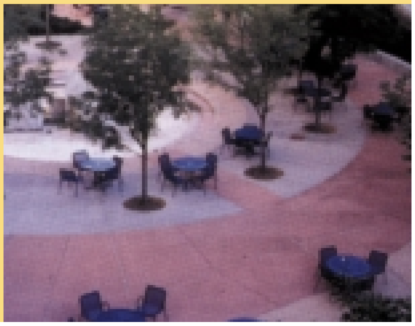
Ensuring the Quality of Colored Concrete Finishes

by Nick Paris and Michael Chusid



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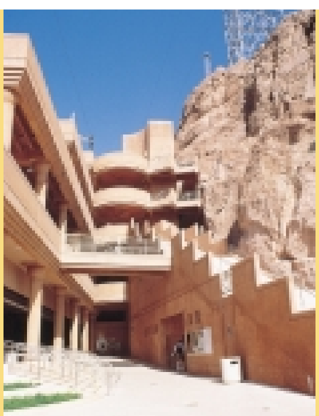


COURTESY BUREAU OF RECLAMATION

2.

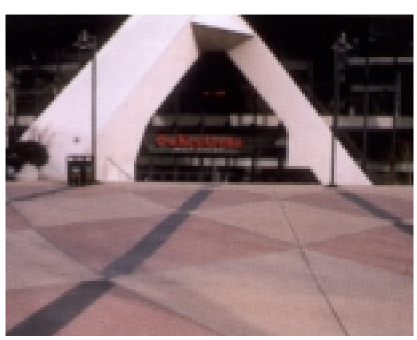
1. Plaza at a high-technology industrial building.

2. Hoover Dam Visitor Parking Structure.

3. Key Arena, Seattle.

4. Phoenix Art Museum.

While most people are oblivious to the ordinary variations in regular concrete, they often have heightened expectations when colored concrete is specified. Some unrealistically expect colored concrete to be completely uniform in appearance like a painted surface. It would be more realistic to compare colored concrete with handcrafted and natural building materials. As with stone and wood, minor variations in appearance contribute to the material's aesthetic appeal. When specified and constructed with reasonable care, color expands concrete's aesthetic potential (*see Photos 1* through *4*).



COURTESY SEATTLE CENTER

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COURTESY BILL TIMMERMAN

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The measures required to produce attractive integrally colored concrete are consistent with those required to produce any high-quality concrete. Usually, appearance defects are not a result of the coloring process but are due to the basic nature of concrete itself. Concrete appearance is affected by many factors, including the ingredients in the mix, mix design, handling and placing procedures, forming and curing methods, surface finishes and textures, environmental conditions, and craftsmanship. In most cases, colored concrete is installed using the same tools and

ADDITIONAL INFORMATION

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Abstract

Some people unrealistically expect colored concrete to be completely uniform in appearance like a painted surface. It would be more realistic to compare colored concrete with handcrafted and natural building materials. As with stone and wood, minor variations in appearance contribute to the concrete's aesthetic appeal. When specified and constructed with reasonable care, color expands concrete's aesthetic potential.

techniques as uncolored concrete. Specifiers and builders who understand the conditions that produce variation can form more realistic expectations and achieve desired results in both cast-in-place and precast colored concrete.

Materials

The first step toward achieving a consistent appearance is using the same ingredients throughout a project. Variations in the color or source of the cement, sand, aggregate, or other materials can affect concrete color.

Leading manufacturers carefully produce color additives to ensure uniform color and tinting strength and to comply with ASTM C 979, Pigments for Integrally Colored Concrete (see *Photo 5*). Mineral oxide pigments used in integrally colored concrete additives resist ultraviolet light, weathering, and the alkalinity of concrete. The microscopic pigment particles become locked into the cement matrix and last as long as the concrete itself.

Carbon black pigments also provide effective tinting, but concrete containing it must be protected from water penetration. While the carbon black pigment itself does not fade, some grades of carbon black can slowly leach out of concrete that is not adequately sealed, creating a faded appearance. In air-entrained concrete or concrete exposed to repeated wet/dry cycles, black iron oxide should be substituted for carbon black (see *Photo 6*).

Portland cement is produced in a variety of shades from white to gray or tan and will produce a similar range of tones in concrete (see *Photo 7*). Adding colors to a light or white color cement base will produce brighter, more pastel concrete; adding colors to gray cement produces more muted hues. To maintain visual uniformity, concrete producers should use cement from the same supplier throughout a project. In addition, they should obtain "Mill Certificates" or "Certificates of Analysis" from cement manufacturers attesting to the Blaine (a measurement of the cement particle size), color, and reflectance, and they should retain samples of cement shipments for future reference.

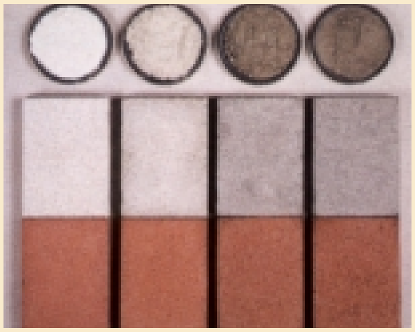
As concrete is mixed, a paste of portland cement coats each grain of sand and aggregate. Although the base color of the cement paste is the primary determinant of the concrete's color, the color and grading of sand and aggregate also contribute to the as-cast appearance, especially when the surface layer of cement paste is removed. This occurs when the concrete is sandblasted, mechanically abraded, or given an exposed aggregate finish. The surface layer of cement paste also can be eroded due to wear or weathering. Under these conditions, any variation in the sand and aggregate will affect the visual uniformity of the concrete.

Variations in the depth of aggregate exposure also affect appearance (see *Photo 8*). As more cement is removed, more aggregate becomes visible and the color of the cement matrix has less impact on the

PHOTOS COURTESY DAVIS COLORS UNLESS OTHERWISE INDICATED

5. Concrete colors should be obtained from a manufacturer with strict quality assurance procedures and a fully equipped color laboratory.

6. Carbon black pigments can leach out of concrete in wet areas unless adequately sealed.



7. Variations in the color of portland cement (top) obtained from different manufacturers will affect the shade of both plain (middle) and colored concrete (bottom).

overall appearance of the concrete. Aggregate exposure methods that fracture, grind, or polish the aggregate also produce a different appearance than techniques that merely expose the aggregate through washing and scrubbing.

Calcium chloride, commonly used to accelerate concrete curing, can produce discoloration and should not be used with concrete colors (see *Photo 9*). Some pigment producers offer "color-conditioned" admixtures, which are pigments preblended with plasticizers, water reducers, or other concrete admixtures. The same result, plus greater economy and control of the mix design, can be achieved by specifying the admixtures separately from the color additives or by using a performance specification that allows the concrete producer to determine the optimum combination of admixtures and colors. Concrete producers routinely stock and use admixtures that have a proven track record with their cement and other raw materials.

Mixes

Variations in the dosage rate of color additives affect concrete's color (see *Photo 10*). The pigment dosage rate is based on the weight of all cementitious materials in a mix, including portland cement, fly ash, and lime.

Increasing the dosage rate produces more intense colors. Color saturation generally occurs at dosage rates beyond 6 percent; thus, adding pigment will not intensify the concrete color. Color addition rates above 10 percent should not be used.

For uniform color, the same color dosage rate must be used throughout the project. In recent years, it has become easier for concrete producers to add the correct amount of concrete color to a batch. In the past, powdered pigments were dirty to work with and had to be manually weighed and poured into a concrete mixer. Color additives are now available in a variety of forms. Concentrated powder, liquid, granules, disintegrating packages, and automated dispensing systems are all designed to make coloring clean, simple, and accurate (see *Photo 11*).

Adding water to a concrete mix produces a paler color (see *Photo 12*). It is generally best to use the lowest water/cement ratio that will provide a workable mix. For cast-in-place construction, a 127 mm (5 in.) slump generally is acceptable. If additional slump is required, a water-reducer or plasticizing admixture should be included in the mix instead of more water.

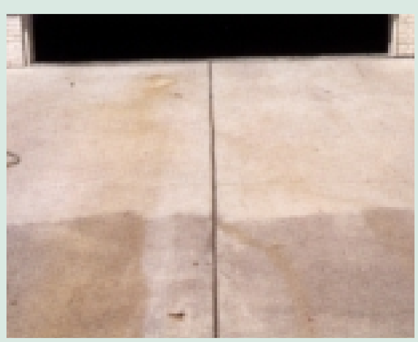
Adding water has other negative effects on concrete. Too much water contributes to dusting, cracking, and reduced durability of the concrete surface. Adding 3.8 L (1 gal) of water per 0.76 m^3 (1 yd^3) of a properly designed mix creates an additional 25 mm (1 in.) of slump, reduces compressive strength approximately 1380 kPa (200 psi), increases shrinkage by 10 percent, and increases the potential for efflorescence.

11. Disintegrating bags of color additives can be tossed into a mixer without opening or pouring.

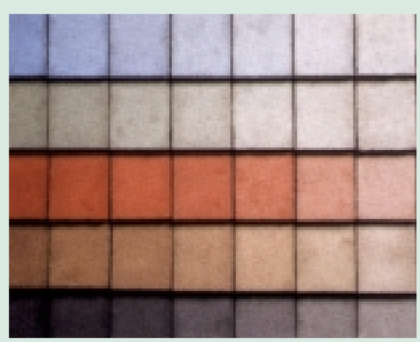
12. different water/cement ratios make plain (top) and colored concrete (bottom) appear pale or faded.

8. While exposed aggregate was used in this project as a design feature, a similar effect can occur due to wear and erosion.

COURTESY PORTLAND CEMENT ASSOCIATION

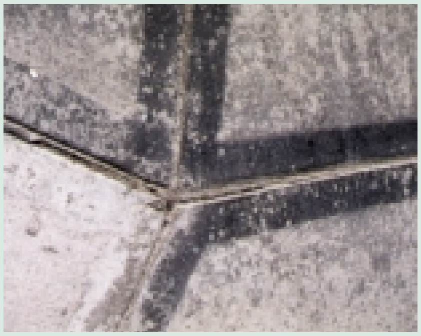


9. Concrete from two batches was used here in adjacent pours. The darker concrete in the foreground was discolored by a calcium chloride admixture.



10. A range of hues can be created by changing the color additive dosage rate.

13. Over troweling can entrap moisture and create dark areas.



14. Edging work, performed after the concrete began to harden, is the likely cause of this discoloration.

15. The pale broom mark, which is permanent, shows the first broom stroke after the broom was wetted.

16. Excessive use of form release agents can contribute to discoloration and voids in a formed concrete surface.

Concrete producers must protect against contamination of a concrete batch with material left in a mixer from a previous batch. It is a good practice to wash out the mixer between incompatible batches, especially between batches of differing colors. Pay attention to the scheduling of deliveries, placing, and finishing. Once again, uniformity is key to consistency. To the extent practical, all concrete placement should be performed under similar environmental conditions. Concrete placed during the hottest periods of the day or under windy conditions may begin drying prematurely and affect the uniformity of the finish.

Flatwork Finishes

If placing or finishing a batch is delayed, the concrete may begin to set and could require additional effort to trowel. Avoid hard troweling, late troweling, or over troweling unless a very dark, smooth surface is desired. Vigorous troweling overcompresses the concrete and effectively "seals" the surface. This inhibits it from "breathing" during the curing process and restricts the rate of water absorption during the chemical hydration (hardening) process. When troweling is inconsistent, hard-troweled areas will be significantly darker than areas that receive less troweling. These darkened areas are typically diagnosed as "entrapped moisture" and may appear randomly or precisely follow the hard-troweled sections.

Entrapped moisture is common in uncolored concrete and is rarely considered a problem. However, colored concrete customers frequently expect more craftsmanship; thus, entrapped moisture should be avoided. The darkened areas of entrapped moisture usually can be reduced by a few hard scrubbings with water and a nonmetal brush. Stubborn spots may require scrubbing with a dilute acid solution. If left untreated, the discoloration may be permanent (see *Photo 13*).

Another cause of darkening is trowel "burn," which is caused by a metal trowel abrading a hardened concrete surface (see *Photo 14*). On the other hand, early troweling, especially with a wet mix, can bring excessive bleed water to the surface and cause the concrete color to pale. For exterior paving, consider omitting troweling altogether and use a broomed, pattern-stamped, or other rough surface. A rough surface is less likely to show discoloration than a smooth troweled surface and may save labor as well.

The concern about water/cement ratio extends into the field. Field personnel should be instructed to minimize or eliminate adding water on the job site. Some installers dip their tools in water or sprinkle water on the fresh concrete surface before troweling or brooming. However, even the small amount of water on wet tools or brooms can lighten the concrete surface (see *Photo 15*).

The water content of fresh concrete is also affected by the substrate onto which concrete is placed. A uniformly damp granular subgrade will provide an acceptable base for pouring concrete on-grade. Subgrade areas containing mud, standing water, or soils with uneven absorptive properties may cause discoloration on the top of a slab.

Formed Finishes

When form release agents are over applied, they form a film that varies in thickness as excess release agent is dislocated during concrete placement and vibration. In the worst case, cement paste and color pigment can "float" in pockets of excess release agent and produce uneven coloring. This also can produce a weak concrete surface, bug holes, small voids, and other visual defects (see *Photo 16*). Oil-based form coatings should be avoided as they may stain the concrete. Reputable manufacturers can provide information on recent developments in

Field personnel should be instructed to minimize or eliminate adding water on the job site.

release agent technology that have improved as-cast surface uniformity.

When concrete is cast against clean, smooth-surface form materials such as steel or plastic-faced plywood, the as-cast concrete surface will be smooth and shiny. While a rough concrete surface will scatter reflected light and soften the impact of blemishes, a smooth surface will make variations more conspicuous. Most cast-in-place and tilt-up concrete is textured for this reason. A variety of textured form liners are available and can be used to create attractive architectural effects.

Another alternative is to use mechanical methods such as sandblasting, grinding, or bush hammering to roughen the surface. Discolorations caused by interaction with the form release is typically only "skin deep" and can be removed using these mechanical abrasion techniques (see *Photos 17* and *18*). Removing additional cement provides an exposed aggregate finish, as discussed above. Many attractive surface treatments can be created by combining a colored concrete matrix with select aggregate in complimentary or contrasting hues.

Porous form materials, such as lumber or uncoated plywood, can cause discoloration (see *Photo 19*). They absorb water unevenly, changing the water/cement ratio. Wood sugars can darken the concrete surface by retarding hydration. This discoloration may be desirable when trying to impart a wood texture to concrete but should otherwise be avoided. Similarly, joints in forms must be sealed to prevent leakage. To maintain consistent curing conditions throughout a project, forms should remain in place for a uniform duration.

Curing

Discoloration will occur if curing is not uniform. Concrete that dries too rapidly will be lighter in tone. Many of the curing techniques acceptable for regular concrete will not produce satisfactory results with colored concrete. For example, water spraying and misting can have an adverse effect on the concrete's water/cement ratio. And covering the concrete with plastic membrane sheets will result in discoloration wherever the plastic is wrinkled and water condenses underneath.

A spray-, lambswool-, or roller-applied membrane curing compound specifically designed for colored concrete will achieve the best results. The curing compounds should be applied evenly and as soon after the initial set as the concrete can be walked on without harming the surface. Clear compounds allow the natural color of the concrete to show. Tinted com-

17. Before sandblasting.

18. After sandblasting. A more uniform color was revealed after the cast-in-place wall was fully cured and sandblasted.

19. Variations in the porosity of lumber form work cause uneven absorption of water from the concrete, resulting in uneven color.

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pounds, in colors to match the concrete, augment the color of the concrete and make it more uniform by covering the surface with a very thin, semi-opaque color coating.

Concrete will continue to lighten until it is fully cured. Allow the concrete to cure at least 30 days before inspecting it for color match or appearance (see *Photos 20* and *21*).

Other Sources of Discoloration

Efflorescence occurs when soluble salts in the concrete are carried to the surface where they are deposited by evaporation. Since the powdery efflorescence deposits are white, they are more visible on dark colored concrete than on light, uncolored concrete. To reduce efflorescence, use a low water/cement ratio, design the mix for less permeability, cure the concrete thoroughly, design the structure to prevent water penetration and leaks, and keep deicing salts away from paving that is not fully cured.

Remove efflorescence as soon as practical after it appears using a mild detergent or mild acid cleaner and scrubbing with a nonmetal brush. If removal is delayed, deposits convert to calcium carbonate, which is permanent. Follow the instructions of the cleaner manufacturer and test in a small area to make sure cleaner will not etch or discolor the surface.

Concrete can be stained by spills, contaminated runoff, incompatible types of aggregate, or rusting reinforcing and ties located close to the concrete surface (see *Photo 22*). The Portland Cement Association's (PCA) *Removing Stains and Cleaning Concrete Surfaces* provides guidelines for removing stains.

Quality Control

The beauty of a colored concrete project is often in the eye of the beholder. Readers of this article may conclude that colored concrete is more trouble than it's worth. The truth is quite to the contrary: colored concrete can be specified with as much confidence as any other architectural concrete. The causes of most defects are clearly understood and can readily be avoided by skilled workers. During the past decade, an increasing number of concrete producers and contractors have gained experience with colored concrete. Additionally, color manufacturers are prepared to assist designers in preparing project specifications and matching custom colors.

Architectural concrete, whether colored or not, requires a higher level of care than structural or utility grades of concrete. Designers and specifiers must have realistic expectations about the range of defects that may occur in colored concrete and then clearly specify project requirements. Whenever a project is large enough to justify a full-size mock-up, one should be used to establish the appearance of the concrete work and verify the acceptability of the proposed materials and methods. Allow 30 days for the concrete to cure before inspecting a mock-up.

Visit projects built by local contractors and suppliers, and discuss the benefits and limitations of colored concrete with your client or the building owner. A successful colored concrete project begins with understanding customer expectations and using knowledge of the causes of common concrete problems to avoid them in the first place.

Additional Information

"Color in Architectural Concrete," *Architectural Record,* June 1997.

Concrete Slab Surface Defects: Causes, Prevention, Repair, PCA Publication IS177.

Color and Texture in Architectural Concrete, PCA Publication SP021.

Finishing Concrete Slabs with Color and Texture, PCA Publication PA 124.

Surface Defects in Concrete, a reprint collection from *Concrete Construction,* Aberdeen Group Publication 3910.

20. Before curing.

21. After curing. Concrete lightens as it cures. Most change occurs within 30 days.

22. These stains could have been avoided by diverting runoff from the concrete face.