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AN INVESTIGATION OF TECHNIQUES FOR ACHIEVING EXPOSED AGGREGATE SURFACES FOR SITE-CAST CONCRETE

Daniel J. Naus, et al

Army Construction Engineering Research Laboratory
Champaign, Illinois

June 1975

construction engineering research laboratory

TECHNICAL REPORT M-61 (Revised)
June 1975

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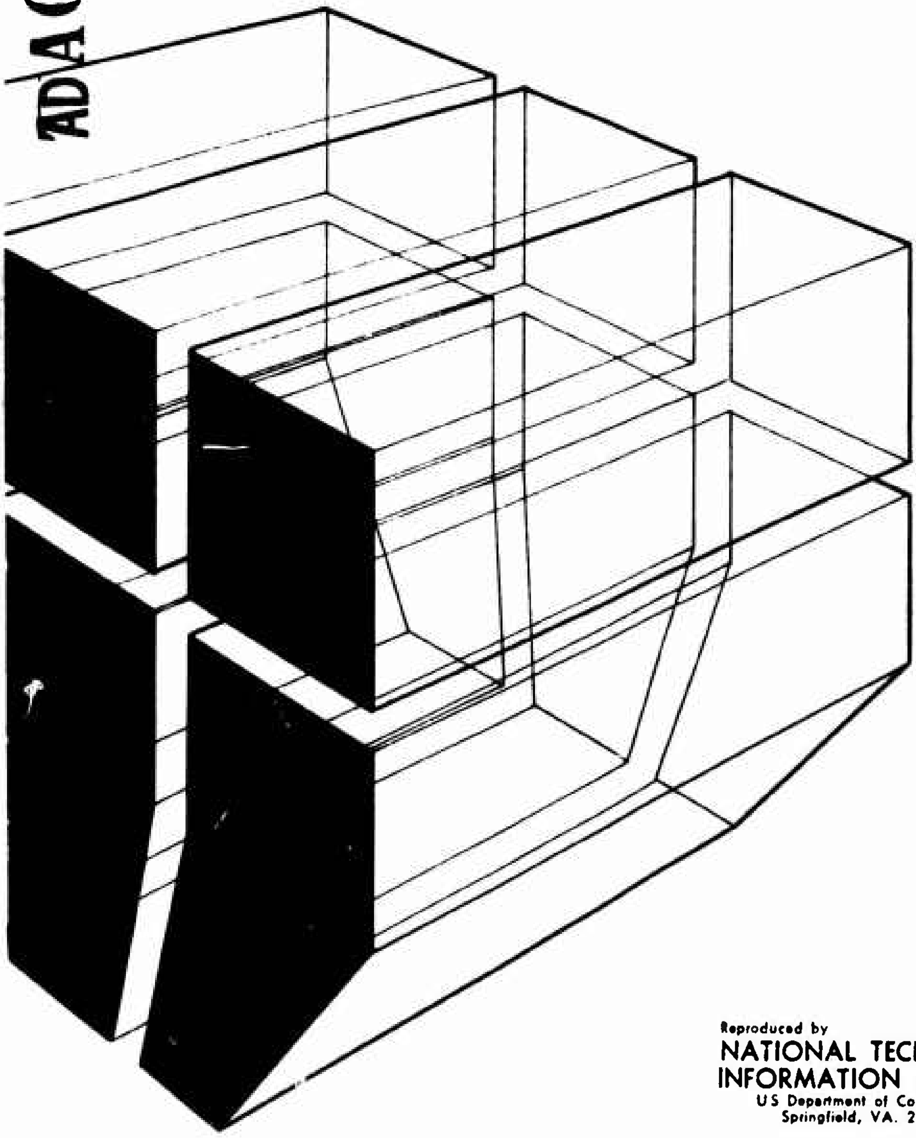

by
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Randy Freeman
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G. R. Williamson

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
CERL-TR-M-61 (Revised)

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
AN INVESTIGATION OF TECHNIQUES FOR ACHIEVING EXPOSED AGGREGATE SURFACES FOR SITE-CAST CONCRETE

5. TYPE OF REPORT & PERIOD COVERED
FINAL REPORT

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Daniel J. Naus
Randy Freeman
Wayne Muir
G. R. Williamson

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
P.O. Box 4005
Champaign, Illinois 61820

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
4DM78012A0K1-03-004

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
June 1975

13. NUMBER OF PAGES
~~19~~ 21

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
site cast concrete
exposed aggregate finish
chemical retardation
mechanical finishing

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

This report describes techniques for producing acceptable exposed aggregate finishes for site cast concrete, including chemical retardation and mechanical methods. Potentially promising techniques are evaluated with regard to labor requirements, material requirements, cost factors, and limitations.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This investigation was conducted by the U.S. Army Construction Engineering Research Laboratory (CERL). The work was performed under Project 4DM78012A0K1, "Engineering Criteria for Design Construction," Task 03, "Application of Construction Methods," Work Unit 004, "Methods of Achieving Exposed Aggregate Facing for Site-Cast Concrete." The Technical Monitor was Mr. R. Liebhardt.

This report was originally published December 1973, but has been extensively revised.

Special recognition is given to Mr. James Shilstone of Architectural Concrete Consultants for his help in obtaining information and data on architectural concrete, and for his review and constructive criticism of the report.

CERL personnel directly concerned with this study were Wayne Muir, Randy Freeman, and Dr. D. J. Naus of Construction Materials Branch (Dr. G. Williamson, Chief), Materials Systems and Science Division (J. J. Healy, Chief). COL M. D. Remus is Commander and Director of CERL and Dr. L. R. Shaffer is Deputy Director.

CONTENTS

AN INVESTIGATION OF TECHNIQUES FOR ACHIEVING EXPOSED AGGREGATE SURFACES FOR SITE-CAST CONCRETE

1 INTRODUCTION

Problem Statement. During the next 4 years the Corps of Engineers will be responsible for building Volunteer Army facilities and other structures at a construction value of over $1 billion. Although redefined objectives resulting from the Volunteer Army program have placed greater emphasis on the aesthetic aspects of site-cast structures, much Corps construction will involve the use of reinforced concrete—which can have an unpleasing appearance when subjected to substandard placement procedures. One potential solution for obtaining concrete structures free of placement defects is the use of cast-in-place exposed aggregate.

Objective. The objective of this investigation is to present an overview of architectural concrete, and to identify techniques for producing acceptable exposed aggregate finishes for site-cast concrete so that the economic advantages of reinforced concrete may be more fully realized.

Approach and Scope. A general overview of architectural concrete was conducted to identify techniques which can be used to produce visually attractive site-cast concrete. Potentially promising techniques were evaluated for labor requirements, material requirements, cost factors, and limitations. Precast element facings and form liners which produce textured concrete surfaces were investigated as alternative techniques for obtaining architectural concrete facings (see Appendices A and B).

Discussion. This investigation revealed that many design and construction experts consider architectural concrete little more than a slight variation of structural concrete. This is not the case. Mix design and placement procedures differ greatly, and if acceptable results are to be achieved, only those with a wide knowledge of architectural concrete should be involved in the design and construction of the material.

Definition. In this report, exposed aggregate site-cast concrete is defined as concrete from which a uniform, visually acceptable result is produced by removing the surface skin to expose the substrate consisting of cementitious paste, fine aggregate and/or coarse aggregate to varying degrees and textures.

2 EXPOSED AGGREGATE FINISHES FOR SITE-CAST CONCRETE

Introduction. Techniques for producing site-cast exposed aggregate concrete finishes involve either chemical retardation or mechanical finishing. Each is discussed later in this chapter.

Mix Design. The design of the concrete mix must be related to the finish objective. Design practices routinely acceptable for structural concrete mixes give little consideration to architectural results. When the objective is an exposed aggregate finish, the mix design must provide both structural integrity and enough uniformly distributed particles in the mix to produce the desired appearance. Regardless of finish objective, the water/cement ratio should be low to minimize potential problems of segregation and/or excessive shrinkage cracks. In designing the mix, it should be recognized that the concrete will be used primarily in vertical construction to be consolidated by mechanical vibrators. Many standard structural concrete mixes are designed for finishing flat slabs as well as for vertical construction. The mortar required for slab finishing, however, is not necessarily required for vertical construction. The demands of lay-down type buckets and pumps should not be given preference over the architectural finish in the mix design. The equipment should be compatible to the mix and not vice versa.

In light textures, the paste and fine aggregate distribution are important; in these cases, conventional structural concrete mix design processes are frequently adequate. When heavy coarse aggregate texture is a major architectural feature, however, special mix design techniques are essential. Use of coarse aggregate dry-rodded unit weight and sand fineness modulus is a good basis for architectural mix designs. Tables currently available from industry are seldom adequate as they are not founded upon modern placing techniques or architectural results. Competent specialists should therefore be sought out to assure production of the intended results. High coarse aggregate factor mixes will require use of a low fineness modulus sand. Limitations of ASTM C-33 do not necessarily have to be observed. For finishes of heavy abrasive blasted or retarded exposed aggregate, the principles of gap grading should be used.

Forms. Erection of watertight forms is necessary for all architectural concrete because any loss of moisture or grout from the concrete will produce either surface discolorations or honeycombing. All joints must be sealed to prevent leakage and all corners should be sealed by closed cell compressible neoprene gaskets. When a heavy texture is to be used, face butt joints should be covered with tape. When a light texture is required, face butt joints should be covered with a grooved rustication and the form sealed before application of the retarder. Construction joints should be articulated by a grooved rustication with the first casting of concrete carried to the top of the root of the rustication. The joint can be made tight by applying a closed cell compressible neoprene gasket over the root of the subsequent form and pulling this tight against the previous casting.

Chemical Retardation. Exposed aggregate concrete surfaces produced by chemical retardation are used primarily in the precast concrete industry, where the exposed aggregate surface is cast horizontally and a high degree of quality control can be maintained.* A uniform surface is very difficult to obtain for vertically cast-in-place surfaces using chemical retardation. Part of the difficulty is that all of the chemical retarders studied were partially soluble in water. This causes varying degrees of etch for a vertically cast surface because as each lift is vibrated the soluble part of the retarder migrates vertically along the form face, producing an increased concentration of retardant with each succeeding concrete lift. Also, if improper concrete placement techniques are used and the concrete is dropped so that it contacts the forms above the placement level, the chemical action of the retarder could be initiated above that level. As a result, when the placement level reaches the level where the concrete previously came in contact with the form, the chemical action would cease and an area where chemical retardation does not occur would result, producing a hard spot. The chemical process can be used effectively in limited areas under very close control. The types of retarders best suited for the specified mix must be carefully evaluated. Some products are suitable for one mix but not another.

Procedure. The best procedure to follow in using a chemical retarder consists of six steps: form erection, application of retardant, concrete mix design, concrete placement, form removal, and surface removal.

The chemical retarder must be applied on a high-quality form to achieve the best results. The product should be carefully applied in accordance with the manufacturer's recommendations and allowed to dry. Excessive or uneven application will result in nonuniform etching that can produce unsightly surface blemishes.

An alternative to the liquid retarder is retarder paper, a chemically treated paper that is attached as a form liner. The impregnated paper offers the advantage of assuring factory-controlled uniform distribution of the chemical. Like the liquid products, it is partially soluble in water and subject to abrasion during concrete placement—thus can have some of the same disadvantages.

Concrete must be placed and compacted with care. During placement it is important that the concrete does not contact the form faces above the current placement level, to avoid premature retardant action. A "tremie" should be used for placement to avoid splashing of the concrete against the form face.

The forms should be stripped according to the schedule recommended by the retardant manufacturer. Immediately after stripping, the concrete surface must be washed and brushed to expose the aggregate. Forms should not be stripped until workers are available to brush the surface.

Figure 1 shows exposed aggregate surfaces produced by using chemical retardants.

Cost Factors. Cost factors[1,2] vary with the source of information; however, a range of costs can be established. Material costs for the chemical retardant, whether liquid or paper, range from $0.30 to $0.80/sq ft. Labor costs for application of the retardant and brushing range from $0.20 to $0.45/sq

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*Poor-quality surfaces (e.g., blemished, honeycombed areas) may be rejected for precast elements but not so readily for site-cast.

[1] *Architects Contractors Engineers Guide to Construction Costs* (Concrete Construction Publications, Inc., June 1972).

[2] R. M. Gensert, "Cost Factors for Cast-In-Place Architectural Concrete," *Journal of American Concrete Institute*, Vol 69, No. 1 (January 1972), pp 36-45.

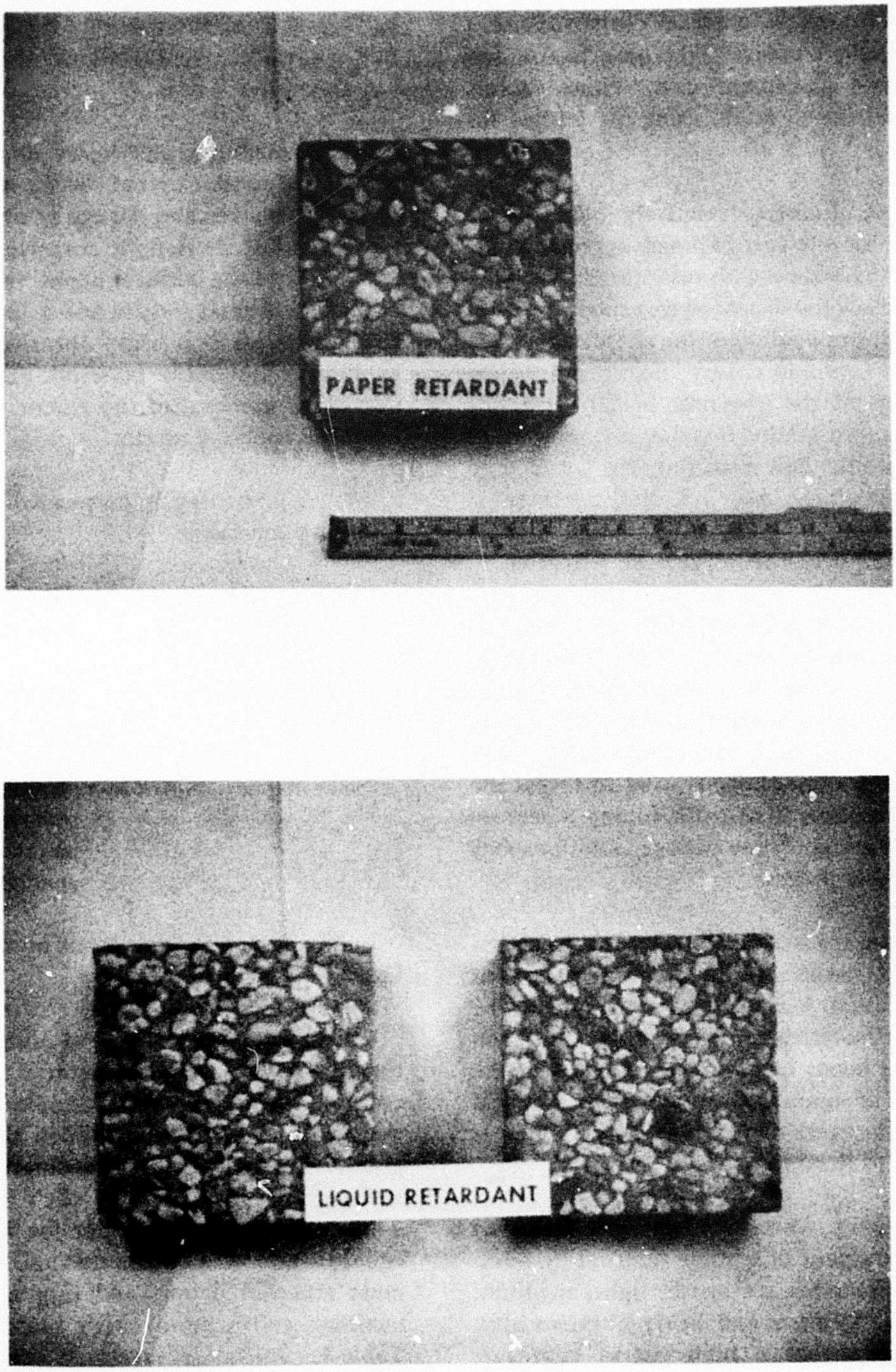

Figure 1. Exposed aggregate surfaces produced by using chemical retardants.

it. Generally, retarders are used when heavy texture is required. Such texture increases costs because it requires a very high coarse aggregate factor and creates an added placement cost. These factors should be considered in establishing the budget for the project.

Limitations. A uniform, relatively blemish-free vertical surface for site-cast exposed aggregate surfaces is difficult to achieve with retardants. As previously noted, well-defined procedures must be carefully followed for application of the chemical retardant, erection of forms to ensure their being watertight, placement of the concrete (which probably should contain a gap-graded mix design), removal of forms, and washing and brushing the surface to expose the aggregate. Also, if the concrete is improperly placed or compacted, large honeycombed areas can occur which require patching.

Mechanical Finishing. Removing the concrete surface mechanically is called mechanical finishing. Means of removing surface material range from light abrasive blasting (sand blasting) to impact hammering (bushhammering, jackhammering, scaling, and tooling). Mechanical finishing is used to reveal the colors of the mix ingredients, developing a texture for the finished surface. Some surface variations may be removed by this process.

The procedures and controls involved in mechanical finishing are essentially the same as those for chemical retardation. It is critical that the forms be watertight, the concrete be properly placed and compacted, and the forms be carefully removed at the proper time. The main advantage of mechanical finishing over chemical retardation is that there is more tolerance to finishing.

Abrasive Blasting. Abrasive blasting is classified according to the extent of surface removal by abrasion. The classifications are brush, light, medium, and heavy blast. Medium and heavy abrasive blast techniques require that a high coarse aggregate factor mix be used, while brush and light abrasive blast finishes can be produced with conventional structural concrete mix designs. A venturi nozzle should be used to deliver a uniform impact of the abrasive over the entire area of contact.*

Brush blasting, a technique that removes only the surface skin of the concrete by scouring, removes minor surface color variations. It can be performed any time after 7 days.

Light, medium, and heavy abrasive blast techniques are similar except for the amount of surface material removed and the age at which the surface is abrasive-blasted. A light abrasive blast removes a small skin of the surface, exposing the coarse particles of the fine aggregate and a few particles of the coarse aggregate; a heavy abrasive blast removes a significant amount of material, exposing the coarse aggregate particles to the extent that they project from the concrete mortar.

Abrasive blasting is performed according to the following timetable:

brush & light abrasive blasting	7 days or more after form removal
medium abrasive blasting	prior to 5 days after form removal
heavy abrasive blasting	immediately after form removal (which should be one to two days after concrete placement)

Figure 2 shows examples of abrasive-blasted surfaces.

- Cost Factors. The cost of abrasive blasting is a function of the amount of material removed from the concrete surface and the accessibility of the work to the men and equipment. When the work is above ground, the cost varies according to the amount of surface area available at each staging location. Abrasive blasting is cheaper for walls than for an equal surface area of columns and beams. Approximate material, labor, and rigging costs for light, medium, and heavy abrasive blasting are shown in Table 1.

- Limitations. Dust and noise control are very important, especially in populated areas. Because of the dust problem, some cities are outlawing this finishing technique in heavily populated areas.

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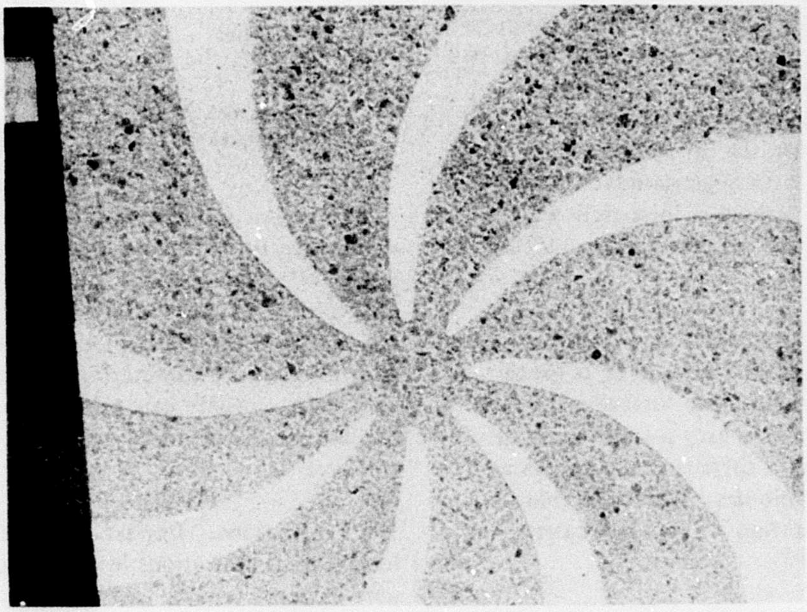
*A conventional nozzle gives high impact of abrasive at the center of the contact area and decreasing impact as the distance from the center of the contact area increases, producing an unevenly blasted area.

a. Medium abrasive blasting



b. Abrasive blasting in conjunction with a template to produce pattern finish

Figure 2. Exposed aggregate surfaces produced by abrasive blasting.

Table 1

Material and Labor Costs for Abrasive Blasting

Technique	Labor Cost $/sq ft	Material Cost $/sq ft	Labor, Materials, & Rigging Cost $/sq ft
Light Abrasive Blast (≅ $^{1}/_{16}$ in. to $^{1}/_{8}$ in. material removal)	0.07 - 0.15	0.03 - 0.07	0.50 - 1.00
Medium Abrasive Blast* (≅ $^{1}/_{8}$ in. to $^{1}/_{4}$ in. material removal)	0.09 - 0.24	0.04 - 0.08	0.85 - 1.30
Heavy Abrasive Blast (≅ $^{1}/_{3}$ in. to $^{1}/_{2}$ in. material removal)	0.12 - 0.33	0.05 - 0.13	1.00 - 1.50

*This does not include environmental protection costs

Workmen must wear protective equipment to avoid silicosis. Another disadvantage is that abrasive blasting tends to accentuate the visual impact of construction-caused discrepancies.

Impact Hammering. Mechanically hammered surfaces are produced by impacting the concrete with a mechanical tool to remove part of the concrete surface. The three techniques commonly used to produce a mechanically fractured surface are scaling, bushhammering, and jackhammering. Mix design requirements for the three techniques are essentially the same; coarse aggregate factors should be increased slightly as texture is increased. Figure 3 shows an example of a surface produced by mechanical fracturing.

Scaling is done with a pneumatic device containing piston-driven chisels that rotate, or a group of needle-like pins that fracture the surface on impact. The scaler's impact removes only a small amount of the concrete, producing a surface that appears as if many small chips or "nibbles" had been removed. Scaling is done not less than 7 days after casting the concrete.

Bushhammering produces a slightly more accentuated texture than scaling. Either pneumatic or hand devices may be used. The tool head generally is about 1½ in. square and is faced with a series of sharply pointed pyramids approximately ¼ in. square at their bases. These pyramids are on a tightly spaced pattern over the head of the tool. The texture is achieved by impacting the points of the pyramids on the concrete. Bushhammering is done not less than 7 days after casting the concrete.

Jackhammering is accomplished with either a chiseled or pointed tool. Its purpose is not to remove aggregate from the concrete matrix, but to fracture it irregularly. Most surfaces can be jackhammered not less than 7 days after casting the concrete.

- Cost Factors. Costs reported for impact hammering vary with the source of information; however, an approximate cost range can be determined. Labor, equipment, and rigging costs for impact hammering techniques are shown in Table 2. Cost varies extensively in different parts of the United States. In some isolated areas impact hammering techniques may be cheaper than abrasive blasting techniques, depending on the availability of skilled labor.

Table 2

Labor and Material Costs for Impact Hammering of Concrete

Method	Labor & Equipment & Rigging Cost $/sq ft
Scaling	0.60 - 1.25
Bushhammering	0.80 - 1.75
Jackhammering	1.50 - 3.00

Equipment and labor costs for impact hammering relate directly to the strength of the concrete and degree of texture desired. As with abrasive blasting, accessibility of work and amount of work at any staging location are factors to be considered. In addition, impact hammering on a concrete structure with many corners can be more expensive because special care is required to avoid breaking off the corners.

- Limitations. Impact hammering techniques have several limitations in producing exposed aggregate surfaces for site-cast concrete. Labor costs are high because the techniques require semiskilled, physically strong labor and proceed at a relatively slow rate. Laborers familiar with impact hammering techniques are difficult to find. Improper vibration techniques can cause honeycombed areas which may be exposed during the mechanical finishing process.

Figure 3. Exposed aggregate surface produced by mechanical fracturing (bushhammering).

If blemished areas are patched prior to impact hammering, the impact hammering process may remove the patches if not carefully performed.

- Advantages. Impact hammering techniques are referred to as "forgiving" finishes since they minimize the appearance of many construction variations. This is because the impact of metal upon dark stone or concrete causes the point of impact to become lighter in color. For this reason, needle scalers are frequently used for abrasive-blasted surfaces in corrective action at lift lines and points of leakage. Due to the forgiving character of the finishing technique, quality of workmanship does not have to be as high as for abrasive blasting This can partially offset the cost of the technique.

Repair of Exposed Aggregate Concrete Surfaces. An exposed aggregate concrete surface produced by chemical retardation or mechanical finishing techniques invariably contains surface defects such as blowholes, honeycombed areas, or color irregularities resulting from a variety of causes. Repairing these defects so that the patched area is not more noticeable than the original defect is difficult.

Minor surface irregularities can be removed by hand tooling. If patches are required on a surface to be abrasive-blasted, they should be applied after the abrasive blasting so they will not be blown from the hole during blasting. Mix constituents for the patch should be essentially the same as for the original mix, but a trial-and-error procedure with a test panel should be used to develop a mix slightly darker than the surrounding concrete. When gray, buff, or tan cements are used, the proportions of the patch ingredients should be the same as for the cast concrete. However, between 5 and 50 percent of the colored cement should be replaced with white cement to lighten the mix. This is necessary because a patch mix with a very low water/cement ratio would otherwise be much darker than the surrounding concrete. The concrete to be placed in the patched area also should be of the same density as the surrounding concrete, especially if a sealer coat is to be applied later. (The application of a sealer over a patched area will accentuate the patched area more if the concrete in the patch differs in density.) After the proper texture is applied to the patched area, the concrete should be cured carefully to minimize the shrinkage effects. For small patches, the concrete should be thoroughly wet before the patch is applied. For large patches, the bond should be improved by painting the concrete to be covered with a bonding material. Care should be taken to avoid dripping the bonding material on the exposed concrete as it will tend to darken the concrete. Bonding agents should not be used as a part of the concrete patch mix because they will perform as an integral sealer. Patch mixes so prepared will frequently be much darker than the surrounding area. Also, when the concrete is wet by rain, the patch will repel the water, thus standing out objectionably. Trial-and-error procedures should be used so that the color and/or surface texture of the surrounding concrete can be matched.

3 CONCLUSIONS AND RECOMMENDATIONS

Conclusions. Successful site-cast exposed aggregate concrete is possible if planning and construction are carefully carried out.

Specifications for exposed aggregate architectural concrete must be procedural since there are no standards to which the specifications writer can refer. A sample to be matched is an unrealistic standard without detailed specifications.

Special attention must be given to assure the use of proper form work, proper mix design, leakage prevention techniques, optimum placement methods and compaction equipment, and reinforcing details that facilitate constructability.

Chemical retardation can be used for cast-in-place work if stripping and finishing are carefully time-controlled, and if extensive work is not required on the projects. The reliability of most retardation products is minimal because of their solubility in water, easy removal from the forms by abrasion as the concrete is placed, and susceptibility to premature initiation of the chemical reaction.

A primary deterrent of mechanical finishing is the adverse environmental effects. Dust and noise control are not only expensive but also extremely difficult. Light blast finishing is easiest type of abrasive blasting to achieve successfully because uniformity of aggregate distribution is not a key factor, in addition, medium and heavy blast textures require early form stripping to achieve economical results. Where possible, a desirable treatment for large expanses of flat surface would be use of a form liner to contribute texture which would minimize the accentuation of individual construction blemishes.

When considering budgets for this type of construction, one must compare the premium costs over the raw structural concrete cost of alternative applied finishes. When raw structural concrete is considered visually unacceptable, more money must be invested in the concrete materials, construction, and finishing techniques in order to achieve acceptable results. These premiums can be defined as a cost per square foot of finished architecture surface and thereby related to similar cost data for masonry, stone, metal, or other cladding materials.

Recommendations. Use of exposed aggregate cast-in-place architectural concrete does not prohibit economical construction of concrete structures. However, its use should be planned and monitored by personnel experienced in the details necessary to achieve the intended aesthetic results.

Architectural concrete specifications should be separated from structural concrete details. If the "or equal" clause is used, the basis of architectural equality must be established. Since few product standards exist for architectural concrete construction, there is no recourse but to specify product names.

Industry standards of acceptability for architectural concrete construction are incomplete. The American Concrete Institute Committee 303, Architectural Concrete, has published a report entitled "Guide to Cast-in-Place Architectural Concrete Practice," and the Dallas Chapter of the Construction Specifications Institute has published a monograph entitled "Cast-in-Place Architectural Concrete." These and other publications in the field should be used by the Corps of Engineers in preparing specifications that would ensure acceptable results when site-cast exposed aggregate is specified.

Table 3 can be used as a planning guide for architectural concrete.

Table 3

Architectural Concrete Quality Planning Guide Chart*

Relative significance of construction details on the results

Published By

General Portland Inc.

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	Relative Significance	AS CAST FINISH				DISTRESSED FINISH													
		Absorptive		Non Abs		Abrasive Blast				Impact Hammer				Combination					Chemically Retarded
		Smooth	Texture	Smooth	Texture	Brush	Light	Medium	Heavy	Scale	Bush	Jack	Tool	Reed and Hammer	Reed and Blast	Reed and Chisel	Var. Reed and Blast	Texture Liner and Blast	
A. CONCRETE MIX																			
1. Cement Color		1	1	1	1	1	1	2	2	2	2	3	3	1	1	2	1	2	2
2. Fine Aggr. Gradation		4	4	4	4	4	2	1	1	3	3	1	3	3	3	2	3	3	1
3. Color		3	3	1	3	2	2	3	1	2	2	2	2	3	2	2	2	2	3
4. Coarse Aggr. Gradation		4	4	4	4	4	2	2	1	4	4	4	4	1	3	1	3	3	1
5. Color		3	3	3	3	1	2	1	1	2	2	2	2	2	3	2	3	3	1
6. Design Technique		2	3	2	3	3	3	2	1	3	2	2	2	3	2	2	2	3	1
7. Admixture		2	3	2	3	3	3	2	1	3	3	3	3	3	3	3	3	2	1
8. Consistency (slump)		2	3	2	3	3	3	2	1	3	3	2	2	3	2	2	2	2	1
9. Mixer Capabilities		4	4	4	4	4	3	2	1	4	4	3	3	3	3	3	3	3	1
B. FORMS																			
1. Selection of Materials		1	2	2	2	1	1	2	2	2	2	3	3	2	2	2	2	2	2
2. Reuse Limitation		3	2	3	3	1	2	2	3	2	3	4	4	3	3	3	3	2	2
3. Butt Joints Location		1	1	1	3	1	1	4	4	4	4	4	4	2	2	2	2	2	3
4. Tape								2	2	2	3	3	3	2	2	1	2		2
5. Rusticate		2	2	2	2	1	3	2	3	3	3	3	3	2	2	3	2	1	2
6. Tightness		1	1	1	1	1	1	2	2	2	2	3	2	2	2	2	2	1	1
7. Rigidity		2	3	1	3	2	2	3	3	2	3	4	3	2	2	2	2	3	2
8. Design Strength		2	3	2	3	2	2	2	2	2	3	4	3	2	2	3	3	4	2
9. Stripping Control		1	1	1	2	2	2	3	3	3	4	4	4	1	1	1	1	3	1
C. RELEASE AGENT																			
1. Product Selection		1	2	1	2	2	2	4	4	4	4	4	3	2	3	3	3	2	2
2. Application Technique		1	3	1	3	3	3	1	4	4	4	4	3	2	3	3	3	3	2
3. Surface Preparation		1	2	1	2	2	2	3	3	3	3	3	3	3	2	3	2	3	1
D. FORM TIES																			
1. System Selection		2	3	2	3	2	2	3	3	3	3	4	3	3	2	3	2	2	2
2. Installation Control		1	2	1	2	1	1	2	3	2	2	3	2	2	2	2	2	1	1
E. CONCRETE PLACEMENT																			
1. Technique		3	3	3	3	2	2	2	1	2	2	3	2	2	2	2	2	2	1
2. Equipment		3	3	3	3	3	3	2	1	3	3	3	3	3	2	2	3	3	1
3. Lift Height		2	3	2	3	2	2	2	[illegible]	[illegible]	3	3	3	3	2	2	2	3	1
4. Time of Lifts		2	3	2	1	2	2	2	1	2	3	3	3	3	3	3	3	3	1
F. CONSOLIDATION																			
1. Equipment Selection		2	3	2	3	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	1	2	3	3	2	3	2	1
2. Operator Training		1	[illegible]	1	2	2	[illegible]	[illegible]	1	3	[illegible]	1	3	[illegible]	2	3	[illegible]	2	1
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4. Degree of Effort		[illegible]	3	[illegible]	2	2	2	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	1
G. REINFORCING STEEL																			
1. [illegible]		2	2	[illegible]	[illegible]	2	2	1	[illegible]	3	3	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]		[illegible]	3	[illegible]	3	[illegible]	2	[illegible]	[illegible]	[illegible]	3	[illegible]	3	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]
3. [illegible]		3	[illegible]	[illegible]	3	3	2	[illegible]	[illegible]	3	[illegible]	2	[illegible]	[illegible]	3	[illegible]	3	[illegible]	[illegible]
4. [illegible]		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5. [illegible]		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H. FINISHING																			
1. [illegible]		1	3	[illegible]	3	4	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]
2. Equipment		[illegible]	[illegible]	[illegible]	[illegible]	3	3	[illegible]	1	[illegible]	2	[illegible]	[illegible]	3	2	3	[illegible]	[illegible]	[illegible]
3. [illegible]		2	[illegible]	[illegible]	2	3	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]		[illegible]	[illegible]	[illegible]	[illegible]	3	3	[illegible]	[illegible]	[illegible]	[illegible]	2	1	[illegible]	3	2	3	[illegible]	[illegible]

This table shows [illegible] the degree of influence [illegible] required [illegible] structural concrete are [illegible] ratings of 1 the degree of influence is high [illegible] the construction process [illegible]

Ratings [illegible] and 3 are relative intermediate levels of influence.

This tab[illegible] intended as a general guide only. Each type of architectural concrete finish must be carefully [illegible] detailed and [illegible] to achieve results worthy of the design.

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APPENDIX A:

ALTERNATE TECHNIQUES FOR PRODUCING EXPOSED AGGREGATE FINISHES

There are alternative construction methods for achieving exposed aggregate architectural concrete. These alternatives include precast fabrication of panels or in-place construction using special techniques.

1 PRECAST EXPOSED AGGREGATE

Precast concrete construction may be applicable for veneers or window walls affixed to structural frames; for systems construction which uses both load-bearing and architectural qualities of the concrete; and for thin-shelled concrete forms to be left in place in composite construction. More uniform product quality is possible with precast exposed aggregate concrete because of better controls in the plant and the possibility of selecting the casting position and technique most appropriate to the results, rather than being restricted to vertical construction for cast-in-place work. Systems construction can aid in early construction completion through the use of concurrent operations and rapid assembly of the components.

Precasting is performed by either the "zero slump" or "wet" processes.

Zero Slump. This process involves the casting of "zero slump" concrete in forms which are alternately lifted and dropped onto shocking tables. The force of the drop consolidates and densifies the concrete in the intricacies of the form. The technique is most frequently used for light texture finishes and as-cast surfaces. Mixes are designed for use with the shock technique and do not include high coarse aggregate factors necessary for dense coarse aggregate finishes. Concrete quality is excellent because of the low water/cement ratio.

Wet Process. The wet process involves use of conventional and gap-graded plastic concrete mixes. Generally the forms are flat, in contrast to the vertical forms used for in-situ construction. The finish is planned to be achieved on either the up or down face. The face-down technique, used most frequently, has a long history of excellent performance.

Face Down Methods. Finishes can be effected by surface retardation, abrasive blasting, impact hammering or sand bed methods. The concrete mix is placed within the forms and consolidated by internal vibrators, form vibrators and/or form table vibration. These processes can be used individually or in combination. When the finish objective is a dense, uniformly distributed coarse aggregate, a grid vibrator is used to force the coarse aggregate to the form face. After this is done, the remainder of the concrete is placed and consolidated by conventional means. Two different mixes can be used within architectural precast concrete. When the mix which will influence the finish is an expensive one, it can be applied in a ±2 in. layer, consolidated, and then topped with a backup mix which is nonarchitectural. When lightweight concrete is proposed for use in the backup for weight reduction or insulation, it is necessary to separate the two mixes.

For medium and heavy textures, the most frequently used process for exposing the aggregate is through the use of retarders applied to the form face before casting. In contrast to cast-in-place capabilities, this technique has been developed to a fine art.

Although abrasive blasting is most frequently used for fine textures, they can sometimes be produced with retarders.

The sand bed method can be used most effectively when the coarse aggregate to be exposed is 1 inch or more in diameter, or large flat plates are to be used to provide a layed-up wall effect. The procedure followed for this technique consists of spreading a layer of fine sand over the bottom of the form to a depth of one-third the diameter of the aggregate particles used; compactly embedding the coarse aggregate particles in the sand; lightly spraying the sand and coarse aggregate with water to settle the sand around the coarse aggregate particles to hold them in place; placing the reinforcing steel into the form; placing a conventional concrete mix (a facing mix if a special effect is desired) into the form without dislodging the embedded aggregate particles; curing the panels; and, after curing, removing the remaining sand particles by brushing, air blasting or washing with a stream of water. This technique is appropriate when only flat panels are planned. It is not possible when the exposed faces are to produce a complex sculptured effect.

Face Up Methods. Face-up methods usually refer to the use of tamping or rolling to embed coarse aggregate particles into the surface of plastic concrete.* The procedure conventionally followed consists of placing and compacting concrete from a normal mix design into forms; leaving enough space at the top surface layer for a facing mix; placing, compacting, and spreading of the facing mix; spreading coarse aggregate to be exposed on the facing mix and tamping the aggregate into the facing mix; and, removing excess mortar displaced by coarse aggregate particles by washing the surface prior to setting of facing mix. Chemical retarders may be used in conjunction with facing mixes to retard the set of the facing mix and allow washing and brushing techniques to be utilized at the most advantageous time. Also, mechanical finishing techniques may be applied to the horizontal panels to achieve an exposed aggregate surface.

2 SPECIAL TECHNIQUES

Several special techniques can be used to achieve an exposed aggregate surface: aggregate transfer, preplaced coarse aggregate and pumped mortar, preplaced facing aggregate and vibration of over-mortared core mix in the open sections of the construction, and thermal texturing. All processes can conceivably be used in both cast-in-place and precast construction. These processes are selected under special conditions and generally may be classified as being expensive.

Aggregate Transfer. The procedure for this technique consists of applying a layer of special adhesive* on the form face; spreading the coarse aggregate particles on the form face in either a random arrangement or as intricate a pattern as desired; allowing the adhesive to cure for a minimum of 20 hours; placing and compacting a good architectural concrete mix around the adhered coarse aggregate particles to be exposed and curing the panels.

Preplaced Aggregate. The total required coarse aggregate can be preplaced within the forms and the bonding grout introduced by pumping through either tubes previously inserted in the forms and raised as the grout level increases, or through holes drilled in the form walls. Coarse aggregate must be well graded with all particles less than 5/8 in. removed and must be cleaned to facilitate flow of the mortar through the voids. The mortar must include specially graded sand and generally incorporates an expansive additive.

Preplaced Face Aggregate. A specially selected coarse aggregate, preferably a 3/4 in. and larger particle size, is placed within a space created by the form and a mesh applied to the outer layer of the reinforcing steel cage. This should be a minimum clear space of 2½ inches. An over-mortared gap-graded concrete mix is then placed within the open space inside the reinforcing steel cage and the surplus mortar vibrated to fill the voids in the face aggregate.†

Thermal Texturing. Thermal texturing is a fast flame spalling process in which an acetylene torch is used to remove the surface of the concrete to expose the coarse aggregate particles. This process is somewhat time consuming and difficult to control to obtain uniform surfaces.

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*Large aggregate particles may also be placed by hand into the concrete matrix if one-third or less of the diameter of aggregate particles is to be left exposed.

*The thickness of the layer of adhesive applied to the forms depends on the particle size of the coarse aggregate. The adhesive used should be water resistant so that it will not soften when the plastic concrete comes in contact with it, and it should be strong enough to securely hold the aggregate but not strong enough to damage the forms when they are being stripped.

†This is the "Arbeton" process and is protected by U.S. Patent.

APPENDIX B:

FORM LINERS

1 INTRODUCTION

Form liners offer a relatively simple way of producing site-cast textured concrete surfaces. Virtually any texture or pattern may be reproduced by proper use of form liners. Fiberglass-reinforced plastics, polyvinyl chloride, rubber, foamed polystyrene, urethane, and rough sawn lumber have all been used successfully to produce attractive concrete surfaces, as long as precautions were taken; i.e., sealed forms, properly designed concrete mix, properly placed and compacted concrete, and careful curing and removal of the forms. The best results have been obtained with site-cast concrete when (1) a heavy form texture was used, (2) the exposed textured surfaces were subdivided into small areas which are easier to control, and (3) a white cement was used in the mix. Form liners have the added advantage that, if properly cared for, they may be reused many times.

2 PROCEDURE

Form liners are available either attached or unattached to a strong backing. If the liners are without a strong backing, they must be attached directly to the forms by gluing, stapling, etc. according to the manufacturer's specifications. The procedure followed for the proper use of form liners consists of erection of the form work, placement of the concrete, curing, removal of the forms, and tooling to produce a special surface effect if desired. Several examples of form liners and the surfaces they produce are shown in Figure B1.

Forms must be watertight if a high-quality, uniformly textured concrete surface is to be obtained. If lumber is to be used to produce a boarded surface, it must be completely sealed to prevent uneven water absorption. Moisture leakage between pieces of lumber can be prevented by using tongue-and-grooved jointing in conjunction with a closed-celled gasketing material at the corners and bottoms of the forms. Fiberglass-reinforced liners are usually interlockable but require gasketing material at the corners and bottoms of the forms. If interlockable liners are not used caulking compounds or epoxies may be used between liner sections to prevent grout leakage. Polyvinyl and rubber liners usually act as their own gasket material; however, gasketing material should be used wherever leaks may occur. Other forming details related to proper jointing use of rustification strips, form tie rods, etc., are as important as for conventional concrete form work. Also, release agents should be applied sparingly to the forms and then wiped with a dry cloth to leave only a thin coat of form release. This minimizes the cement skin which comes off and produces a discoloration as the forms are removed.

Proper placement and compaction of concrete are very critical factors in attaining high quality site-cast architectural concrete. The proper mix design produces a concrete with a slump of approximately 3 in. Conventionally accepted practices for concrete placement should be followed. Sufficient vibration should take place to allow the coarse aggregate to move toward the form faces and to ensure that the cement paste has sufficient time to flow, filling all voids created during placement. Extended vibration times are required with form liners because time is needed for the concrete to flow, conforming to the texture of the liner. (A properly designed mix is not easily overvibrated.)

The concrete is cured as is conventional concrete. After sufficient curing, the forms should be carefully removed. If tooling is applied to the textured surface to produce a special effect it should be done as soon as possible. Figure B2 illustrates examples of surface variations obtainable by mechanical finishing, and Figure B3 illustrates examples of special surfaces produced by custom form liners.

3 COST FACTORS

The cost of form liners varies from $1.40/sq ft to $12.00/sq ft depending on the texture and the type of form liner material. This does not, however, provide a true indication of the relative cost. In general, the form liners which are initially higher in cost may be cheaper on a life-cycle cost basis since they are fabricated from a higher quality material which may be reused several more times than the inexpensive liners.

4 LIMITATIONS

The primary limitation to the use of form liners is that proper use requires labor skilled in the placement of architectural concrete. Techniques used to place structural concrete are not always acceptable for architectural concrete placement. Also, as with all architectural concrete, the labor costs will be relatively high.

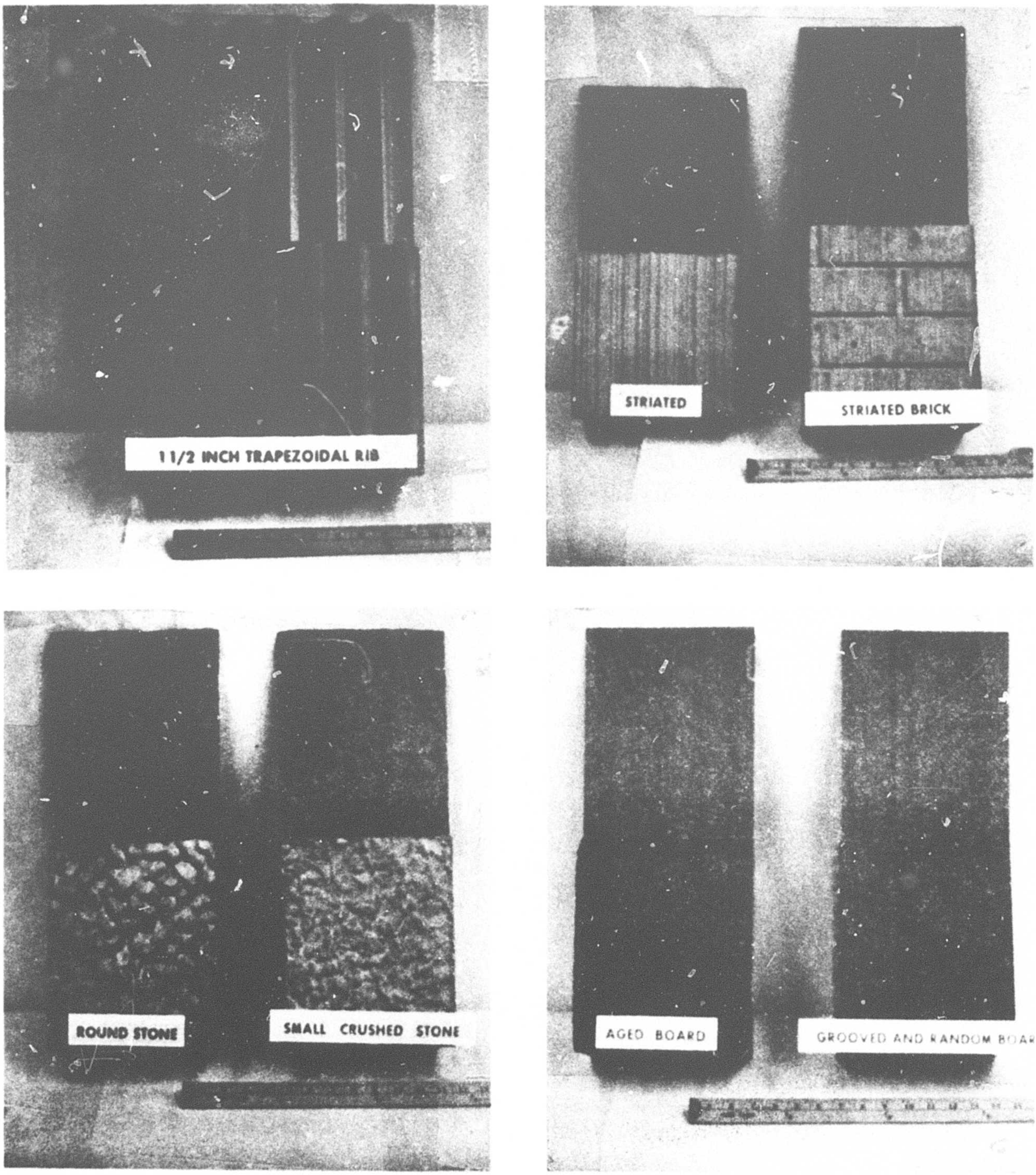
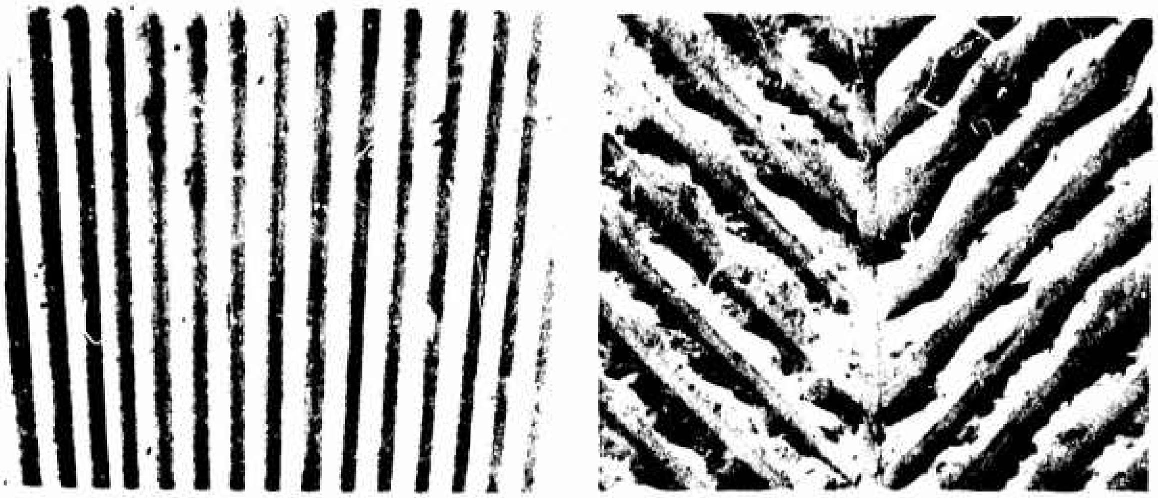
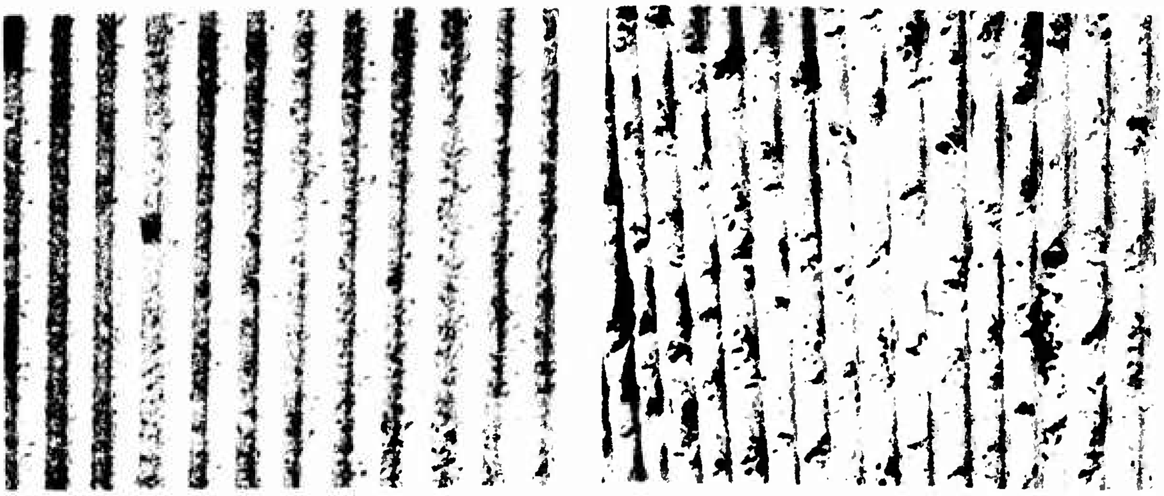


Figure B1. Typical form liners and surfaces produced.



a. Rib surface after form removal

b. Chiseled surface of concrete cast with liner rotated 45°



c. Light abrasive blast

d. Hand tooled finish: chiseled

Figure B2. Examples of surface variations obtainable by mechanical finishing of surface produced by form liners.

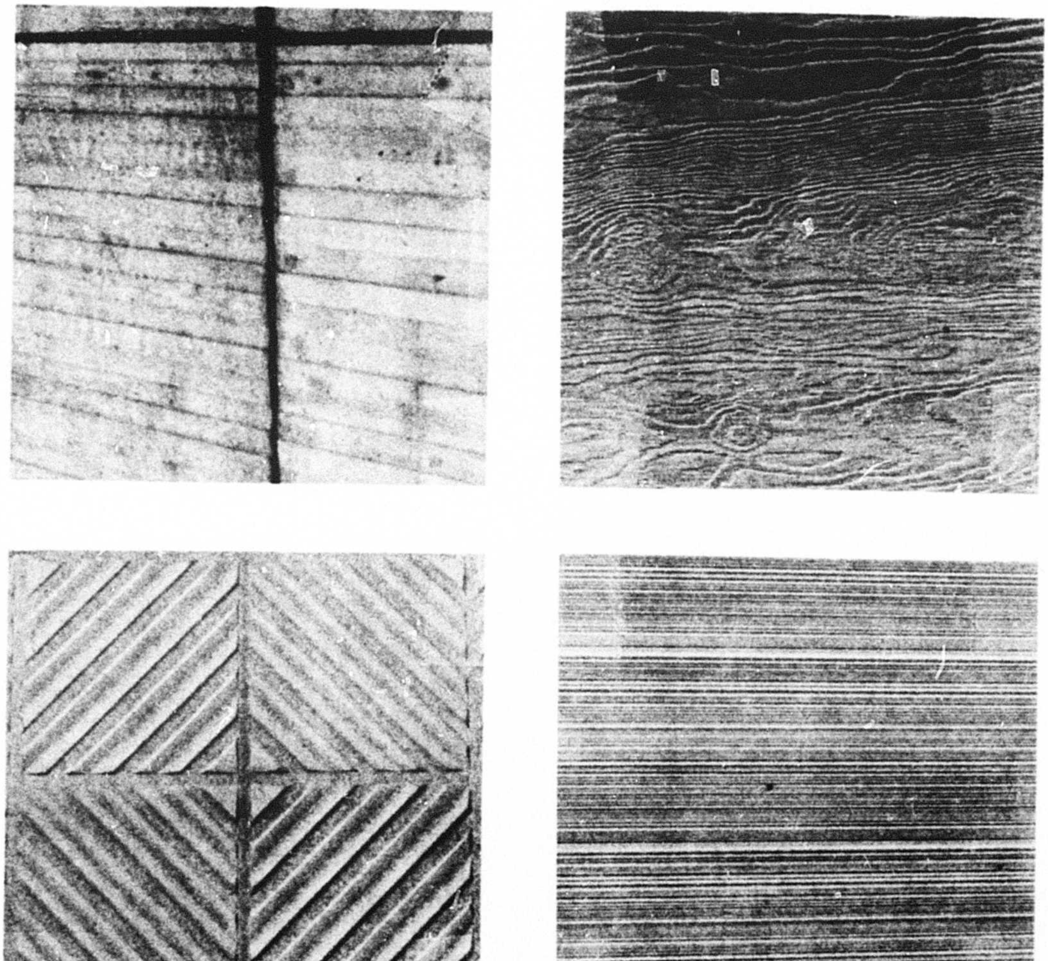


Figure B3. Surfaces produced by custom form liners.