0.12
1	0.45	0.66	0.32	0.16	0.15
2	0.77	1.23	0.64	0.28	0.26
3	1.18	1.83	0.99	0.43	0.41
4	1.66	2.48	1.38	0.61	0.59
5	2.76	3.66	2.09	0.93	0.90
6	3.39	4.26	2.42	1.07	1.03
7	3.96	4.82	2.77	1.21	1.16
8	4.57	5.46	3.16	1.42	1.38
9	5.15	6.09	3.53	1.59	1.53

* The control specimen was a 28-day cured portland cement-sand mortar. Its purpose was to show the flow rate through a nonmodified mortar.

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