

COLOR and TEXTURE

in Architectural Concrete



PORTLAND CEMENT
ASSOCIATION

COLOR and TEXTURE

in Architectural Concrete Second Edition

Contents

Introduction to Surface Esthetics	1
Section 1	
White Architectural Concrete	2
Section 2	
Mineral Pigments for Coloring Concrete	5
Section 3	
Exposed Aggregate Surfaces: Aggregate Properties	6
Section 4	
Precast Exposed-Aggregate Panels	8
Section 5	
Cast-in-Place Exposed Aggregate Concrete	14
Section 6	
Exposure Techniques	20
Section 7	
Textures and Patterns from Forms and Form Liners	24
Section 8	
Patching and Cleaning	30
Section 9	
Surface Protection	31
References	32

Page 1 Photos

Upper left: White concrete precast in custom molds to present the design of sculptor Harvey Wheeler at the Porthaven Professional Building, Cuyahoga, OH

Lower left: A 2-in. (50 mm) trapezoidal rib form liner used to produce textured facade.

Right: Epson America Corporate Headquarters, Torrance, CA
Precast panels in natural concrete color offered strength and durability, while expressing the owner's outlook in design philosophy and finishes.
Architect: Gensler and Associates

Front Cover Photos:

Top: Montreal South-Shore Wastewater Treatment Plant, Montreal, Quebec
Wide rib pattern on lower section of precast concrete wall panels was used to create visual unity.
Architect: Boudrias, Boudreau, St-Jean

Center, left: Office building at 1501 M Street, NW, Washington, DC
Acid-washed precast concrete columns provide neo-classical detailing, resembling costly cut stone.
Architect: Hartman Cox Architects

Center, right: Benjamin S. Rosenthal Library at Queens College, Flushing, NY
Rosy tones of precast exposed aggregate panels used in the library facade are repeated in the vast concrete hard-scape in front of the building.
Architect: Gruzen Samton Steinglass Architects, Planners

Bottom: Stanford University Parking Structure Number 1, Palo Alto, CA
Light cream-beige color is in keeping with the warm Mediterranean character of the Stanford campus, permitting the building to blend in with its neighbors.
Architect: The Watry Design Group

Photo courtesy Ted Hunt



Photo courtesy Fitzgerald Forminers



Michael Arden photo courtesy Gensler and Associates



Introduction to Surface Esthetics

Concrete can be seen in almost every form, texture, and color to satisfy the esthetic and functional requirements of modern architecture. This publication deals with decorative surface finishes. It describes and illustrates methods of obtaining attractive surfaces on both precast and cast-in-place concrete.

The art and technology exhibited in the wide range of surface finishes shown here and in the many others attainable are part of one of the most exciting architectural stories since medieval man first built lofty Gothic cathedrals in Europe. This is a new architectural age of dynamic shapes and forms that colorfully express the designer's imagination and innovation. An intimate part of this new expression is the concrete curtain

wall—a milestone in the evolution of surface esthetics. The utilitarian and dull surfaces that characterized the building blocks of the stone age have given way to a palette of wall colors that rivals that of any period in history.

The boundless range of shapes, sizes, textures, and colors that concrete may take gives to concrete the distinction of accommodating almost any form into which it is molded. It offers surfaces that vary from glassy smooth to bold and rough and a spectrum of color that ranges from the icy blues of crystalline quartz, through delicate pastels, to the flaming reds of vitreous and ceramic decorative aggregates.

Thus, concrete can readily express a formal or informal architectural mood. Concrete now offers a dy-

namic new dimension in multicolored, patterned, and textured precast and cast-in-place walls. Furthermore, when the costs of different enclosures for a building are compared, precast or cast-in-place concrete emerges as a truly economical material. For the architect, concrete offers a beautiful wall material with possibilities for unprecedented design freedom.

Esthetically, the new surface treatments have captured everyone's imagination because of the tremendous variety of new textures that can be created on a concrete surface.

Section 1

White Architectural Concrete

Architectural concrete and structural concrete are made with similar materials but have entirely different concrete mix designs. The attention given to mix designs to achieve high-strength structural concrete can be matched only by the attention given to mix designs to produce exceptional surface finishes. This section deals entirely with white architectural concrete mixes and requirements to obtain an acceptable wall finish on the jobsite.

Producing a good architectural concrete building calls for consistency in all phases of the project. The structure must be conceived, designed, detailed, engineered, constructed, and supervised as an architectural concrete job. A prebid conference with prospective bidders should be held to familiarize them thoroughly with the details and specifications. After the contract is awarded, the successful bidder should prepare a preconstruction mockup using proposed equipment, materials, and construction procedures so that the architect can see what the final appearance will be, before construction starts.

Cement

White portland cement is made of selected raw materials containing negligible amounts of iron and manganese oxides, as those materials produce a gray color. White cements have inherent color differences depending on their source. Some have a buff or cream undertone, while others have a blue or green undertone. Therefore, cement of the same type and brand from the same mill should be used throughout the entire job to minimize color variation.

White portland cement is a true portland cement conforming to ASTM

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Baha'i House of Worship,
Wilmette, IL

Delicate tracery of religious symbols in the precast panels is dramatized by the exposure of white quartz aggregate set in a white concrete matrix. Main pylons are 45 ft (14 m) tall, and the dome has outer and inner shells, both of exposed aggregate concrete.

Architect: Louis Bourgeois



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C150. Two basic types are produced: Types I and III, conforming to the ASTM specification C150. In addition, there are some companies that manufacture what is termed a water-proofed white cement by adding a small amount of water-repellent material such as stearate of sodium or aluminum to the portland cement clinker during its final grinding. The water-proofed cement reduces capillary water transmission under little or no pressure, but does not stop water vapor transmission.

Aggregates

The choice of aggregates can have a considerable effect on the color of white concrete. Due to the greater difference in color between the white cement and the aggregates, coating the aggregates with white cement is less likely to keep the aggregate color from showing through than coating them with gray cement. Thus, special consideration must be given to the selection of suitable aggregates to help prevent variations in color and color intensity on the finished surface.

The sources for coarse and fine aggregates should be kept the same for the entire job. The architect may specify the size, grading, color, and quality of aggregate to be used. A light-color aggregate is preferable to a dark aggregate to avoid the possibility of getting shaded or toned areas. However, if the aggregate is to be exposed, special colors or gradings may be required.

The type of sand used in white concrete greatly affects its color. The fine sand particles act as a pigment in the cement paste. If maximum whiteness is desired, a white or light yellow sand should be used. Most natural sands lack the required whiteness, so it may be necessary to use manufactured fine aggregates to achieve the white color desired. Generally, these aggregates consist of crushed limestone or quartzite sands.

For uniform white concrete, a mix should be rich in cement, with a high fine-sand content and coarse aggregate having a smooth grading curve. The mixes may be considerably richer than is normally required to achieve a specified strength.

Although a high proportion of sand is recommended to reduce color vari-

ations, a low proportion of sand is required to prevent bugholes—small rounded cavities that result from air trapped at the form surface during placement. It is necessary, therefore, to decide which blemish it is more important to eliminate for a particular purpose. The aim generally should be to produce uniformity of color and to avoid segregation. If suitable form materials, release agents, and placing techniques are used, bugholes on the surface can be almost eliminated or at least reduced in size and number to an acceptable level.

Batching and Mixing

All ingredients for white concrete must be measured accurately for each batch. Good, clean equipment should be used, with special attention given to eliminating oil, grease, dirt, and other contaminants. As far as possible, the mixing time should be the same for each batch. Variations in water or cement content can have a

considerable effect on the color tone of concrete. Cement paste with a low water-cement ratio almost always has a deeper tone than a high-water-cement-ratio paste made with the same cement.

Use trial mixes to determine the proportions that produce the most desirable color, along with proper workability and strength. ACI Committee 303 (Reference 1) recommends that the water-cement ratio be no more than 0.46, and that slump be kept as low as possible consistent with the methods of placement and consolidation.

Titanium dioxide pigment is sometimes used in quantities of 1 to 3 percent (by weight of cement) to increase the opaqueness or to intensify the whiteness of the white concrete.

Formwork

Special care in forming—for example sealing joints to prevent leakage—is required when working with white cement concrete surfaces, just as it is



U. S. Courthouse Federal Office Building, Orlando, FL
Precast white concrete spandrels and columns.

Architects and engineers, a joint venture: Smith and Swilley, Architects, Davy Power Gas, Inc., and Schweizer Associates, Architects, Inc.

when working with all architecturally finished concrete. However, white concrete is more sensitive to staining and discoloration, so untreated wood and many common form oils must be avoided and extra precautions taken to maintain cleanliness of the forms.

The formwork face against which white concrete is cast influences the color of the concrete. As a general rule, the more water absorbed into the formwork face, the darker the tone of the concrete. When absorbent materials take water from the concrete face, the water content of the surface layer of concrete is reduced. However, the finer cement particles that are brought to the surface during this moisture movement are too large to penetrate into the pores of the form face material. The higher cement content and lower water content of this surface layer can result in a denser, deeper tone on the surface. Therefore, where control of color is important, nonabsorbent form surfaces or linings should be used.

Smooth finishes are commonly formed against impervious materials such as steel, treated plywood, fiberglass reinforced plastic or other plastic form liners. These impervious surfaces usually produce a concrete of lighter color and more uniform appearance.

If plywood is used as the contact surface of the form, it should be an overlaid grade. High density overlays of resin-impregnated paper bonded to the plywood surface completely hide the timber grain and require only a light application of release agent between uses.

Some overlaid plywoods leave a reddish discoloration called pinking on the concrete surface when first used. Such a discoloration is more apparent on white concrete, but it usually disappears with exposure to sunlight and air. Any substance or coating which will form an alkali resistant film between the concrete and the overlaid surface will significantly reduce or eliminate pinking. Some release agents are effective barriers. Prewashing the form before use with a cement-water slurry may also help prevent pinking.

Impervious forms provide beneficial initial curing for the concrete, and some authorities recommend leaving them in place as long as the placing schedule permits. Even more impor-



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Cast-in-place white architectural concrete at the Holtzman & Silverman Office Building in Southfield, MI

Entrance tower at grade houses an elevator that carries visitors to earth-sheltered offices on the lower level. Built into a sloping site, the one exposed face has windows overlooking a wooded ravine. Light colored Drummond Island limestone was exposed by medium sandblasting.

Architect: Gunnar Birkerts & Associates, Inc.

tant is maintaining uniform stripping time throughout the entire job, to avoid variations in color from one part of the work to another.

Smooth concrete surfaces, which might seem to be the simplest to produce, are actually the most difficult to achieve on both cast-in-place and precast concrete. The designer who expects cast-in-place work to equal the smoothness of precast concrete is likely to be disappointed. Smooth surfaces tend to reveal any bugholes, nonuniform color, and undesirable shadow effects due to form misalignment and bulging.

Because of this, knowledgeable architects avoid specifying large expanses of absolutely smooth concrete. Projects have been more successful when one of the texturing or tooling methods described later in this book has been used. Textured and tooled areas are often used in combination with smaller areas of smooth concrete, with rustication grooves defining the boundary between them. Such an approach conceals the construction joints and joints between form panels, and obscures many of the minor variations in concrete color and finish.

Section 2

Mineral Pigments for Integral Color in Concrete

Although natural gray architectural concrete has been successfully used for many architecturally significant structures, new concrete buildings need not be limited to gray. Many concrete colors can be produced to enhance the appearance of a surface, often providing a cost-effective simulation of natural stone, wood or other building materials. Integrally colored concrete is made by adding mineral oxide pigments to concretes made with either white or gray cements. The concrete aggregates, particularly fine aggregate, should be selected carefully to enhance the color effect.

The amount of coloring material added should not exceed 10% by weight of the cement, because larger amounts of pigment may excessively reduce the concrete strength. Strong color can usually be produced with less than 10% addition of pigment. Different color intensities are achieved by varying the amount of coloring material or by mixing two or more pigments. White cement is used when

lighter, more delicate shades of concrete are desired, but red, tan, dark gray, and other hues are produced very satisfactorily using gray cement.

Variations in all components of the concrete mix make color formulas only approximate. Experiment with trial mixes for best results. After a basic color is selected, the exact shade may be determined by preparing a number of small panels, varying the ratio of pigment to cement. Once the desired shade is selected, be sure to use the same materials and proportions in all of the actual work. To properly evaluate panels, store them for about five days under conditions similar to the actual work. Panels will be darker when damp than when dry.

Coloring Materials

Finely ground iron oxides, either natural or synthetic, are the most widely used pigments for coloring concrete. Chromium oxide and cobalt oxide

(mentioned below) usually cost significantly more than iron oxides.

- For BLUES, use cobalt oxide.
- For BROWNS, use brown iron oxide.
- For BUFFS, use yellow iron oxide.
- For GREEN, use chromium oxide.
- For REDS, use red iron oxide.
- For GRAY or SLATE, use black iron oxide.

Untreated carbon black and lamp-black should not be used because they are unstable, fade, and reduce air content.

Pigments should meet quality standards of ASTM C 979 (Reference 2). C979 sets limits for water solubility, wettability, light resistance, and other essential pigment properties, and outlines tests for these properties.

Some manufacturers supply pigments in pure oxide form, while others offer pigments combined with set-controlling and water-reducing admixtures. Pigments are now available in special disintegrating bags which simplify adding a preweighed amount of pigment to a ready mix truck. They can be added at the ready mix plant, or at the job site when the specifications permit.

Construction Practices

The precautions normally recommended for architectural concrete are important for success with colored concrete. Batching, mixing, and placing practices must be uniform, and brands and sources of ingredients must be constant throughout the job. For large jobs, and projects constructed over a prolonged period, it is common to stockpile sufficient materials to assure color uniformity to the end of the work. Avoid admixtures that contain calcium chloride since it can cause discoloration.

Clean forms as well as nonstaining release agents are vital. Check the pigment manufacturers' recommendations for release agents, and test curing procedures on a mock-up before construction. Wet curing can affect color adversely, but in some cases the membrane-forming compounds are suitable. Forms that remain in place sometimes provide sufficient curing. A critical need is that forms remain in place the same length of time throughout the job to maintain color uniformity.

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Integrally colored concrete in deep tones was used to restore the Palace of Fine Arts, San Francisco, CA. Deteriorating plaster and stucco of the Beaux Arts original rotunda and colonnade were replicated in concrete, using molds cast against the original ornamentation. Architect: Bernard Maybeck

Exposed-Aggregate Surfaces: Aggregate Properties

An exposed-aggregate* surface is a decorative finish for concrete work achieved by removing the outer skin of mortar and exposing the coarse aggregate.

Through a variety of techniques, exposed-aggregate textures can be obtained on all surfaces of precast or cast-in-place concrete members. The wide range of available colors and textures and the demonstrated durability of exposed-aggregate concrete have led to its use in all types of vertical and horizontal surfaces on buildings.

Producing exposed-aggregate concrete is neither difficult nor overly simple for the experienced concrete craftsman. Proper attention to details and a basic knowledge of concrete are essential. There is an element of artistry in the selection of aggregates and matrix, but certain key factors must be considered for successful production of exposed-aggregate surfaces. Exposure techniques are discussed in Section 6.

Aggregates

Aggregates should be selected on the basis of color, hardness, size, shape, gradation, method of exposure, durability, availability, and cost. The more popular decorative aggregates are the natural materials such as quartz, granite, marble, limestone, and gravel, and the manufactured materials such as glass and ceramics.

Color

The colors of natural aggregates vary considerably according to their geological classification and even among rocks of one type.

*Not all aggregates illustrated in panels may be available locally.

Quartz aggregates are available in a variety of colors—clear, white, yellow, green, gray, and light pink or rose. Clear quartz is used widely as a sparkling surface to complement the color effect created by the use of pigmented concrete. Clear quartz is also used in combination with other colored aggregates to emphasize the color of the matrix. White quartz ranges from a translucent white verging on clear to a deep, milky white. Rose quartz gives finishes ranging from a delicate pink to a warm rose.

Granite, long known for durability and beauty, is available in shades of pink, red, gray, dark blue, black, and white. Traprock such as basalt can be used for gray, black, or green. Among the natural aggregates, marble probably offers the widest selection of colors ranging from green, yellow, red, and pink to gray, white, and black. Crushed limestones are available in white and gray colors.

Certain gravels, after being washed and screened, can be used to make attractive brown or reddish brown finishes. Yellow ochers, umbers, and buff shades are abundant in riverbed gravels. An almost pure white rock comes from several sedimentary formations. Gravels vary widely in color depending on the area in which the pits are situated.

Ceramic aggregates are vitreous materials that offer the most brilliant and varied colors available for exposed-aggregate work. The colors of ceramic aggregates are bright and clear.

Expanded lightweight shale aggregates meeting ASTM C330 may be used to produce colors that are reddish brown, gray, or black. These porous, crushable materials produce a dull surface with soft colors. These aggregates should be tested for iron staining characteristics.

The relative importance of aggregate or cement in determining the

color of exposed-aggregate concrete depends largely on the selection of the proportion of materials and the treatment given to the face of the concrete. In most exposed-aggregate finishes, the color of the cement is less important because a major part of the visible area is covered by the aggregate. Nevertheless, the cement has an effect on the general tone value of the mass, and for this reason, the color of the cement should be considered when the aggregate is chosen. Gray cement can be combined effectively with a number of aggregates, but the use of white cement, with or without color pigments, greatly extends the range of possible color combinations.

Hardness

Aggregate hardness and density must be compatible with structural requirements and with durability under anticipated weathering conditions. Quartz aggregates are very hard, having a rating of 7 on Mohs' scale, which is about equal to that of carbon steel. Table 1 shows Mohs'

Table 1. **Mohs' Scale of Mineral Hardness in Relation to Other Materials**

Scratch test	No.	Material
Fingernail Copper coin	1	Talc
	2	Gypsum
	3	Calcite
	4	Fluorite
	5	Apatite
Pocket knife Window glass	6	Feldspar
Steel file	7	Quartz
	8	Topaz
	9	Corundum
	10	Diamond

scale. Granite, composed of 30% quartz and 70% feldspar, has a rating nearly as high as quartz. Gravel and marble may vary from 3 to 7 on Mohs' scale. Vitreous aggregates rate at approximately 5.5. Ceramic aggregates have not been tested for hardness but are believed to be about 7 to 9 on Mohs' scale.

Size

Aggregates suitable for exposure may vary from ¼ in. (6 mm) up to cobblestone 6 in. (150 mm) to 7 in. (175 mm) in diameter and larger. The extent to which they are exposed or revealed is largely determined by their size. Exposure should be no greater than one-third the average diameter of the aggregate particle.

Aggregate size is selected on the basis of the distance from which it is to be viewed and the appearance desired. When surfaces are some distance from the viewer, large aggregate is required for a rough-textured look. A suggested visibility scale is given in Table 2.

Table 2. **Suggested Visibility Scale**

Aggregate size, in. (mm)	Distance at which texture is visible, ft (m)
1/4-1/2 (6-13)	20- 30 (6- 9)
1/2-1 (13-25)	30- 75 (9-23)
1-2 (25-50)	75-125 (23-38)
2-3 (50-75)	125-175 (38-53)

Shape

Aggregate shape will affect surface pattern and texture and may affect color slightly. Large irregular-shaped aggregate may permit more of the concrete matrix to show, changing the overall color effect. Cubical or rounded aggregates will give the densest area coverage. Long, flat



Office building at 1501 M Street, NW, Washington, DC

Precast concrete columns 18 feet tall were given an acid-washed finish, lightly exposing fine aggregate to produce a light texture and warm hue matching that of more costly limestone. The columns were cast vertically in a glass-fiber-reinforced plastic mold, in a single pour with no visible seams. A picture of the entire building facade appears on the cover.

Architect: Hartman Cox Architects

pieces should be avoided or at least limited.

Aggregates with rough surfaces have better bonding properties than those with slick, glassy surfaces. For example, bond problems have occurred with some milky white quartz aggregates. Bond is more important in cases where small-size aggregates are used, as some of the aggregate pieces may be only half embedded in the cement matrix. With larger aggregate sizes, say ½ in. (13 mm) or larger, enough of each piece (as much as two-thirds) will be embedded to ensure against loss of bond, even in the case of glassy, smooth aggregates.

Aggregate shape affects the appearance of a surface after weathering. Rounded aggregates tend to remain clean, but angular aggregates of rough texture tend to collect dirt and confine it to the recesses of the matrix. For better weathering, as well as architectural appearance, the area of exposed matrix between the pieces of stone should be minimized. It may be advisable for the matrix to be darker than the aggregate in structures subject to considerable atmospheric pollution. Protection of exposed-aggregate concrete from airborne contaminants is discussed in Section 9.

Gradation

Close control over gradation of aggregate sizes is essential to assure uniformity in surface texture in the finished product. Sieve analysis tests during the work will ensure uniformity of materials received and serve as a check on the consistency of gradation with the aggregate supplier's reported sieve analysis, taking into account expected changes in gradation that may be caused by rough handling in shipment. Sieve analyses should be made as frequently as necessary to help assure uniformity of appearance on the finished surface.

Durability

Any aggregate for exterior use should be thoroughly evaluated for the climatic conditions to which it will be exposed. The specific gravity and absorption of the coarse aggregates should be determined according to ASTM C127, and a petrographic analysis should be made according to ASTM C295 to ensure that the aggregates selected are durable, inert, and free from deleterious materials that may cause staining.

Moisture absorption rates for aggregates should be low. Moisture

absorption rates for quartz, granite, marble, and gravel generally vary from 0.05% to 1.5%, which are negligible amounts. Moisture absorption rates of vitreous aggregates are even lower. The moisture absorption qualities of ceramic aggregates are related to their chemical composition and time-temperature cycle.

Exposed aggregate surfaces may be subjected to salting, freezing, thawing, and wet-dry cycles. Therefore, optimum durability is desired.

Cost and Availability

Cost is a factor in the selection of an aggregate, and cost comparisons must be made on an equitable basis. Natural aggregates range in price according to their availability. Marbles are relatively low priced, while quartz and granite are relatively high priced, largely because of the cost of crushing to desired sizes. Manufactured aggregates cost more to produce than natural aggregates. Local gravel is generally the lowest priced of all, since it requires only washing and screening. However, even the most expensive aggregates are often practical in exposed-aggregate concrete, especially when they are used only in small quantities for special effects.

In general, aggregates used in concrete of any type represent only a small part of the cost of concrete in place. Any mistakes made through use of an inferior aggregate cannot be readily corrected. So it is often wiser to use high-quality aggregates, from a distant source if need be, rather than a local material of questionable quality.

Section 4

Precast Exposed-Aggregate Panels

Precast exposed aggregate wall panels are available nationwide. Their widespread use can be attributed to the inherent flexibility of precasting in various sizes, shapes, and colors. A great variety of colors and textures can be produced either in precast products plants or at the jobsite—the latter, for example, in tilt-up construction. The panels provide the surface skin of a building and at times are designed to act as structural load-bearing units as well. Panels may be cast either in two layers or as a single layer of concrete. With proper cross ties or shear connectors, sandwich panels can also be produced with a layer of insulating board between the two concrete layers.

Mix Design

Concrete mix designs used in exposed aggregate work differ from those with which most concrete users are familiar, but many of the same theories and methods apply. Color in exposed aggregate panels was described in Section 3.

Two-Layer Concrete Panels

For reasons of economy, two mixes are frequently used in precast exposed aggregate work. The facing mixes contain special decorative aggregates, often in combination with white portland cement and sometimes with a pigment. Backup mixes are composed of more conventional aggregates and gray cement, and are used to reduce material costs in large units that have a decorative facing mix. Where precast units are of complex shape, the facing mix may be used for the entire member if procedures for separating the facing and backup mixes become too cumbersome.

Backup mixes are usually ordinary structural concrete, while the facing

mixes are specially designed to achieve the desired surface appearance. It is important that the two mixes have reasonably similar shrinkage and thermal expansion characteristics to avoid possible undue bowing or warping. This means the two mixes should have similar water-cement and cement-aggregate ratios.

The strength of backup and facing concretes is usually evaluated by testing 6x12-in. (150x300-mm) standard cylinders. If fabrication of cylinders is impractical, 4-in. (100-mm) cubes may be tested, but the measured cube strength should be reduced 20% to obtain an estimate of the cylinder strength.

Facing mixes. Mix proportions for facing mixes are determined by considerations of appearance and weathering. All concrete will absorb some moisture, but the facing mixes should be as impermeable as possible. The Precast/Prestressed Concrete Institute (Reference 3) recommends a maximum 24-hour absorption of 6% by weight. As an improved weathering (staining) precaution, lower absorption—between 3 and 4%—is feasible with some mixes and consolidation methods.

Regardless of the method for producing the exposed aggregate finish, the ratio by weight of cement to fine aggregate should be at least 1:3, but not richer than 1:1. With mixes leaner than 1:3, there is a danger of dislodging pieces of coarse aggregate during handling. The ratio by weight of fine to coarse aggregate in the facing mix is usually about 1:2.5 or 1:3. This permits a higher concentration of coarse aggregate to be exposed at the surface.

Structural concrete mixes, or architectural mixes designed for light exposure by acid etching, ordinarily have fully (continuously) graded coarse

aggregate, which means that it contains all the sizes of aggregate below the maximum in amounts that assure an optimum density of the mix. However, where aggregates are to be exposed more deeply by removing the cement/sand matrix from exposed surfaces, coarse aggregate in the middle size range may not be able to adhere to the remaining surface. This may leave too much matrix exposed, or an uneven distribution of remaining coarse aggregate. To remedy this, exposed aggregate panels are commonly produced using a gap-graded mix—that is one or more of the intermediate sizes of coarse aggregate are left out.

Apart from strength considerations, a low water-cement ratio improves the durability and weathering characteristics of exposed aggregate panels. ACI 303 (Reference 1) recommends a maximum water-cement ratio of 0.46 by weight for all architectural concrete. PCI shows 0.40 in its guide specifications for plant produced architectural precast. Slump should be as low as possible, consistent with the type of concrete, and methods of placing and consolidation. Workability must be suited to individual job conditions, such as the shape of the unit, the amount and complexity of reinforcement, and the method of consolidation. Very stiff mixes require more labor to place and special vibration techniques.

Single-Layer Concrete Panels

Single-layer concrete panels may have selected aggregates embedded on either the top or bottom by methods described later in this section. Single layer panels may also have their integral aggregates exposed by brushing and washing, with or without surface retarders, or they may have mechanically tooled finishes that expose the aggregate. Use of a gap-graded mix improves the appearance when the integral aggregate is to be exposed, and a minimum cement content of 564 lb per cu yd (335 kg/m³) is usually needed to assure workability and placeability.

If the base concrete is to receive a special exposed aggregate surface by seeding, slump should be in the range of 3 to 5 in. (75 to 125 mm), and the maximum size of coarse

David Sailors photo courtesy Ewell W. Finley and Partners



Benjamin S. Rosenthal Library, Queens College, Flushing, NY

Precast exposed aggregate panels clad the reinforced concrete frame in rosy color. The building's color repeats in exposed aggregate bollards and other parts of the hardscape.

Architect: Gruzen Samton Steinglass Architects, Planners

Precast Exposed-Aggregate Panels continued



Stearns-Roger Center, Denver, CO
Exposed aggregate precast concrete spandrels and columns.
Architect: Stearns-Roger Engineering Corporation



Density of exposed aggregate on surface attained by face-up seeding method.

Below: Head Smashed In Buffalo Jump Interpretive Center near Calgary, Alberta.

Buff colored exposed aggregate precast panels clad a cast-in-place frame and interior of the same color.

Architect: The LeBlond Partnership

Photo courtesy The LeBlond Partnership



aggregate should be $\frac{3}{4}$ in. (19 mm) to ease the embedment of the special aggregate. Sometimes an over-sanded mix is used for the same reason. The smaller sizes of coarse aggregate should be eliminated from the base mix when crushed stone or an aggregate whose color is not compatible with the selected seeded-topping aggregate is specified.

Admixtures

It is advisable to check the influence of admixtures on color at the time of making the preconstruction mock-up, or with smaller approval samples even earlier.

Air-entraining admixtures will improve the workability of harsh gap-graded facing mixes as well as improve the resistance to freezing and thawing cycles in the presence of moisture. Air entrainment of 4% is normally desirable, but a range of 3% to 5% may be permitted, in view of placing techniques often used for facing mixes. Since architectural precast panels are normally erected above grade in a vertical position, this relatively low air content appears to be satisfactory for what is considered a moderate exposure.

Other water reducing, accelerating, or retarding admixtures may be used to modify workability or other properties of the mix, but calcium chloride or admixtures containing calcium chloride should not be used in architectural concrete because they may contribute to darkening and mottling of the concrete as well as to corrosion of embedded metals.

Pigments and pigmented admixtures are discussed in Section 2. Generally, pigments are limited to 10% by weight of cement; 5% is more commonly used, because larger amounts do not contribute proportionally to the intensity of color.

Mixing

The type of mixer and the characteristics of the concrete have a bearing on the mixing procedure. For the harsh low slump mixes used in exposed-aggregate panels, a pan-type or rapid countercurrent mixer is a definite asset. The method and sequence of loading the mixer is very important to

the quality of the concrete output. For central plant mixing, ribbon feeding of aggregates and cement is recommended. Loading procedures for truck mixers must be designed to avoid packing of the material. A few of the basic guidelines applicable for all architectural concrete mixing are noted here. Consult ACI 304R (Reference 4) for detailed recommendations for different types of mixers.

Liquid admixtures should be pre-mixed with the mixing water and charged to the mixer at the same point in the mixing sequence batch after batch. Consult manufacturers' recommendations when pigments or pigmented admixtures are used. If lightweight aggregates are used, they should be prewetted before mixing to eliminate rapid absorption of mixing water into the aggregates.

Mixing should be thorough to produce a uniform mix, and constant from batch to batch to avoid undesirable variations in the appearance of the concrete as placed. This is particularly important when using white cement with or without color pigments and when colors of sand and cement differ. Mixers should never be loaded beyond the rated capacity if thorough mixing is to be achieved. For example, truck mixers are limited to 63% of the drum volume.

Good, clean equipment is essential. Special attention should be given to prevent contamination of the mix by oil, grease, dirt, and chunks of hardened concrete that may break loose from the mixer blades. When colored or white concrete is used in conjunction with normal gray concrete—for example in panels having facing and backup mixes—separate mixers and handling arrangements are required.

Control of Concrete Temperature

Concrete temperature should be maintained above 50°F (10°C) during mixing, transporting, and placing. For the best uniformity of color, ACI 303 (Reference 1) recommends keeping concrete between 65°F and 85°F (18°C and 29°C). Consult References 5 and 6 for specific recommendations for hot- and cold-weather concrete work.

Special Methods for Jobsite Precasting

In addition to two-layer panel casting and single-layer casting for exposure of integral aggregate, there are several methods for placing a special aggregate at the panel surface. Choosing the proper technique depends on many factors including the desired size of aggregate to be exposed as well as the cost of the special aggregate.

Seeding Aggregate for Face-Up Precasting

Face-up methods usually involve seeding the coarse aggregate onto the surface of the concrete panel and embedding it by tamping or rolling. After the required period of setting, the aggregate can be exposed by washing away the surface layer of mortar with water. Large aggregate can be hand-placed in the matrix if one-third or less of the diameter of the individual pieces is to be left exposed. The face-up method is used widely for surfaces with exposed aggregates from $\frac{3}{8}$ to 1 in. (9 to 25 mm). Techniques for site-cast panels are much the same as for seeding concrete flatwork, explained in detail in Reference 7.

Face-Down Precasting Methods

When aggregate to be exposed is $1\frac{1}{2}$ in. (38 mm) or more in diameter, the sand embedment technique is frequently used. Stones ranging from 3 to 8 in. (75 to 200 mm) in diameter produce walls that look bold and massive. Flagstone also has been used this way.

One face-down precasting method is to spread a layer of fine sand over the bottom of the form to a depth of about one-fourth the diameter of the single size aggregate used. Aggregate pieces are placed close together and pushed into the sand for dense coverage. Extreme care is necessary to distribute the aggregate evenly and densely. A fine spray of water is used to settle the sand around the aggregates and yet leave about one-third of each piece embedded in the sand.

An alternate method is to spread a layer of aggregate on the panel form and then sprinkle fine dry sand over the aggregate, allowing it to sift down around the pieces until its depth is one-third the aggregate size.

If a white matrix is desired, place a white mortar over the aggregate after embedding the aggregate in the sand. Use 1 part white cement to 2.5 parts by volume of well-graded white or light-colored sand mixed with sufficient water to get a creamy consistency.

Now the panel is ready for placement of reinforcement and any attached bolting and welding inserts. The reinforcement may be supported on plastic or galvanized chairs, or the mortar mix or part of the backup concrete may be placed and screeded to a flat surface before the reinforcement is positioned. Be careful not to dislodge any of the aggregate when placing the first layer of mortar or concrete.

If a mortar facing mix is used, usually the backup mix is of a low slump, a maximum of 1 in. (25 mm), to absorb excess water from the facing mix. Otherwise the backup mix is standard structural concrete with a slump of 3 to 5 in. (75 to 125 mm). After the backup mix is placed, a vibrating plate screed is used to compact the concrete. Careful use of a small spud vibrator adjacent to the forms will improve consolidation of the panel edges. Care must be exercised during vibration not to disturb the sand or aggregates, causing uneven aggregate distribution or letting concrete filter onto the face.

When the panels have cured, they are raised, and any clinging sand is removed by brushing, air blasting, or washing with a stream of water. Some sand bonds to the concrete; therefore, the color of the bedding sand should be carefully chosen to harmonize with the aggregate to be exposed.

Horizontally precast exposed-aggregate concrete panels Chemically retarded surface

Panel No. 15. Use of three aggregates—verde antique, white marble, and pink granite, on a white background produces a colorful surface.

Panel No. 16. The combination of black obsidian and milky quartz results in a striking contrast.

Panel No. 17. Rose quartz presents a pleasing variety of pink shades against a white matrix.

Panel No. 18. The green of the exposed cordierite aggregate produces a lighter hued surface when viewed from a distance.

Panel No. 19. Pink feldspar is a platy rock that orients itself in the horizontal position during consolidation. The resulting exposed-aggregate surface is very dense and uniform. The large flat crystals reflect light from myriad surfaces.

Panel No. 20. The exposure of very white silica stone on an integrally colored light blue background is most interesting. The distant viewer sees a moderate blue surface with the exposed aggregate barely visible. A closer view shows the mild contrast caused by exposure of the aggregate.

Panel No. 28. Reddish brown Eau Claire gravel contrasts with uniform white background.

Panel No. 29. Use of expanded slag fines results in a coarse-textured white background for the reddish brown Eau Claire aggregate.

Panel No. 30. A chemical surface retarder produced the correct degree of exposure for the ¾-in. (19-mm) to 1-in. (25-mm) Eau Claire aggregate.

Panel No. 36. Exposure of pink marble on white background provides a subtle coloration.

Panel No. 37. Black labradorite rock fractures along crystal faces, and exposed portions sparkle in the sunlight. Aggregate of the size shown here results in a very black surface.

Panel No. 38. White marble in a matrix of silica sand and white cement produces an all-white panel.

Panel No. 39. The brown-yellow-white quartz fractures into flat pieces that orient themselves against the bottom surface of the form. The result is excellent exposure of the quartz.

Panel No. 40. The form was covered with a surface retarder and pink marble was hand-placed uniformly on it. White cement-sand mortar was placed over the marble and consolidated. Backup concrete was then placed and consolidated.

Panel No. 43. Dark expanded shale fines produce a dark background that contrasts with the buff-colored Elgin pea gravel.

Panels No. 43, 44, and 45 demonstrate the effect of increasing the size of coarse aggregate. A range of surface retarders produced the correct reveal for the aggregates.

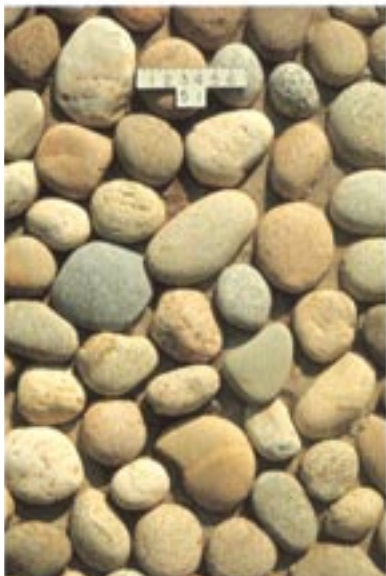
Panel No. 54. A single-colored green glass was used for the exposed aggregate, yet a two-color effect was obtained due to the difference in size of the translucent aggregates. A special glass that was nonreactive with portland cement was used.

Panel No. 55. Combination of a reflective orange glass with a nonreflective brown natural aggregate makes a very interesting panel.



Precast exposed-aggregate concrete panels Sand-bedding technique

Panel No. 49. 1-in. (25-mm) to 1½-in. (38-mm) Elgin stone panel.
Panel No. 50. 1½-in. (38-mm) to 3-in. (75-mm) Elgin stone panel.
Panel No. 51. Rocky Mountain cobblestone panel.
Panel No. 21. Flagstone panel.



Section 5

Cast-in-Place Exposed- Aggregate Concrete

Quality cast-in-place exposed-aggregate walls can be produced by using a gap-graded aggregate in the concrete. In this type of concrete mix design, a gap in the aggregate gradation exists between the essentially one-sized coarse aggregate to be exposed and the fine aggregate, usually a white silica sand or natural masonry sand. The mix is proportioned so that the sand is about 25% to 35% of the total aggregate by volume. The resulting large percentage of coarse aggregate assures the desired uniform distribution and quantity of aggregate exposed on the vertical surface. Cast-in-place vertical walls using natural rounded stone, crushed limestone, and crushed granite can be produced with very satisfactory decorative characteristics. The technique incorporates the economy of cast-in-place construction while achieving a more costly quality appearance.

Gap-Graded Concrete

For a gap-graded aggregate of ¾-in. (19-mm) maximum size, the No. 4 (4.75-mm) to ¾-in. (9-mm) particles can be omitted without making the concrete unduly harsh or subject to segregation. In the case of 1½-in. (38-mm) aggregate, the No. 4 (4.75-mm) to ¾-in. (19-mm) sizes should be omitted. Eliminating the material under ¾ in. (19 mm) prevents separation of sizes in the bins, thus giving a more uniform product.

Fine aggregate generally consists of material passing the No. 8 (2.36-mm) screen. The percentage of sand should be chosen carefully. Too low a percentage of sand may result in segregation or honeycombing due to an excess of coarse aggregate. An ex-



All photos © R. W. Steiger



Arizona-Sonora Desert Museum, Tucson, AZ

Warm-tone concrete cast in place with medium exposure of the aggregate by sandblasting blends readily with desert surroundings and specialized desert life exhibits. Exposed aggregate in the flat-work (lower left photo) harmonizes with the vertical surfaces.



cess of sand results in a less desirable architectural appearance. Concrete with a low density and high water requirement also can result from too much sand. Sand is usually 25% to 35% by volume of the total aggregate. The lower percentage is used with rounded coarse aggregates and the higher with crushed material. The

sand content is influenced by the cement content, type of aggregate, and workability.

Since low-slump, gap-graded mixes use a lower percentage of sand, producing harsh mixes, air entrainment is a standard requirement for workability, with added durability as a bonus. Workability and

placeability generally require a minimum of 564 lb of cement per cubic yard (335 kg/m³) of concrete to consolidate properly and minimize the occurrence of honeycombing. A water-cement ratio of 0.50 by weight should be considered the maximum. Any water used above the absolute minimum needed for placing may

cause segregation and paste accumulations, which in turn may result in imperfections in the exposed-aggregate surface.

Segregation must be prevented by restricting the slump to the lowest value consistent with good consolidation. This may vary from zero to 3 in. (75 mm) depending on the thickness of the section, amount of steel, height of casting, etc. For example, a thin, heavily reinforced wall might require a 3-in. (75-mm) slump, whereas $\frac{1}{2}$ -in. (13-mm) slump or less would be sufficient for a massive section with a lower percentage of reinforcing steel. Because of their low sand volume and low water-cement ratio, gap-graded mixes might be considered unworkable for cast-in-place construction. When properly proportioned, however, these concretes are readily consolidated with extra vibration.

Ease of placement is an important consideration. Gap-graded mixes do not flow readily down a long chute or from a Georgia buggy. Placing methods should be planned so that concrete drops vertically in all handling operations, since the mixes can be dropped considerable distances without segregation.

Satisfactory cast-in-place gap-graded concrete panels have been produced in the PCA laboratories and are on display there. The panels are 5 ft (1.5 m) high, 3 ft (0.92 m) wide, and 4 in. (100 mm) thick. The concrete was mixed in a rotary drum mixer and consolidated in the form with internal vibration. Proper internal vibration of this low-slump concrete is essential. While a slump test would indicate about 1-in. (25-mm) slump or less, this test is not truly indicative of the workability of this type of concrete. Experience and tests show this concrete to be quite workable when subjected to vibration. The coarse aggregate was usually sized $\frac{3}{4}$ in. (9 mm) to $\frac{3}{4}$ in. (19 mm), but two of the panels illustrated were made with coarse aggregate sized $\frac{3}{4}$ in. (19 mm) to $1\frac{1}{2}$ in. (38 mm) and one was made with $\frac{3}{8}$ -in. (9-mm) to $1\frac{1}{2}$ -in. (38-mm) coarse aggregate. The fine aggregate was either minus No. 8 mesh Elgin or minus No. 16 mesh white silica sand. The exact percentage of fines used was determined by trial mixes and depended on the shape and surface texture of the coarse aggregate.

Cast-in-place exposed-aggregate concrete walls Gap-graded aggregate



Panel No. 47. The vertical panel form was coated with a water-insoluble chemical surface retarder prior to casting. The panel was stripped, and the retarded paste was brushed and washed off 24 hours after casting.

Panel No. 48. This cast-in-place panel was moist-cured for several days prior to sandblasting with white silica sand at the rate of 1 sq ft (0.10 m²) per minute. The sandblasted panel has a uniform dense texture.

Panel No. 22. Cast-in-place panel was moist-cured for one week and bushhammered at one month at the rate of $\frac{1}{4}$ sq ft (0.02 m²) per minute. Adequate internal vibration of this low-slump concrete is necessary.

Panel No. 23. Cast-in-place panel was moist-cured and then air-dried for several days prior to sandblasting. The surface was sandblasted with white silica sand at the rate of $\frac{3}{4}$ sq ft (0.07 m²) per minute.

Panel No. 24. Cast-in-place panel was moist-cured for several days and then allowed to dry in the weather. The panel was sandblasted with white silica sand at the rate of $\frac{1}{2}$ sq ft (0.05 m²) per minute.

Exposure of the aggregates in these cast-in-place panels was accomplished by the use of chemical surface retarders, sandblasting, and bushhammering. A water-insoluble chemical surface retarder was painted on the form prior to erection and allowed to dry before casting. The forms were stripped 18 hours after casting, and the retarded paste was brushed and washed off, resulting in uniformly exposed vertical surfaces.

Sandblasting and bushhammering were done at variable rates depending on the size of aggregate being treated and the architectural effect desired. Sandblasting rates of approximately $\frac{1}{2}$ sq ft (0.05 m²) to 1 sq ft (0.10 m²) per minute were usual, while bushhammering was accomplished at rates of $\frac{1}{4}$ sq ft (0.02 m²) to $\frac{1}{3}$ sq ft (0.07 m²) per minute.

The various procedures employed are illustrated by panels 22, 23, 24, 47,

and 48. Panels 47 and 48 illustrate the difference in surface texture obtained by two methods of aggregate exposure on identical concrete panels.

Preplaced-Aggregate Concrete

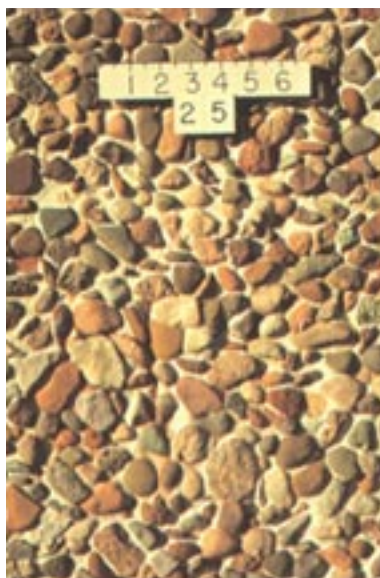
Preplaced-aggregate concrete is named for its unique placement procedure. Forms are filled with coarse aggregate, then structural quality grout is injected under pressure into the voids around the aggregate to produce concrete. There are several proprietary processes for producing preplaced-aggregate concrete. These techniques avoid one main disadvantage of exposing the aggregate in conventional cast-in-place concrete—the irregular surface texture caused by uneven distribution of the coarse aggregate. Following is the method used in the laboratory study conducted by PCA.

The aggregate to be exposed was placed in a vertical form and consolidated with an external vibrator, using ample water in the form to facilitate consolidation. The aggregate was larger than $\frac{1}{2}$ in. (13 mm) to avoid the difficulty of grouting smaller-size aggregate. When the form was filled with aggregate, a cover plate with overflow pipe and valve was attached. The panel was then grouted under pressure with a cement-sand-water slurry through a hole near the bottom of the form. Water in the form was displaced by the slurry and escaped through the overflow pipe. Grouting was continued until the consistency of the slurry passing through the overflow pipe was uniform, at which time the valves at the grout hole and overflow pipe were closed. Unless otherwise noted, the panels were stripped about 24 hours after grouting.

Exposure of the aggregate was accomplished by one or more of three procedures: (1) The forms were coated with a chemical surface retarder prior to their assembly and prepacking with aggregate. Immediately after stripping, usually 16 to 24 hours after grouting, the retarded paste at the surface was removed with brushing and water spray. (2) Exposure of the aggregate was accomplished by sandblasting the hardened concrete

Cast-in-place exposed-aggregate concrete walls Preplaced aggregate

Panels No. 25, 46, 27, 26. Vertical wall forms were coated with a chemical retarder prior to grouting. The following day the forms were filled with gravel. The walls were then grouted with a cement-sand-water slurry. The panels were removed from the form 24 hours after grouting, and the retarded paste was brushed and washed. Subsequent sandblasting was done to achieve a deeper exposure of the aggregate on panels 25 and 46.



Cast-in-Place Exposed-Aggregate Concrete continued

surface. The age at which sandblasting was done depended on the depth of penetration desired, the hardness of the preplaced aggregate, and other variables. In actual construction the numerous architectural effects that can be achieved require that samples be prepared to define the desired finish. Sandblasting was usually done two to seven days after grouting. Several panels used a combination of chemical retarders and subsequent sandblasting to attain considerable exposure of the aggregate. Panels 25 and 46 (page 17) show the result of this dual treatment, in contrast to Panels 26 and 27 which were only brushed and washed.

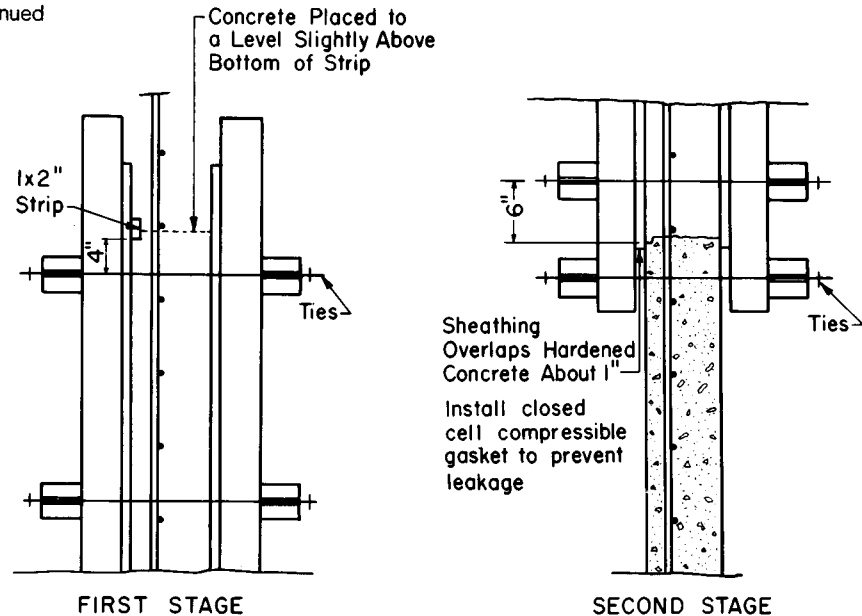
A third method, bushhammering, was used to expose the aggregate in some of the panels. Successful bushhammering requires that the concrete be as uniformly hard as possible. Therefore, it is desirable to use a coarse aggregate having a hardness comparable to that of the cement paste. Crushed aggregate is generally more satisfactory than gravel when concrete is to be bushhammered, because the round gravel will fracture more easily in a transverse direction and loosen in its socket. The bushhammering was done when the compressive strength of the concrete reached a minimum of 3500 psi (24 MPa).

Forms

Cast-in-place exposed aggregate concrete requires quality form workmanship. Forms must withstand the increased vibration time normally associated with placing exposed aggregate concrete. For cast-in-place work, light steel forms that vibrate as the concrete is vibrated may cause nonuniform aggregate distribution near the surface of the concrete.

Forms must be tight and accurately aligned at butt joints, since the slightest misalignment may be visible in the exposed surface, showing up under certain light and shadow conditions.

Tape, seal, or calk the joints in formwork to prevent leakage of water and fines. A pressure-sensitive compressible tape can be placed in the joints between forms. Press-on tape may be used on the inside of the forms when significant removal of the surface to expose aggregate is planned. If joints are not sealed, a dark line will appear



Use of a 1x2 (25x50 mm) strip creates a straight, even horizontal construction joint in a wall. Similar details may be used where rustication grooves are desired. A tie or anchor not more than 4 in. (100 mm) below the joint holds the form tightly against the hardened concrete (from Reference 12).

on the finished surface, sometimes even after heavy texturing by bushhammering or abrasive blasting.

Construction joints and joints in form sheathing material can be masked by rustication strips (splayed fillets) attached to the form face. Rustication strips can also be used to hide tie holes. The architect can plan joint locations between surface areas on a scale and module suitable to the size of available materials and prevailing construction practices. If this is not aesthetically satisfactory, dummy rustications can be introduced to give a smaller pattern. Rustication strips are commonly 1 to 3 in. (25 to 75 mm) wide and 3/4 in. (19 mm) or more in depth, with a slight taper for easy removal. Ready-made plastic rustication strips are now available to supplement the older standard wood strips.

Proper selection and installation of form ties are important to prevent rusting of the ties and subsequent staining of the wall. Ties should be carefully sealed or tight-fitting to prevent leakage at holes in the form. They should be of a type that leaves no metal closer to the surface than 1 1/2 in. (38 mm) for steel ties and 1 in. (25 mm) for stainless steel ties. Whether one piece or threaded internally disconnecting ties, they may be fitted at the ends with wood or plastic cones that increase the size of the tie hole, often

desired for architectural expression. Cones reduce leakage where ties pass through the form, and they leave round, relatively clean holes that may be patched flush or with a slight recess for architectural shadow effect. When tie holes are left exposed in predetermined patterns for architectural effect, patching is eliminated, but the back of the hole should be well sealed to prevent water from contacting the embedded ties and causing rust.

Careful sealing is also necessary when ties are of the type that may be withdrawn from the wall entirely. Ties that are to be pulled from the wall must be coated with nonstaining bond breaker or encased in sleeves to facilitate removal.

Glass-fiber-reinforced plastic ties (GFRP) are now available in many colors that closely match concrete colors. These nonmetallic ties can be cut off flush with the concrete surface, require no patching, and are nearly imperceptible in an exposed aggregate surface.

Side form spacers are devices designed to maintain the desired distance between vertical forms and the reinforcement. They are particularly important in architectural concrete to assure adequate cover of the steel and prevent development of rust streaking on the concrete. Plastic, plastic-protected, rubber tipped, or

other non-corroding spacers should be attached to the reinforcement so that they do not become dislodged during concrete placement and vibration.

Form Stripping

Stripping time for cast-in-place work depends on factors such as:

- safety
- effect on concrete
- most favorable time for aggregate exposure

Stripping must be done at a time that will ensure complete safety of the structure. For elements not supporting the weight of concrete or construction loads above, forms may be stripped as soon as the concrete is strong enough to resist damage from stripping. Where the forms do not support loads, they may be removed as early as 4 hours after casting if the aggregate is to be exposed by early washing. Under more normal conditions, forms are removed when the air surrounding them has been at 50°F (10°C) for a cumulative total of 12 to 24 hours.

If formwork is removed from structural members that support the weight of concrete or other loads above, shoring or bracing should remain in place until the specified 28-day compressive strength is reached, unless otherwise specified or permitted. Additional protection in hot and cold weather may be needed as detailed in References 1, 5, and 6.

Stripping time should be uniform throughout the job; otherwise color differences will be visible in the concrete from one area to another. Generally the longer the forms stay in place, the darker the concrete becomes.

Vibration

Once in the forms, the low slump concrete can be consolidated by internal vibration. Harsh mixtures with gap-graded aggregates generally require more powerful vibrators and longer vibration times, and forms should be designed with this in mind. The concrete should be placed in layers generally not exceeding 20 in. (500 mm), with the vibrator inserted vertically at uniform spacing. The distance between insertions should be such that the area visibly affected by the

vibrator overlaps the adjacent just-vibrated area by a few inches (several centimeters).

Vibrators should be placed in the concrete rapidly to penetrate approximately 6 in. (150 mm) of the previous layer and withdrawn slowly. This minimizes air trapped between the concrete and the form and blends the layers. Insufficient vibration rather than overvibration often is a source of difficulty. Stop vibrating when the mortar level reaches the top of the aggregate, to prevent mortar lines between layers.

Keep vibrators at least 3 in. (75 mm) from the formed surface that will be exposed, or the coarse aggregate will be driven away from the form face. Use a small diameter vibrator for thin sections.

Curing

Impervious form surfaces, such as steel or plastic, provide satisfactory protection against loss of moisture

from wall faces. These impervious forms should be left in place as long as practicable, always remembering to keep the form removal time the same from one part of the job to another. Protect the top exposed concrete surfaces against drying. Soil soaker hoses and plastic sheeting have been used, but beware of water flowing over the architectural surfaces and plastic in direct contact with the concrete because they may produce uneven colors or mottling. Check out the proposed curing methods on the preconstruction mockup along with all of the other construction practices.

Absorbent forms such as untreated wood or plywood can be kept moist by sprinkling, especially during hot, dry weather if a test pour shows no adverse effects on concrete appearance. Unless wood forms are kept moist, they should be removed as early as practical and another method of curing started without delay. References 5 and 6 give ACI recommendations for hot- and cold-weather curing.

Photo courtesy M. K. Hurd



Non-metallic form ties offer a way to avoid tie hole problems since they can be cut off flush with the concrete surface. These concrete samples each contain a gray glass-fiber-reinforced plastic form tie in the center. Exposed aggregate finish on the left and smooth-ground surface on the right are from the same concrete mix.

Exposure Techniques

Architectural working drawings for exposed-aggregate walls should detail the vertical and horizontal joints of the exposed-aggregate surface areas, as well as show their location and dimensions. When exposing the aggregate, special considerations should be given to mix designs (see Section 4). Accepted standard practices for mixing, placing, and vibrating should be strictly followed.

Specifications should define the appearance desired, while leaving methods of reaching that appearance to the contractor or precaster. Preconstruction mockups should be specified to serve as acceptance standards for the completed work.

Three degrees of aggregate exposure are commonly described as:

Light exposure: Only the surface skin of cement and sand is removed, exposing only the edges of the closest coarse aggregate.

Medium exposure: A further removal of cement and sand causes coarse

aggregate to appear approximately equal to the matrix in area.

Deep exposure: Cement and fine aggregate are removed from the surface so that coarse aggregate becomes the major surface feature.

ACI 303 (Reference 1) further defines these classes in terms of *reveal* or depth of aggregate exposure, and adds a fourth category, *brush*. A brush finish removes the surface sheen but does not provide any reveal.

Seven general methods of exposing aggregates listed below are explained in more detail in Table 3 (page 22):

1. Surface retardation
2. Water washing with brushing
3. Acid etching (washing)
4. Abrasive blasting
5. Bushhammering or tooling
6. Grinding and polishing
7. Water blasting

Skilled operators are essential to achieving good results with all of these methods. For each method, factors in

the concrete mix design, such as aggregate size, water-cement ratio, design strength, slump, and consolidation, must receive careful attention to assure that anticipated results are obtained. Provisions must also be made to increase concrete thickness over reinforcement to allow for surface material removed. A short description of each of the seven listed methods follows.

1. *Surface retardation* involves the application of an agent to the concrete surface or to the form surface to delay set of the surface cement paste so that the aggregate can be exposed easily. Upon hardening of the concrete mass (normally overnight), this outer layer of cement paste is then removed by brushing or water spraying or a combination of both.

2. *Water washing with brushing* is normally done to unformed surfaces or to surfaces from which the molds are stripped prior to complete hardening of the cement. The cement paste is removed by water washing to the required depth just prior to setting.

The appearance of aggregates subjected to retardation or water-washing does not change during the exposure process. These methods may be used for all three degrees of exposure, but are most commonly used for medium or deep exposure.

3. *Acid etching* removes the outer cement layer by chemical action. This may change the aggregates slightly depending upon their reaction to the acid. The aggregates should be acid-resistant, like quartz or granite, rather than limestone or marble which can be dissolved by the acid. Acid etching may leave aggregates looking brighter than before, but in normal weathering they will lose this brightness and will closely resemble their original condition.

Acid etching is a finish that is easy to produce in acceptable quality on a 12-in. (300-mm) sample, but is one of the more difficult finishes to match with similar quality on large areas.

4. *Blasting with abrasives* or sand normally changes the aggregate appearance permanently by dulling the surface. The degree of change will depend upon the relative hardness of the aggregates and abrasive. Most sandblasted aggregates maintain their appearance with little change due to weathering, apart from the possible dirt accumulation to which all



Panel No. 41, precast with white marble aggregate concrete face and a backing of structural lightweight concrete. Aggregate exposed by bushhammering.
Panel 52, horizontally precast, was ground and polished. Facing aggregate pieces were individually hand placed.

buildings are subject. Sandblasting is used for all three degrees of exposure.

The degree of uniformity obtainable in a sandblasted finish is generally in direct proportion to the depth of sandblasting. Light sandblasting may look acceptable on a small sample, but uniformity is rather difficult to achieve on architectural-scale surface areas.

Where such sandblasting means only one pass for the blast, great demands are made on the skill of the operator, particularly if the units are sculptured. Small variances in concrete strength at time of blasting may further complicate results. Air voids hidden under the surface may be exposed by a light sandblast. If such voids are of a reasonable size, 1/8 to 3/16 in. (3 to 5 mm), it is strongly recommended that they be accepted as part of the texture because sack-rubbing to fill them is expensive and may cause color differences. The importance of realistic samples in shapes reflecting the final unit cannot be overstated for this finish.

5. *Bushhammering or tooling* to expose the aggregate fractures both the concrete and the larger aggregates. This produces an appearance somewhat different from other types of exposed aggregate.

Bushhammering is most commonly applied to well-graded mixes with softer aggregates such as dolomite and marble, provided these are durable. Power tools with multiple-impact chisels working simultaneously will decrease the cost of this finish.

Bushhammering at corners tends to cause jagged edges. If sharp corners are desired, power tooling is stopped 1 to 2 in. (25 to 50 mm) or more from corners. Normally, areas near corners are bushhammered by hand since many tools will not reach into inside corners.

6. *Grinding and polishing* concrete surfaces is more labor-intensive than the other treatments, especially on vertical or overhead surfaces. The result is similar to terrazzo work, comparing favorably with polished natural stone.

Panel 52 (page 20) was horizontally precast, ground and polished. It was made by a special production technique involving hand placement of facing aggregates. More typical polished precast panels may be one- or two-layer construction like other exposed aggregate panels, but the

concrete is usually not gap graded. Since the aggregates polish better than the matrix, it is essential to have a minimum matrix area. A continuous-graded concrete mix works best if it is carefully designed to provide maximum aggregate density on the surface to be polished.

7. *Water blasting* with high pressure water jets in combination with air is also used to expose aggregate, with or without the use of surface retarders. Proper time of application must be determined for each concrete and its

curing conditions to get the proper amount of reveal without loosening the aggregate.

The water-jet blast with a sand injector attachment is gaining acceptance as a replacement for conventional sandblasting. Sand injected into the water stream and propelled at high velocity enhances the cutting ability of the stream and helps erode the mortar surrounding the aggregates. Wet sandblasting eliminates the dust cloud and eases the cleanup afterward.

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Entrance to Holtzman & Silverman Office Building, Southfield, MI

Light colored limestone aggregate exposed by medium sandblasting, with surface details (below) shown from two different viewing distances. Crisply formed rustication grooves and exposed tie holes contribute to sharpness of overall detail. Entrapped air voids, which appear as dark spots in the closeup are evenly distributed and do not detract from surface appearance at normal viewing distance.

Architect: Gunnar Birkerts & Associates, Inc.

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Table 3. Exposure Techniques

Method and types of surfaces	Equipment and supplies	When to begin exposing aggregate	Typical Procedures
<p>Surface retardation is used for both vertical and horizontal faces when a prime concern is to retain the full, natural colors of the aggregate.</p> <p>Great care is required to obtain a uniform effect on vertical surfaces.</p>	<p>Chemical retarders are brushed or rolled onto form surfaces before concrete is placed, or sprayed onto face-up panels cast flat.</p> <p>Manufacturers' instructions must be followed closely for each retarder product.</p>	<p>For best results remove surface mortar when concrete strength is from 1000 to 1500 psi (5 to 10 MPa). Forms are normally stripped within 24 hours.</p>	<p>Retarded mortar paste should be removed immediately by washing and brushing. High-pressure water blasters are more efficient and economical.</p> <p>If a chemical retarder is used for cast-in-place walls, place concrete through chutes to prevent it from hitting the sides of the form and removing the retarder.</p>
<p>Washing with brushing is usually used for surfaces of panels cast flat. Used on aggregate-seeded surfaces.</p>	<p>Use soft or hard plastic-bristled brushes and special exposed aggregate brooms. Do not use wire brushes.</p> <p>Surface retarders may be used to permit the base concrete to attain initial set before the washing and brushing begins.</p>	<p>Allow concrete to stiffen until water sheen disappears and surface can bear weight of a man without indentation.</p> <p>Begin washing while the panel is still in the form and as soon as it is stiff enough to prevent dislodging the aggregate.</p>	<p>Surface layer of mortar is carefully washed away by spraying lightly with water and brushing until the desired exposure is achieved. Depth of exposure varies with the size of the aggregate. Several passes may be required to get the proper exposure.</p>
<p>Acid etching is commonly used for precast units in a products plant. Used for light to medium exposure, producing a texture closely resembling natural stone. Use acid-resisting aggregates such as quartz and granite.</p>	<p>Use a 5 to 35% hydrochloric acid solution. May be applied with a stiff-bristled fiber brush, by spraying, or by immersing units in an acid-filled tank.</p> <p>Workers must have protective clothing and covering to prevent injury from splattering.</p>	<p>Best results are obtained when the concrete is at least two weeks old, or has reached a compressive strength of 4500 psi (31 MPa).</p> <p>Surfaces to be left with aggregate unexposed and any exposed metal in the unit must be protected from the acid.</p>	<p>Concrete should be well wetted with clean water before acid treatment. Acid should not be allowed to lie on the surface more than 15 minutes. The surface is then scrubbed and thoroughly flushed with water.</p> <p>Repeated acid applications may be required to obtain the desired depth of exposure. Curing can be continued after aggregate exposure.</p> <p>Neutralization and/or proper disposal of runoff is essential.</p>
<p>Sandblasting or abrasive blasting is used to texture both horizontal and vertical surfaces of hardened concrete.</p> <p>Concrete with soft aggregate will have a flatter appearance if blasted at later ages.</p>	<p>Sandblasting is done in a stream of compressed air. Abrasive materials include silica sand, aluminum carbide, black slag particles, and walnut shells.</p> <p>Consult the manufacturer regarding safety requirements of the equipment being used. As a minimum, protective clothing must be provided for the operator, and the working area enclosed to prevent dust being blown about.</p>	<p>Time of sandblasting depends on concrete strength, hardness of the aggregate, and the visual appearance desired. Concrete surfaces will be easier to cut in the first 24 to 72 hours after casting.</p> <p>All surfaces should be blasted at the same age for uniform results.</p>	<p>Type and grading of the abrasive are important to control of the process. Increasing the size of grit and the air pressure increases the impact and abrasive effect. The operator also controls by varying the angle and the distance of the nozzle from the concrete, usually between 4 and 24 in. (100 to 600 mm). Different nozzles with apertures to suit various jobs are available.</p> <p>For reveals deeper than ¼ in. (6 mm) retarders can reduce sandblasting time considerably.</p>
<p>Tooling or bushhammering is used for both horizontal and vertical surfaces.</p> <p>Power or hand hammers are used to remove mortar and fracture aggregates at the surface of hardened concrete to produce an attractive textured surface.</p>	<p>Pneumatic tools fitted with bushhammer, comb, chisel, or multi-pointed attachments are used.</p> <p>Hand tools are used for areas where power tools cannot reach, and at corners where it is important to retain sharp edges.</p>	<p>Concrete compressive strength of 4000 psi (28 MPa) and a minimum age of 14 days are required to prevent loosening of the aggregate. Better uniformity is obtained in many cases at 21 days, when the concrete is drier.</p>	<p>Tooling removes a layer of hardened concrete while fracturing the aggregate at the surface. Provide 2 to 2½ in. (50 to 63 mm) cover over reinforcing steel for all cast-in-place work to be tooled or blasted.</p> <p>Surfaces attained can vary from light scaling to a deep, bold texture achieved by jackhammering with a single-pointed chisel. If sharp corners are desired, hold bushhammering back 1 to 2 in. (25 to 50 mm) from the corners.</p>

Method and types of surfaces	Equipment and supplies	When to begin exposing aggregate	Typical procedures
Grinding and polishing for both horizontal and vertical surfaces gives a terrazzo-like finish.	Equipment may vary from a simple hand grinder to an elaborate multi-head machine. Grinding elements consist of carborundum particles bonded together with resin, or diamonds set in cutting surfaces. Polishing compound and a buffer are used for honed finishes.	Concrete surface blemishes including bugholes should be patched. The concrete and any surface patches should be at 5000 psi (33 MPa) before any honing or polishing operations.	Honing consists of several successive grinding steps, each with a finer grit than the preceding step. Air voids in the surface must be filled with a sand cement mixture before each grinding operation. Grinding is delayed until the fill material has cured and reaches sufficient strength.
Water blasting is used to texture the surface of hardened concrete where local environmental restrictions prohibit use of sandblasting.	High pressure water jets used in combination with air on retarded or unretarded concrete surfaces.	Time of application must be determined for each concrete and its curing conditions, to obtain the desired amount of exposure without loosening the aggregate. If retarders are not used, begin treatment immediately after early form removal. Concrete should have a minimum 1500 psi (10 MPa) compressive strength.	Procedure is similar to sandblasting, but with different problems of site cleanup.

All photos courtesy Concrete Technology Inc.



Procter & Gamble Development Research Building, Mason, OH

Contrasting textures and colors of exposed aggregate contribute to architectural definition of this contemporary structure. Sand-blasted off-white panels form horizontal bands above and below the windows, while reddish tones of exposed Canadian granite dominate the vertical piers. The warm colored aggregate of the pier panels was exposed using a chemical retarder, followed by washing and brushing, which left a deeper texture than in the lightly sand-blasted white panels.

Architect: CUH2A Inc., Princeton, NJ

Textures and Patterns from Forms and Form Liners

Architects specify patterned and textured concrete surfaces for both aesthetic and practical reasons. Aesthetic interest is generated by the play of light and shadow on textured surfaces, and the patterned concrete does not reveal so plainly the minor imperfections that can mar a smooth concrete surface. Bugholes, color variations, and leakage at form joints are all less conspicuous when the surface has a distinctive pattern or texture of its own. Patterned forms and liners also make it possible to simulate economically in concrete the traditional look of wood, brick, or stone.

From the owner's point of view, rougher concrete surfaces discourage graffiti and often are easier to maintain. Textured concrete surfaces also make a good background for landscape plantings and provide a place for natural vegetation to cling and grow.

Selection of Liner Materials

Texture and pattern can be imparted to concrete by forms and form liners of many materials including the basic forming materials of wood, steel, or aluminum, as well as paper, rubber, cardboard, and plastic. For textured off-the-form-finishes patterned plastic liners are the most widely used today. The choice of liner material may depend on whether the work is precast, cast in place, or tilt-up. Thin liners that work well for horizontal casting may wrinkle and sag in vertical forms. Thicker liner materials are better suited for vertical forms, where they must withstand the lateral pressure of freshly placed concrete, not just the gravity load imposed by horizontal casting. Because some liners are made to withstand concrete pressures no greater than 1000 psf (48

kPa), a controlled rate of concrete placement may be necessary.

The construction cycle and potential number of uses of the lined form also influence the choice of liner material. Form liners like the plastic foams usually are used only once, while many elastomeric liners are good for 100 or more uses with reasonable care. Top-of-the-line elastomers that cost \$20 per square foot may turn out to be the economical choice where schedules permit numerous reuses.

As with other types of architectural concrete surfaces, a preconstruction mock-up is particularly helpful in confirming the choice of patterned liner materials. If it is built on site using the same materials, methods, and work force that will be used for the job, it can remain as a reference standard for inspectors and workers, and a physical reminder to the architect of what he has approved. A good mock-up should be large enough to show full size floor, wall, or other units that will have architectural finish. Where patterned surfaces are used, it is important to include a repaired area that shows how any defects will be patched.

Wood Forms and Liners

The wood grain look can be achieved by casting concrete against sand-blasted, wire-brushed, or striated plywood. Unfinished sheathing lumber can also be used to produce a rough board-marked concrete. For a surface showing only mild accentuation of joint lines, 1-in. (25-mm) boards rough on only the contact surface are used. Finished edges make it possible to draw the boards tightly together, and surfacing on one side reduces variations in thickness so that the offset between adjoining boards is not so great. For very rugged textures, nei-

ther side of the sheathing lumber should be finished.

Sometimes the boards are wetted or sprayed with ammonia before applying release agent to raise the wood fibers and accentuate the grain marking. Tongue and groove boards may be spaced with a small gap to accentuate the fins, or edges may be beveled to create projecting fins. The boards or plywood can be designed to serve directly as form sheathing, or they may be placed as a liner within other structurally adequate forms.

Natural variations in the absorbency of wood create color variations in the concrete surface. The more absorptive the form face, the darker the concrete will be. As wood forms are used and reused, the natural absorbency decreases. If it is necessary to patch or adjust a much-used panel, location of the new boards will show up as a color difference that may take years to weather away. To avoid this problem, experienced constructors make up an extra panel or two to keep in the form rotation. Then if one panel is damaged it can be replaced by one already seasoned with use.

Wood forms can be sealed to minimize concrete color differences. Impervious plastic form liners described below are also used to produce wood grain finishes free of color differences due to absorbency variations.

Plastic Form Liners

The plastic-based form liners commercially available include stiff or rigid materials such as polystyrene sheets, ABS (acrylonitrile butadiene styrene), glass-fiber-reinforced plastic (GFRP), and polystyrene foam. Also widely used are elastomeric (rubbery) liner materials, principally made of urethane. Literally hundreds of liner patterns are available, including brick

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Photo courtesy M. K. Hurd



Buell Building at Lawrence Technological University, Southfield, MI

Fluted white concrete cast in place using ribbed form liner. Closeup shows how plain bands provide contrast between fluted areas and reveal tie holes as part of the surface pattern. Untextured areas also eliminate difficult-to-execute horizontal butt joints in the liner material.

Architect: Louis G. Redstone/Redstone Architects Inc.

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Orlando Public Library, Orlando, FL

Rough and random look of board marked concrete dominates the facade of Florida's largest public library. Expansion in the 1980s successfully matched original construction from the 1950s.

Examination of exterior walls at close range reveals the impressions of nail heads as well as contrasting wood grain textures resulting from different sawing methods. Note also ribs created by varying the board depth, and projecting fins resulting from intentional leaks in the form surface.

Architect:

Original design: John Johansson
Addition: Schweizer Incorporated



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Photo courtesy Symons Corporation



Architectural concrete columns at Stratford Square Center, Bloomingdale, IL

Extruded plastic form liner with ribs 4½ in. (115 mm) on center was adapted with elastomeric liner strips glued to the ribbed liner to achieve the desired wood grain look. Cement with a warm natural color enhanced the realism of the wood simulation. Overall quality and uniformity were improved by pumping concrete into the forms from the bottom for all 80 columns in the mall interior. One-piece standard fiber-glass-reinforced plastic round column forms provided structural strength to withstand concrete pump pressure.

Architect: RTFL Associates Inc.

and stone masonry, wood grain, flutes, and fractured ribs. One manufacturer supplies a plastic liner that holds real brick or thin brick layers in place to produce a brick-faced concrete wall. In addition, many manufacturers make custom liners that will translate original designs or works of art into concrete. Standard liners can be combined with customized details, and raw materials are available for constructors who want to make their own custom liners.

Rigid Plastics

Rigid plastics such as ABS (acrylonitrile butadiene styrene), PVC (polyvinyl chloride), and high-impact polystyrene sheet material can be molded or extruded to produce liners in a variety of stone, wood, brick, and other textures. There are several single-use liner products appropriate for tilt-up work.

As with any rigid form material, a draft or taper is needed to facilitate stripping. This is why the fluted liners used to produce ribbed surfaces have a trapezoidal (sloped side) cross section instead of a rectangular one. The taper is virtually invisible in the resulting concrete ribs.

The rigid liners are typically supplied in sheets of 4x8-, 4x10-, and 4x12-ft (1200x2400-, 1200x3000-, and 1200x3600-mm) nominal size, but they can be special-ordered in lengths of 30 ft (9 m) or longer. Ribbed patterns are done well with ABS and PVC liners, and some have interlocking panel edges to help conceal vertical joints. Joints running transverse to panel edges require carefully detailed closures. By leaving a plain area between textured surfaces, the architect can avoid problems with horizontal butt joints in the liner material.

Glass-Fiber-Reinforced Plastics

Laminated GFRP liners look much like the other rigid plastics, but they are stronger and more durable. They are well-suited for simulating brick, stone, and wood textures, and they expand less with heat than the other plastics. If they have an extra gel coat of plastic resin at the surface, the glass fibers do not bloom out during use. Extruded GFRP liners are less costly (and less durable) than laminated GFRP, but they often provide an eco-

nomical way to form ribbed or fluted surfaces. Custom lengths up to 40 ft (12 m) are available.

Elastomeric Plastics

Elastomeric or rubbery plastic liners are generally the most costly of the group, but they are tough and wear resistant, and flexible enough to accommodate fine detail with some undercuts. Since the draft or taper needed with more rigid materials is not required, design possibilities are greatly expanded. Polyurethane, either pure or mixed with fillers, is the principal material used. Standard sheets are available up to 4x12 ft (1200x3600 mm), but custom ordering of larger sizes permits elimination of troublesome horizontal butt joints.

The elastomeric liners are relatively heavy, often weighing several pounds per square foot, so they require good support. Typically they are attached to form sheathing with adhesive, but some manufacturers supply them pre-bonded to plywood sheets. They are sensitive to temperature change and may deform objectionably as surface temperatures go above 140°F (60°C).

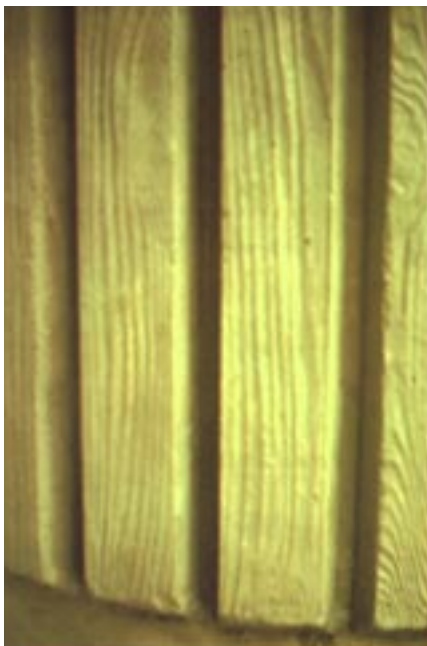
Polystyrene Foam

Single-use liners of polystyrene foam may be supplied in large sheets like the other liners, or in smaller interlocking modules that fit together with hidden joints. One liner, for example, is made in pieces to fit inside a standard round column form to produce fluted columns. Most polystyrene foam liners are destroyed in stripping after a single use.

The foam is molded for patterns sold in large quantities, and custom cut to produce unique patterns for specific jobs. Computer controlled hot-wire cutting devices have made custom work available at moderate prices.

Molded foam liners have a surface skin that can be coated with a compatible release agent. Raw cut edges of polystyrene foam will bond to concrete, so an added membrane seal or coating may be required for these edges to secure a smooth concrete surface. Builders strip the foam by hand or with air and water jets, sometimes wire brushing or sandblasting if the foam has bonded to the concrete. It is also possible to dissolve the foam with petroleum products, leaving a thin shiny coating on the concrete.

Photo courtesy Symons Corporation





Atlanta Public Library, Atlanta, GA

Precast panels have ¼-in.-wide (6 mm) diagonal flutes. There are two colors of cement and two types of aggregate in the concrete.

Architect: Marcel Breuer Associates.



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Retaining wall and overpass railing, I-696 in Southfield, MI

Fractured rope texture imparted by elastomeric form liner, as seen from three different viewing distances. Flexibility of the liner made it possible to strip deep undercuts cleanly, even though form panels were sometimes ganged to 100 ft (30 m) in length.



© R. W. Steiger





Elastomeric form liners molded from natural rock surfaces can be attached to conventional form panel and can be used to create a variety of patterns. The finished concrete surface has a realistic stone texture, with up to 10 in. (250 mm) of relief possible.

Construction Practices

Textured or patterned forms and form liners can produce high-quality architectural concrete, but only if joints in the forms and liners are executed carefully, and the liner materials are handled properly. It is important to check liners for compatibility with release agents and adhesives, and to design for temperature-related movement of the liners. Although some plastic liners can be stripped without release agents, better overall performance and uniformity of concrete surfaces can be achieved with a light coating of chemically active release agent.

Concrete Placing

For ribbed surfaces, the largest size aggregate particles should be smaller than the rib width to avoid incomplete filling of the liner ribs. Placing concrete through a flexible rubber tube (elephant trunk) reduces segregation and entrapped air. It also prevents spattered concrete that may dry on the form before another lift is placed, and minimizes the abrasion or deforma-

tion that may occur when concrete is dropped directly against the liner.

Many form liners are designed for concrete pressures no larger than 1000 psf (48 kPa). This may call for restricted rates of placing and careful planning for any plasticizing admixtures. Limiting the rise of concrete in the forms to no more than 4 to 5 ft (1200 to 1500 mm) per hour is usually satisfactory.

Adequate vibration is important to avoid lift lines and reduce small surface air voids (bugholes). Liner manufacturers frequently recommend not more than 2-ft (600-mm) layers of concrete, with the vibrator inserted vertically at uniform spacings, penetrating at least 6 in. (150 mm) into the previous layer. Vibrators must be kept out of contact with the liner surfaces, and extra vibration will be needed because the textured liners have two or three times as much surface area as a smooth form panel.

Reinforcement and Ties

Ties should be of a type that will leave no corrodible metal closer than 1½ in. (38 mm) to the finished concrete surface. Tight-fitting tie holes, drilled or cut with a hole saw, are important. Sealing around the holes prevents

grout loss and the resultant discoloration of surrounding concrete. Compressible plastic rods or tape can be used to seal around the penetrations through rigid liners. Cone fittings on the tie ends also help to seal the holes. Locating ties in the recessed part of the concrete, such as the base of fluted grooves, makes the tie holes less conspicuous.

Supports and spacers for reinforcing bars should be plastic, plastic tipped, or stainless steel to avoid rust stains on the concrete as it weathers. Side-form spacers, devices that maintain the desired distance between a vertical form and the reinforcing bars, should be used to assure proper cover on vertical bars. All spacers or supports should rest against a part of the liner in direct contact with the form backing. Some contractors and precasters prefer to brace the rebar cage strongly against movement, and use temporary spacers during concrete placement.

Adequate cover over all reinforcing steel is essential. When working with recessed or grooved textures, the minimum required or specified cover over the steel will be measured from the bar to the deepest indentation of the concrete surface. For concrete exposed to weather, at least 2 in. (50 mm) of cover is usually required. For #5 bars, W31 or D31 wire, 1½ in. (38 mm) is sufficient.

Form Stripping and Curing

In many cases forms for vertical surfaces can be stripped within 12 to 24 hours after placing concrete, so long as those forms carry no construction loads from above. Many liner manufacturers recommend stripping forms at about 24 hours to prevent exposing the liners to prolonged heat of hydration from the concrete. This generally gives a better surface color, as well as protects the form liner. Stripping while the concrete is relatively green permits minor fins and flash lines to be removed by stoning. More important than the precise time of stripping is that it be uniform throughout the job to minimize color variations.

Specifications frequently require concrete to be cured for 7 days or until at least 70 percent of the specified compressive strength is attained. Proper curing requires maintaining moisture and temperature conditions favorable to the development of

desired concrete properties. For patterned concretes, and architectural concretes in general, proposed curing methods should be checked out on the preconstruction mock-up. Curing practices appropriate for structural concrete may not be suitable for architectural concrete finishes. Ponded or flowing water may affect the concrete color, sheets or films of plastic may cause mottling, and spray-on membranes may discolor or prevent bonding of later coatings.

Aluminum Forms

Many aluminum wall forming systems are available with brick-pattern faces—either textured or smooth brick—or with vertical rib or board and batten patterns. Generally aluminum wall forms are 3 ft (900 mm) wide and 8 ft (2.4 m) high, with filler panels available in numerous widths ranging down to 1 in. (25 mm). Sections are held together with metal pins. A metal wedge pulls the form together and tightens the joints, minimizing the possibility of unsightly seams in the finished wall. By deepening the simulated mortar joints in the concrete surface, the joints between form panels are effectively obscured.

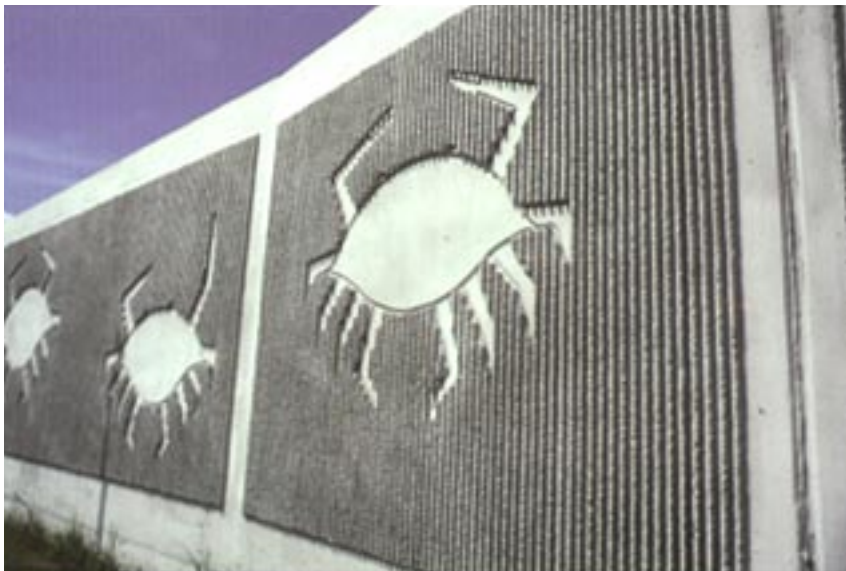
Aluminum forms are lightweight and strip easily from the concrete. When the surface is painted, the brick simulation is heightened. Lanolin, palm oil, oil-based emulsions or oleic acid base release agents have been used successfully with aluminum forms. Recheck with form manufacturers for current recommendations.

Release Agents

Release agents are materials applied to the liner or face of the form that contacts the concrete. They help to prevent forms and liners from sticking to the concrete, and aid in production of high quality architectural surfaces.

The safest approach in selecting a release agent is to evaluate several products under actual job conditions on a test panel. Recommendations of the release agent manufacturers explain their compatibility with liner materials, and describe proper application methods. Consult ACI 303R (Reference 1) for more detailed information and recommendations for storage and use.

Photo courtesy The Scott System



Graphic designs created in this flood wall by placing templates against the ribbed elastomeric form liner, then carefully sealing the liner channels to maintain the relief pattern.

Photo courtesy M. K. Hurd



Precast concrete panels for this small home were cast against liners having a used brick texture. Simulation was heightened by painting with carefully chosen colors distributed in a random pattern.

Photo courtesy M. K. Hurd



Untreated off-the-form brick pattern cast in place against modular aluminum wall forms. Two-color painting of this pattern is a cost-effective interior treatment.

Section 8

Patching and Cleaning

The appeal of any architectural concrete surface is different for each person who looks at it, and varies greatly with lighting and distance. The American Concrete Institute (Reference 1) defines generally acceptable architectural concrete surfaces as those with minimal color and texture variation and minimal surface defects when viewed at 20 ft (6 m).

Almost all architectural concrete will contain some defects. Small blowholes or bugholes, for example, are considered common to concrete and therefore are generally acceptable. Attempts to patch areas of excessive bugholes may fill the holes but produce a patch more unsightly than the holes. Patching requires skill and close attention to matching the surrounding area. Only careful repair will assure that the remedy is not more unsightly than the original defect. Fortunately, bugholes are not so apparent in rough-textured surfaces and exposed-aggregate concrete surfaces.

Patching: Exposed Aggregate Concrete

It is easier to patch exposed aggregate than plain smooth concrete elements. First, the damaged area should be chipped out and cut back to a depth a little more than the maximum size of exposed aggregate. For example, go down 1 in. (25 mm) for ¾-in. (19-mm) aggregate. The sides of the hole should be at right angles to the surface; it is not necessary to undercut. Then the area must be thoroughly dampened with water to assure good bond of the patch. Use of a scrubbing brush in this operation is good practice. After the patching area is well dampened, brush in a mixture of cement and water the consistency

of a thick paint. The damaged area now is ready to receive the patching mix.

The patching concrete must contain the same materials as those used in the original, minus the coarse aggregates exposed. If the original matrix was made with gray cement, a small amount of white cement normally must be added to the patching mix to duplicate the original color. This is because the lower water-cement ratio of the patch causes it to dry darker than the original concrete.

The amount of white cement to add varies, but about 25% is average. On the other hand, if the original concrete matrix is white, a small amount of gray cement may have to be added to the patching mix to match the slight gray tint that was imparted to the white concrete by drum wear during mixing.

Trial mixes are essential to determine exact quantities. These mixes should be allowed to age for 7 to 14 days before a final selection is made. The patching mix must be stiff, but not so stiff that the exposed aggregates cannot be pressed into it.

The patching mix should be compacted into the cavity immediately after the neat cement slurry coat is applied. The mix should be vigorously hand-tamped and then struck off level with the surrounding concrete.

On horizontal surfaces the aggregate to be exposed is next spread on the surface of the new patch to match the surrounding area. The stones are patted into the surface with a small wood block. On vertical surfaces or overhead work, each piece of aggregate must be hand-placed. After a few minutes set, a wet sponge can be dabbed against the surface of the patch to remove any matrix from the aggregate so that it matches surrounding areas. Finally, the patch should be cured with water and cleaned with acid if the rest of the unit was so treated. The patch may need

sandblasting if the rest of the wall was sandblasted.

When producing exposed-aggregate elements with small-size aggregates of about 1/8 to 1/4 in. (3 to 6 mm), it is often difficult to obtain uniform exposure with retarders. To restore the surface, wet it, and then smear and brush a grout coat of cement, sand, and water into it to match the original concrete matrix. This operation also fills small voids in the surface. Shortly after it has set, excess grout is carefully brushed off the aggregate.

Precast panels that are patched after erection get similar treatment at the jobsite by the precaster's patching specialist. Frequently, a broken-off piece can be glued back in place with an epoxy bonding agent. Broken surfaces of panel and the piece should both be painted with the adhesive.

Patching: Tie Holes and Defects in As-Cast Surfaces

Outline honeycombed or otherwise defective concrete with a ½- to ¾-in. (13 to 19 mm) deep saw cut and remove such concrete down to sound concrete. Dampen the area to be patched and brush with a coat of bonding grout before applying the patch. Fill with patching mortar of the same materials as the concrete to be patched, but with no coarse aggregate. It is usually necessary to substitute white portland cement for part of the gray cement to produce a color closely matching the surrounding concrete. The amount of white cement should be determined by test mixes for each individual job.

Form tie holes should be plugged to prevent corrosion and resultant stains on the concrete surface, unless the ties are stainless steel. In a rough surface, small holes can be filled flush with the surface and concealed. Tie holes in smooth surfaces will be more apparent, and it is better to hold the filler material back a small distance from the surface, leaving the tie holes as part of the surface design.

Materials for plugging tie holes include portland cement mortar, epoxy mortar, plastic or precast mortar plugs, and lead plugs. Mortar of a

dry-tamp consistency will be less likely to smear on the surrounding surface than a wetter mortar. For portland cement mortar patching prepare the surface as for patches described above.

Cleaning

Various techniques and materials to clean exposed-aggregate concrete include washing with plain water or hot water containing detergents or other commercial cleaners, steam, light abrasive blasting, and application of dilute hydrochloric (muriatic) acid. The last method is most commonly used in the precasting plant.

Exposed aggregates can be brightened by washing with a 5% to 10% concentration of hydrochloric acid, which removes the dull cement film remaining from some exposure techniques, especially washing and brushing. The acid normally is applied to a prewetted surface by brush, but it can be sprayed. The surface is wetted to reduce acid penetration. All traces of acid should be flushed from the panel with plenty of clean water before the panel dries. The best procedure is to use two workers; one applies the acid while the other hoses the surface. Workers should be protected, as should adjacent areas and materials. The acid and brush must be kept clean.

Acid cleaning is best used after a one- or two-week delay, but often it is done immediately after the initial curing to reduce handling operations. Acid washing that is done too soon contributes to formation of white deposits on units with a gray cement matrix or with dark-colored aggregates. The deposit results from the reaction of hydrochloric acid and portland cement, forming a somewhat soluble silica gel that soon becomes insoluble and extremely difficult to remove. Delaying the acid wash reduces significantly chances of a silica gel deposit forming, because of more complete hydration of the portland cement.

Hydrofluoric acid is effective in removing these white deposits, but its use is extremely dangerous and is discouraged except under very closely controlled conditions for safety.

Section 9

Surface Protection

Many specifiers require that precast and cast-in-place architectural concrete surfaces be protected by a water-repellent coating or a sealer. These coatings serve several purposes; they

- resist deterioration of concrete surfaces by industrial airborne chemicals
- inhibit soiling of surfaces
- facilitate cleaning of surfaces
- prevent color changes caused by water absorption
- accentuate the color of aggregate and mortar in exposed-aggregate concrete

A coating selected for these purposes should be water-clear, capable of being absorbed into the concrete surface, and long lasting. It should not give a glossy-coating effect, nor discolor on exposure to sunlight or atmospheric contaminants.

Numerous products of varied chemical composition are sold for this use. Laboratory research (References 8 and 9) shows that low-viscosity acrylic resins based on methyl methacrylate offer the best protection for exposed-aggregate surfaces. Silanes and siloxanes are also effective water-repellents for architectural concrete. They are breathable materials that permit the movement of water vapor, and they do not discolor the concrete.

Coatings should be selected carefully, because some coating materials may cause permanent discoloration of the concrete surface. For exposed-aggregate finishes, choose a coating guaranteed by the manufacturer not to stain, soil, darken, or discolor the finish, and strictly follow the manufacturer's directions for applying the coating.

Poplar Creek Library, Streamwood, Ill.

Clear sealer sprayed on exterior and interior concrete walls.

Architect: O'Donnell Wicklund Pigozzi Architects, Inc.



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Other Publications Used as Source Material

Some parts of this book have been carried forward from the 1980 edition which drew heavily from such works as William Panarese and Sidney Freedman's "Exposed Aggregate Concrete," originally published in *Modern Concrete*, November and December 1969, and January 1970; and from Sidney Freedman's article, "Insulating and Gap-Graded Concretes," *Modern Concrete*, June 1969.

Back Cover Photos

Upper left: Epson America Corporate Headquarters, Torrance, CA. Precast panels of unusual depth were cast economically, with natural concrete color and smooth finish. The natural, permanent, and substantial appearance contributes to the powerful simplicity of the design. Architect: Gensler and Associates

Upper right: San Diego Convention Center, San Diego, CA. White architectural concrete "fins" with a light sandblast finish were cast in place in custom steel forms. The fins, designed to establish a maritime look in combination with a draped fabric roof, will provide seismic resistance for the structure. Architect: Convention Center Architects

Bottom: Head Smashed In Buffalo Jump, near Calgary, Alberta. Buff-colored exposed aggregate concrete satisfied the owner's desire for a building in harmony with the environment, built into bedrock in such a way that the original historic buffalo jump remained unspoiled. Architect: The LeBlond Partnership

Notes and Acknowledgments

While every effort has been made to acknowledge architectural designers of pictured concrete, a few could not be positively verified. Information on any of the missing designers will be welcomed.

Photographers and/or providers of photographs have been indicated throughout the interior pages of the book. Front cover pictures were provided as follows: top, Boudrias, Boudreau, St-Jean; center left, Alan Karchmer photo courtesy Hartman Cox Architects; center right, David Sailors photo courtesy Ewell W. Finley and Partners; bottom, Douglas Salin photo courtesy the Watry Design Group. Back cover pictures are from the following sources: upper left, M. Lorenzetti photo courtesy Gensler and Associates; upper right, M. K. Hurd; bottom, The LeBlond Partnership.

The American Concrete Institute granted permission for use of the drawing on page 18.

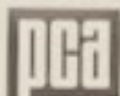
CAUTION: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS, or SERIOUS EYE DAMAGE. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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KEYWORDS: aggregates, cleaning, color, concrete finishes (hardened concrete), curing, exposed aggregate concrete, form liners, formwork (construction), mineral pigments, mixing, mix proportioning, patching, protective coatings, retarders, white cement

ABSTRACT: Explains how to achieve great color and texture in concrete walls, both cast in place and precast. Copiously illustrated in full color. Explores the potential for enhancing concrete structures made with white and pigmented concretes, exposed aggregate surfaces, and decorative as-cast textures achieved with a variety of form liner systems. Discusses gap grading, materials properties, aggregate exposure methods, and construction practices essential to achieving optimum results with each of these techniques.

REFERENCE: *Color and Texture in Architectural Concrete* (SP021.02A), Portland Cement Association, Skokie, IL, Second Edition, 1995.



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