

The Technology of Concrete  
Floor Coatings:  
A **Durability + Design**  
Collection



### **Introductory Note**

The 5 articles from this collection appeared originally in *The Journal of Architectural Coating's*, the predecessor of the current magazine *Durability + Design*, The Journal of Architectural Coatings.

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## Concrete and coatings: A complex relationship

Challenge of protection and decoration requires attention to the physics and chemistry of the materials



**C**oncrete must certainly rank as the most versatile building material extant. Aside from its solid structural-engineering properties, it can be textured, colored, stained, or coated to achieve a range of aesthetic qualities. But looks can deceive: concrete is not indestructible, and it needs to be protected to retain its appearance and performance properties. Use of the proper treatment or coating technology can provide this protection.

Modern concrete is a mixture of Portland cement, water, fine and coarse aggregate, and, in some cases, various admixtures. When properly formulated and mixed, the cement cures and hardens to a dense solid in the chemical process of cement hydration.

But the matrix of cement and aggregate can deteriorate or otherwise sustain damage. Concrete can be highly porous, allowing water to penetrate; if freezing occurs, the resulting expansion can weaken the concrete from within. Moisture can carry salts into the concrete, causing damage or attacking the steel reinforcing rods embedded in the concrete.

*Passing the Test*  
By Allen Zielnik,  
Atlas Materials Testing  
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### Floor applications put coatings to the test

One of the most demanding service environments for protective concrete coatings is presented in the form of applications to floors. These coating applications can range from industrial settings such as chemical plants or warehouses, to hygienic facilities for food or pharmaceutical processing, to automobile dealer and repair shops, and on to a host of commercial and institutional venues.

Prominent among these highly demanding applications, where appearance and protection both figure prominently in a complex environment, is aircraft maintenance hangar flooring. A review of the performance requirements for this application can serve as an example when considering the special needs of other industrial and commercial environments.

### Concrete characteristics, and implications for coatings

Before addressing coatings for specific applications, it is useful to understand some of the special properties of concrete for flooring as well as desirable floor-coating properties.

The cement ‘glue’ that holds concrete together is made up of alkaline hydrates. This key constituent is responsible for the alkaline nature of concrete and its reactivity to acids. ‘Carbonation’ is a process where the calcium hydroxide in the hydrated Portland cement combines with carbon dioxide in the presence of moisture to form calcium carbonate. Fresh concrete normally exhibits a surface pH in the range of 12 to 12.5. The carbonation process

naturally lowers the pH with time.

Coatings, as a result, must be alkaline compatible, particularly in moist areas, to perform successfully. The pH of the concrete surface should be between 6 and 9 to ensure successful application with most types of coatings, so acid neutralization is sometimes required to prepare the surface.

Concrete is highly porous, allowing water vapor and gases to move freely within the matrix. Coatings, thus, must be characterized by enough porosity, or “breathability,” to allow water vapor to migrate up through the concrete surface and evaporate, while preventing penetration of water in the liquid form. Failure to “breathe” can quickly cause a coating to blister and lose adhesion. Concrete can take years to fully cure, and water not consumed by the hydration reaction (called “waters of convenience”) need to escape and evaporate.

If subjected to freeze/thaw cycles, moisture in concrete will cause internal stresses that can result in damage. If deicing salts are used on the concrete, the freeze/thaw damage can be more severe and show up as surface scaling or flaking. If salt permeates the concrete and reaches the steel reinforcement (rebar), concrete degradation due to expansion of corroded steel can occur.

The wait period before proceeding with application of a coating to new concrete varies, but typically a minimum of three to four weeks is required to allow for early shrinkage and drying; however, certain coatings are formulated for application to wet or “green” concrete surfaces. A variety of measurement techniques can be employed to check concrete moisture levels. Particular attention should be paid to the limitations of surface measurements, as low moisture readings may not reflect the content at greater depth, and the coating could fail.

Applying a suitable penetrating sealer formulated to be compatible with a topcoat may control surface powder or excessive absorbency. Insufficient curing or exposure to carbon dioxide during early hydration can lead to the development of a soft, dusty surface. Coatings-manufacturer directions for application should be followed, as brush, roller, spray, or flood-coat application may be recommended to achieve the proper build and surface penetration.

Concrete must possess and retain adequate tensile strength, or a weak top layer of the concrete can delaminate. Additionally, concrete must be capable of resisting mechanical impact and wear.

During concrete cure, cement and fine aggregate can be carried to the surface, resulting in a thin, weak layer of cement called “laitance.” If not removed prior to coating application, the coating will likely lose adhesion.

Minor surface defects such as pinholes, larger holes (called bugholes), thin cracks, and other defects can form during concrete cure. The coating must be elastic enough to bridge these defects and provide a smooth surface.

### **The delicate balancing act of coatings for concrete**

The chief function of a protective coating is to prevent moisture and oxygen from reaching the substrate. With steel surfaces, a zinc-rich primer is often used to fulfill this function, as the zinc pigments serve in a “sacrificial” role to prevent corrosion of the steel. Coatings for concrete, however, do not employ sacrificial functionality. The coating itself must form a physical barrier between the concrete and the environment, preventing damaging liquids and gases from passing through it and reaching the concrete.

A variety of coating types have been developed for concrete flooring, including epoxies, polyurethanes, and polyesters. Regardless of the chemistry, one of the key parameters is the

ability to allow the passage of water vapor, a property measured as the moisture vapor transmission (MVT) rate. The higher the permeability, however, the lower the resistance to entry into the concrete by liquid water or chemicals from the environment. Therefore, the coating system must possess a balance of ‘breathability’ and ‘impermeability’ for the application to perform successfully.

If the proposed coating is moisture sensitive, as in the case of moisture-cure polyurethanes, a vapor emission survey can be conducted using ASTM D4263, *Indication of Moisture Content of Concrete by the Plastic Sheet Method*. With this method, a relative humidity level of 79% or lower under the sheet after a 72-hour period is required to proceed with the application of flooring or related materials. An alternate procedure that can be used is ASTM F1869, *Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride*.

Aircraft hangar floors are subject to a range of stress not typically encountered in other applications. If selected for application in this type of setting, a coating must be able to resist the effects of the following.

<b>Acids, from batteries</b>	<b>Degreasers</b>
<b>Bases, or caustics</b>	<b>Detergents</b>
<b>Organic solvents</b>	<b>Flammable liquids</b>
<b>Chlorinated solvents</b>	<b>Hot water</b>
<b>Fuels</b>	<b>Tire rubber</b>
<b>Oils</b>	<b>Deicing chemicals and road salt</b>

In addition to chemical contact, mechanical and service stresses can include forklift and tug traffic; pedestrian traffic; vehicular and other wheel traffic; compressive load or impact; thermal cycling, including freeze/thaw; wet conditions; vibrating equipment; dirt abrasion; and full or partial sunlight exposure.

Coatings provide protection by forming a film that prevents damaging substances from working into the pores and capillaries of the concrete. These barrier films are not always completely impervious, and the level of protection provided by new and in-service coatings must be satisfactory. An additional consideration is ease of coating maintenance and, if necessary, repair.

As indicated previously, the primary enemy of concrete is water. Freezing causes microcracks and spalling. Water can carry dissolved salts and carbon dioxide into the concrete, resulting in carbonation. Water can corrode steel reinforcement. Excess water in the concrete can cause the coating to fail by blistering and delaminating.

The effectiveness of a coating in preventing water absorption by concrete can be evaluated by immersion or ponding water tests, or through more sophisticated laboratory tests. One method uses Rilem tubes—small water-filled standpipes affixed to the coating; the drop in the water level in the tubes over time can be used to measure the absorption rate.

The liquid water-barrier effectiveness of a coating is also dependent on film thickness, so it is important to measure the applied coating thickness and ensure that the manufacturer’s specifications have been met. Laboratory tests such as ASTM E96/E96M, *Standard Test Methods for Water Vapor Transmission of Materials*, are useful for comparing coatings under standardized conditions, but field tests conducted on the coating, as applied, are recommended.

In the example of the aircraft hangar mentioned previously, it may be desirable or necessary to test a prospective coating system for resistance to other chemical and physical

stresses unique to an application. For example, to evaluate the effectiveness of a coating as a barrier to dissolved salts, chloride-penetration resistance can be measured in the laboratory using ponding and immersion procedures and a salt solution. The test methodology may also include repeated wet/dry cycles and even exposure to ultraviolet light or solar radiation.

As the visual appearance of a concrete floor can significantly affect architectural and design impressions, it makes sense to evaluate the aesthetics as well as the physical integrity of the coating. Weatherability or color lightfastness tests employing artificial lighting, window-filtered daylight, or direct and indirect sunlight can be used to evaluate color fade, hue shift, and gloss retention. ASTM G151, *Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources*, provides general guidance on a variety of suitable laboratory tests.

### **Different settings, different solutions**

The central concept that must be emphasized with regard to coatings and treatments for concrete is that a wide range of protective and decorative materials can be considered for application to industrial and commercial concrete flooring. The varying substrates, surface conditions, and environmental and service demands make a one-size-fits-all approach impractical. Different coating formulations offer varying degrees of protection for specific problems.

When evaluating coatings, it is critical to first characterize the intended service environment, and then to match the coating to the specific environment. While coating specifications under laboratory conditions provide a useful basis for comparison, it is important to field test the coating application to ensure long-term success and avoid costly failure.

# Water Woes

Moisture content and movement loom large in success or failure of concrete coating and flooring application



*A distribution center concrete floor coated with an epoxy primer and an aliphatic urethane topcoat. Photos courtesy of the author*

Epoxies, urethanes, and other high-performance, chemical-resistant coatings have long been used in light- to heavy-duty industrial settings, including petrochemical, pharmaceutical, food-processing, and power-generating industries. More recently, these coating materials have made inroads into more architecturally oriented settings, such as decorative concrete flooring.

These coatings can be formulated in a wide range of colors and finishes while still maintaining high levels of chemical resistance and durability. As good and as tough as these coatings may be, they are still vulnerable to de-

lamination and, in some cases, blistering. In certain situations, delamination and blistering can arise from moisture vapor pressure differentials across the concrete slab. Another factor responsible for blistering, and to some extent, larger-scale delamination, is osmotic cell development.

This article seeks to introduce architects and designers to the problems of moisture vapor and hydrostatic pressure and their effects on protective and decorative paints and coatings applied to concrete floor slabs.

For the scope of this discussion, examples and narrative will be limited to the effects of direct water vapor and hydrostatic pressure, and will not include the effects of osmotic pressure that may visually appear identical in nature.

There are two types of water-transmission problems associated with failures of slab-on-grade flooring or topping systems:

- Hydrostatic water pressure is the static condition of moisture in a slab;
- Water-vapor pressure is the dynamic condition of moisture in the form of vapor emanating from a slab.

This discussion will explain hydrostatic and water vapor pressures and their adverse effects on coated concrete, identify corrective measures, and describe methods of detecting and measuring moisture in concrete.





A Mercedes dealership showroom concrete floor coated with an epoxy primer and an aliphatic urethane top-coat

The effects of hydrostatic or moisture-vapor pressures on coatings are not usually associated with elevated concrete slabs. Elevated slabs have, however, been involved to a limited extent with problems associated with osmotic blistering.

Architectural concrete classified as decorative must be sealed to protect the decorative finish. In addition to providing a degree of protection, sealers significantly enhance the color of the concrete. Coatings used as sealers for stained, stamped, or integrally colored decorative concrete applications are usually clear acrylics, acrylic copolymers, or clear single-component methyl methacrylates.

The acrylics can be water- or solvent-based, while the methyl methacrylates are solvent-based. The acrylics stand up adequately to typical day-to-day foot traffic, but are relatively weak in chemical resistance compared to methyl methacrylates. The methyl methacrylates are preferred for substrates subject to vehicular traffic, as they are resistant to gasoline and oils, and also exhibit a higher degree of abrasion and scuff resistance. Another advantage for methyl-methacrylates over acrylics is a greater degree of breathability to the passage of moisture vapor, resulting in a lower propensity to blister or delaminate due to trapped moisture vapor.

### The source of the problem

Hydrostatic water pressure is derived from water in the liquid phase.<sup>1,7</sup> It is sometimes known as head pressure (Fig. 1). Hydrostatic pressure is the result of force exerted by a column (head) of water. The pressure is equal to 0.43 psi per linear foot of water height (9.76 kPa per linear meter).

This force is the result of the differential between the highest elevation of a water column and the lowest physical point of a structure. Hydrostatic water-pressure problems are generally associated with below-grade slab or areas subjected to high water tables. Other water liquid-phase pressures and dynamic forces associated with hydrostatic pressure result from capillary pressures developed within the concrete matrix pore spaces and up through the subsoil (Fig. 2), and osmotic pressures developed within the concrete matrix and across the coating membrane to its top surface (Fig. 3).

Water-vapor pressure, or water in a vapor (gaseous) phase, acts and responds in an entirely different way than water in a liquid phase, i.e., hydrostatic water.<sup>1,7</sup> Water vapor has a density only 1/250,000 of water in a liquid phase. Vapor can readily pass through most concrete substrates that have capillary spaces as small as 5 micrometers.

Water-vapor pressure is the combined result of the dynamic effects of ambient environmental

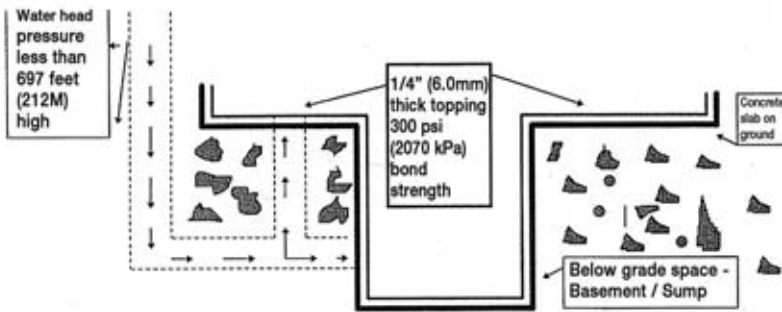


Fig. 1: Hydrostatic pressure as exerted by a column of water. Formula: an arbitrary column height of 700 ft (212 m head x 0.43 psi (2.9 kPa)/ft (m) head = 300 psi (2,070 kPa) head pressure. In this example, the bond strength of the topping exceeds the head pressure of the column of water.

Figures courtesy of Phoenix Engineering Services, Inc.

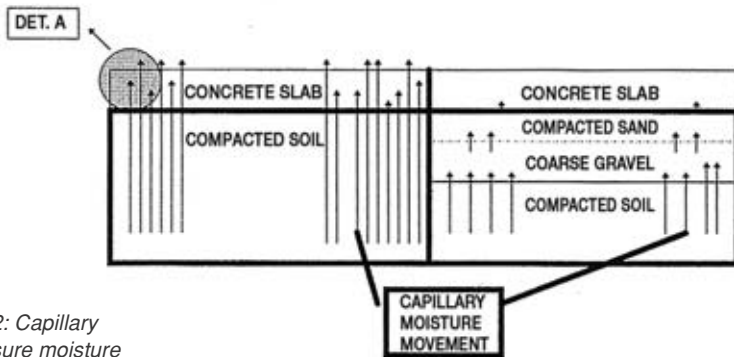
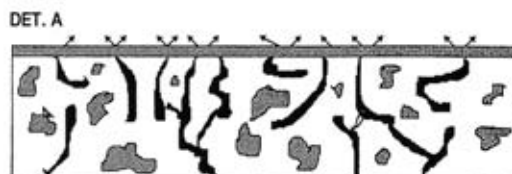


Fig. 2: Capillary pressure moisture transmission. The dark spots represent aggregate.



Exaggerated Pore Structure within the Concrete Matrix

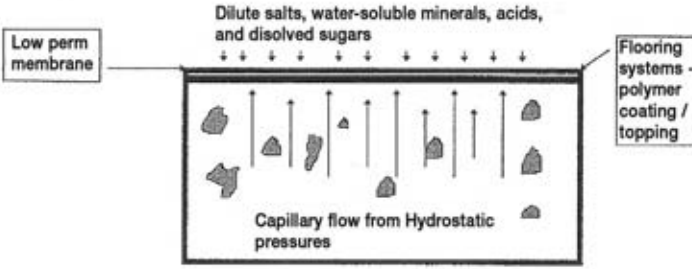


Fig. 3: Osmotic pressure

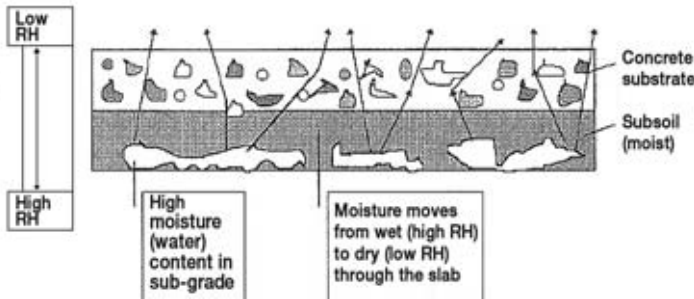


Fig. 4: Moisture vapor transmission (MVT)

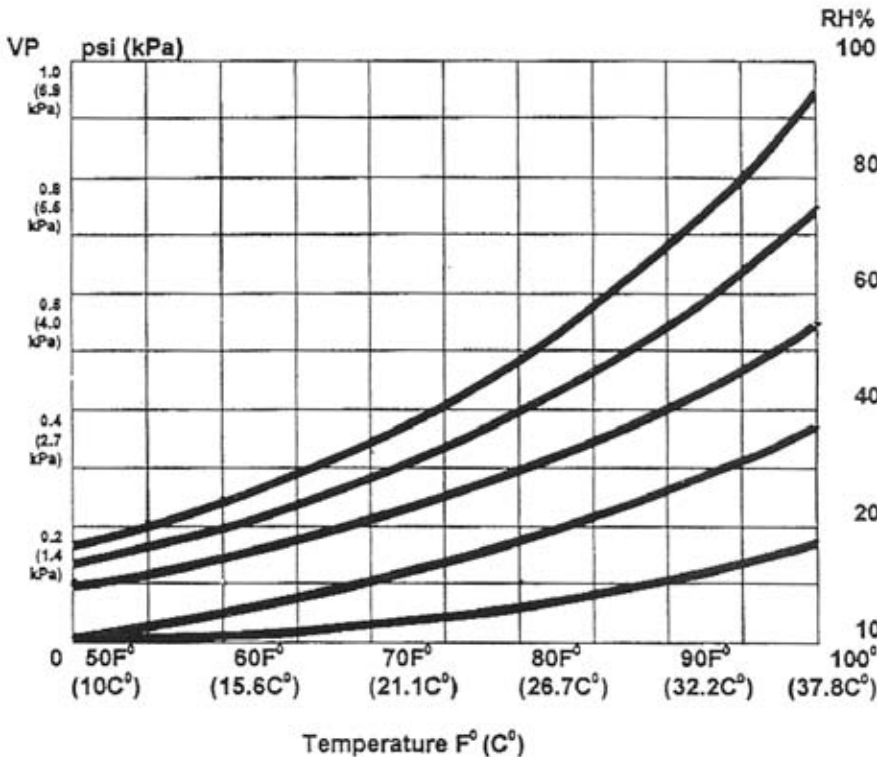


Fig. 5: Moisture vapor pressure (VP) at different temperatures and relative humidity (RH)

parameters—the amount of available liquid-phase water (moisture content) present to become vaporized, the temperature, and the relative humidity.

Water-vapor movement through concrete requires the development of pressure as the driving force, due to a differential in vapor pressure between the above- and below-slab ambient environments, i.e., temperature and humidity (Fig. 4). Vapor-pressure differentials are developed due to differences of relative humidity and temperature above and below the slab (Fig. 5). Water-vapor pressures are related to changes in temperature and relative-humidity differentials.

### Adverse effects

Hydrostatic and water vapor pressures have a variety of detrimental effects on slabs-on-grade, coatings, and flooring systems.<sup>2,4,7</sup>

### Slabs-on-grade

Hydrostatic and water-vapor pressures may transport water-soluble minerals from both the subsoil and the slab concrete towards the slab surface. Concentrations of the minerals at or near the slab’s surface occur when the water/moisture has evaporated, thereby recrystallizing the minerals in place.

Crystallization of minerals is an expansive physical reaction that can exert strong disruptive forces within the concrete matrix, weakening or disintegrating and subsequently breaking up the slab itself. Certain water-soluble mineral deposits on the concrete’s surface can also result in osmotic blistering of the applied coating. Waterproofing prevents water in its liquid phase from entering into and through concrete from hydrostatic pressures.

Moisture-vapor controls are used to prevent water from escaping in its gaseous state and emanating from a slab’s surface.

Coatings and flooring materials Hydrostatic and vapor pressures build up on the negative side of impermeable (non-breathing) membranes, coatings, or other types of flooring materials such as VCT tile or sheet

stock.

Positive and negative sides apply to all membranes with respect to moisture-vapor pressures. The positive side refers to the side where contact from the moisture source is being made. The negative side is opposite the moisture source. Higher pressures are found on the positive side. If the pressures are allowed to accumulate, or are not dissipated or relieved by venting, they may disbond the coating or flooring system from the slab. Bond failure will occur when the hydrostatic or vapor pressures exceed the



*An epoxy coating that blistered was subsequently scraped off, exposing the concrete floor beneath. The surrounding and scattered spots are where blistered caps were removed down to the concrete.*

adhesive bond strength of the coating or flooring system to the parent concrete substrate. Breathable (high-permeance) coatings and flooring systems are far less susceptible to the effects of hydrostatic or vapor pressures than non-breathing coatings or flooring systems. Breathable materials typically exhibit U.S. perm ratings of greater than 3.0 perms. (Perms = grains of moisture per hour per square foot per inches of mercury).

Crosslinked, chemically cured epoxy and urethane coatings and flooring systems typically exhibit very low ratings of 0.15 perms or less. Moisture emission from slab-on-grade concrete is quantified as pounds of water emitted per 1,000 sq ft (90 sq m) per 24-hour period. Mois-

ture emissions are the combined total of moisture from hydrostatic and water-vapor pressures. Moisture emissions as dictated and recommended by industry associations should not exceed 3.0 lbs/1,000 sq ft/24 hrs 0.5 kg/100 sq m/24 hrs).<sup>10</sup>

## Corrective measures and remedial actions

### *Design and construction*

Corrective measures may be taken during the design and construction phases of slab-on-grade concrete.<sup>3,4,7,9</sup> Some easily controlled design and construction parameters and practices used to curtail or eliminate slab-on-grade moisture problems are listed below.

- Gravel capillary break

The use of ¼ to ¾ in. (6 to 10 mm) gravel is effective as a capillary break between the concrete slab bottom and the underlying subsoil. Gravel layers may be 8 to 12 in. (200 to 300 mm) deep. Gravel breaks the up capillary pressures resulting from transmission of liquid-phase moisture from wet or damp subsoil to the concrete itself.

Unlike concrete, coarse sand, fine sand, and fine silt and clay subsoils, gravel completely lacks the interconnected network of microscopic-size pore spaces needed to effectively transport water upward by capillary pressure. Subsoil is an excellent medium for capillary transfer. The moisture content of soils is proportional to the fineness of the soil particles—the finer the soil, the greater the capillary water transfer. Capillary transfer of water through clean, graded gravel is negligible.

- Low-perm vapor barriers

The use of low-perm vapor barriers (sheet materials) under the slab and over the gravel or subsoil layer is effective for controlling hydrostatic and vapor pressure. Commonly used sheet stock vapor-barrier materials are polyethylene (4 to 10 mils

[100 to 250 micrometers]), polyvinyl acetate-reinforced polyethylene (4 to 10 mils [100 to 250 micrometers]), roofing felt (55 lbs [25 kg]), asphalt-impregnated fiberglass, and polymer-modified paper. Reinforced 10-mil- (250-micrometer-) thick polyvinyl acetate sheet seems to offer the best overall physical properties for slab-on-grade moisture control.

Construction damage (punctures), unsealed seams, pipes, and other obstructions can breach the monolithic quality of vapor-barrier sheets and significantly reduce their effectiveness. Some coating and flooring manufacturers offer a “complete systems approach” with integrated seam seals and boots to seal around pipe and conduit slab penetrations.

Empirical testing has shown that the thickness of the membrane sheet has little or no significant impact on its effectiveness. The inherent permeability of the membrane material itself is the determining factor. Thicker films are, however, less likely to puncture or tear.

- Secondary capillary breaks

A secondary capillary break consisting of coarse sand 4 in. (100 mm) deep may prove beneficial when placed on top of the sheet barrier material. This break may prevent the capillary wicking of moisture into the concrete slab where the integrity of the sheet barrier has been compromised. The synergistic combination of capillary-break gravel, vapor-barrier sheet, and secondary capillary-break sand has been proven to afford the highest resistance to moisture and vapor transmission into slabs-on-grade.

- Insulation to reduce condensation The use of insulation under a slab and around its perimeter edge greatly reduces water condensation on the slab surfaces. Insulation materials must not be damaged by contact with water. The insulating properties must be capable of withstanding cyclic wetting and drying, and should be highly resistant to pests, termites, fungus, and mildew.

Condensation is defined as water vapor changing from a gaseous to a liquid state. Condensation occurs when the surface temperature of the slab is equal to or below the dew-point temperature of the ambient air. Insulation aids in keeping the slab’s surface temperature above the ambient dew-point temperature. Insulation will reduce or eliminate the condensation (sweating) or water vapor on the perimeter or underside base of the concrete slab. Water condensation on a base concrete surface will be transmitted into, and through, the concrete primarily by capillary pressure.

- Reduced water-to-cement ratio

Water-to-cement (w/c) ratios in concrete slab-mix design play an important part in controlling moisture problems.<sup>4</sup> Concrete mixes possessing w/c ratios greater than 0.50 require substantially and progressively longer wet curing times to form relatively impermeable cement paste. The longer curing time lengthens the waiting time required before installing low-permeability flooring systems over new (“green”) concrete.

The lower the w/c ratio, the denser and stronger the concrete. The denser the concrete, the higher its resistance to moisture transmitted from hydrostatic and water-vapor pressures. High w/c ratios produce porous, lower-strength concrete. Low w/c ratio concrete slabs reduce the evaporable mixing water (waters of convenience), the curing period, and the moisture permeance of the concrete, as well as provide a stronger mix.

The use of high-range water-reducing agents or “super plasticizers” in the concrete mix greatly aids in achieving low w/c concrete of less than 0.40 while maintaining flowability and slump characteristics.

Pozzolans have also proved very effective. These materials, such as fly ash, silica fume,

and some meta-kaolin clays, can be mixed with water in the presence of Portland cement to form additional high-quality calcium silicate hydrate cement paste. This paste can result in concrete with higher densities, better physical properties, and lower water/gas permeability.

New concrete slabs on grade should be allowed sufficient time to form dense, impermeable cement paste before flooring materials are installed. Usually two or more months are needed for cure before the absolutely safe application of coatings or finished flooring (28-day absolute minimum).

Flooring problems occurring over newly placed, green concrete are most likely the result of the excess water of convenience being not completely used up in the hydration process. Only 0.3 lbs of water is required to completely hydrate 1.0 lbs of Portland cement.

A w/c ratio of 0.57 requires approximately 135 wet-cure days to obtain impermeable cement paste. A w/c ratio of 0.52 requires only 50 wet-cure days. A w/c ratio of 0.45 requires fewer than 14 days. Any additional water is added for the convenience of placement flowability.

Site grading to improve drainage Grading the site to achieve surface water drainage away from the slab will reduce the potential for hydrostatic problems.<sup>3</sup> Site grading should be performed to carry water away from the building's exterior and slab in all directions. Finished grades away from the slab should be a minimum 12-inch (30-centimeter) drop for every 25 ft (7.5 m) in all directions. This is equal to a 4% slope. Finished grades at outside walls should be a minimum of 8 in. (20 centimeters) below the top surface of the slab. Finished grades next to slab-on-grade concrete should also show a 12-inch (30-centimeter) drop for every 25 ft (7.5 m) in all directions, i.e., a 4% slope.

### **Corrective and remedial measures on existing slabs**

Corrective and remedial measures may be required on existing slabs-on-grade after design, construction, and concrete placement. Some common materials and practices are discussed below.

#### ***Liquid silicate penetrants***

Liquid silicate-based penetrants restrict (plug up) capillaries only at the surface of the concrete slab. They are classified as concrete hardeners/dust-proffers.

Penetrants that clog and physically block capillaries are usually based on potassium and sodium silicates. The potassium silicates are applied directly to clean concrete surfaces by means of low-pressure spray.

These proprietary formulas react in-situ with available calcium hydroxide to form insoluble carbonate compounds (calcium silicate hydrate) that fill in and block the concrete's open capillaries. Both potassium and sodium silicates are usually applied at rates of 200 to 250 sq ft/ gal. (4.9 to 6.1 sq mil). The rate depends on the porosity and surface texture of the concrete.

Neither the potassium nor the sodium silicate is effective enough by itself to completely eliminate the higher vapor or hydrostatic pressures sometimes present; however, each has been used effectively in conjunction with other methods. ACI publication 212.3-91 states in part that the use of chemical admixtures such as sodium silicate is "detrimental to concrete strength" and is "not effective or acceptable in controlling moisture migration through slabs on grade."<sup>5</sup> This statement is in reference to its use as an admixture and not as a topical surface treatment.

### ***Surface coatings***

Polymer coating materials for concrete slabs may include various deck paints, epoxies, urethanes, acrylics, and other surface-applied liquid films. Chemically cured and crosslinked materials such as epoxies and some two-part urethanes possess extremely low perm rates compared to higher-perm (higher-breathability) coatings such as waterborne acrylics and some single-component methyl methacrylates. Alkyd and oil-based coatings should be avoided at all costs due to saponification problems on high-alkalinity concrete.

### ***Breathable (high-perm) coatings***

Coatings with high perm ratings of 3 or more exhibit the ability to “breathe” and allow moisture vapor to pass through, thereby maintaining their bond to the concrete and allowing the release of vapor pressures. While these coatings are “breathable” to moisture in the vapor phase in this fashion, they will not readily allow passage of moisture in the liquid phase. High-perm, breathable coatings are not very good moisture-vapor barriers, however, and are still susceptible to loss of adhesion due to hydrostatic liquid-phase water pressures. One such coating type, methyl methacrylate, is classified as a clear concrete sealer for the protection and sealing of decorative concrete.

The overall effectiveness of surface coatings is highly dependent on their tensile and bond strengths. They must also exhibit resistance to the high pH (12.5–13.5) alkalinity of concrete. Generally speaking, low-perm coatings such as epoxies and two-part aliphatic urethanes should not be used in situations where they must reduce more than 50% of the moisture transmission as quantified and measured by instrumental techniques. Given a general consensus, industry-recognized standard of 3.0 lbs of water/1,000 sq ft/ 24 hrs (1.5 kg/100 sq m/24 hrs) as a maximum amount permitted, a measurement of greater than 6.0 lbs (3.0 kg) would exceed the 50% reduction requirement. The resultant back-pressure development and, in some cases, the increase in surface pH, can lead to disbondment or spalling on the surface of the concrete slab.

Surface coatings should not be used alone to reduce or eliminate moisture transmission through slabs. Applied to concrete slabs, surface coatings are usually used to protect the concrete from its immediate environment, which may include chemical attack and physical damage. Considering the above, surface coatings may become part of the moisture problem rather than a remedy.

### ***Moisture barrier (low-perm) coatings***

For surface-applied coatings to be effective moisture barriers, they must possess the following characteristics:

- Low perm ratings (typically less than 0.50 U.S. perms);
- Resistance to the effects of high pH (alkalinity), including saponification;
- Adhesive bond strengths greater than the combined pressure effects of hydrostatic and vapor pressures; and
- Adequate chemical resistance and physical properties to perform in their intended service environment.

### ***Membrane moisture-dispersion systems***

Membrane moisture-dispersion materials include any surface-applied material that allows for and accommodates moisture-vapor emission absorption, wicking, expansion,

and subsequent evaporation. Two basic systems are presented here.

Cement-based coatings, sometimes modified with acrylic polymers, are cementitious coating materials usually brushed on or applied by broom directly to the cleaned concrete slab surface. Application may be followed by placement of an impervious, low-perm vapor-barrier sheet material, itself followed by another coat of cementitious coating. The incorporation of an acrylic polymer in the cementitious coating increases the physical properties, bond strength, and vapor pressure resistance of the coating.

Fiberglass wicking systems are made with woven strand fiberglass matting impregnated with an acrylic resin binder to create a membrane-like sheet. The fiberglass is capable of transporting moisture through wicking (capillary pressure) from the concrete slab. The moisture is transferred laterally throughout its surface, to be dissipated and evaporated into the ambient air. These systems are effective only for the control of moisture in its vapor phase, and only up to the moisture saturation threshold of the fiberglass membrane itself. The systems are, however, highly effective up to its saturation threshold limit.

### **Detection and measurement of moisture**

This discussion<sup>6,7,8,10</sup> must be prefaced with the warning that contractors planning to install low-permeance (non-breathing) flooring or coating systems to slab-on-grade substrates should perform slab moisture emission tests only when the environmental conditions closely approximate the anticipated in-service conditions. Moisture vapor and hydrostatic pressures are not constants, and are therefore subject to significant change at any time.

The amount of water in a liquid phase within a slab is measured and quantified in percentage factors. Moisture content in slabs is quantified as a direct percentage of the water weight of the concrete.

Water vapor emanating from a slab's surface in its gaseous state is measured and quantified in weight/area/time. Consensus in the flooring industry holds that moisture-vapor emission from slabs on grade should not exceed 3.0 lbs of moisture/sq ft/24 hours (14.7 kg/sq m/ 24 hours).<sup>10</sup> Moisture emission is quantified by the weight of water emanating from 1,000 sq ft (90 sq m) of slab surface over a 24-hour period. Moisture detection and measurement techniques performed as pre- and post-installation testing include the following.

#### ***Measuring methods for moisture content***

Various methods and techniques can be used for the field measurement of moisture in concrete. The methods that measure the actual amount of moisture emitted by the concrete slab are important tools in the coating and sealing of concrete. Some of the more common methods include, but are not limited to, gravimetric testing, radio frequency, electro-conductive (DC resistance) testing, plastic sheet testing (ASTM D 4263), and the calcium chloride test (ASTM F 1869).

In addition, several types of 'moisture meters' can be used, with the most common instruments employing radio-frequency or electro-conductive principals. These meters only measure the amount of static moisture present in the concrete, but not the more important quantification of emitted moisture.

The readings do not provide absolute data, but only relative data. They should be calibrated to a known amount of moisture in the same concrete being measured.

The plastic sheet method—ASTM D 4263—is perhaps the least expensive and easiest to perform. One possible drawback with the plastic-sheet method is that it does not measure the actual amount of moisture being emitted from the concrete slab, but only whether any moisture is being emitted—essentially a go/no-go indicator.

The best and by far the most accurate field method is the calcium chloride method, ASTM F 1869. This method is fairly easy to perform and provides a quite accurate, quantifiable assessment of the actual amount of dynamic moisture vapor emitted by the concrete slab in pounds of moisture over a 1,000 sq. ft. area in a continuous 24-hour period. This method has become the accepted industry standard. Commercial proprietary calcium chloride test kits are available for a nominal cost.

Most other test methods measure only the static moisture in the concrete, but not the amount of moisture emitted.

Regardless of the measurement method employed, it must be utilized in a high enough test frequency with selective placement locations to provide meaningful results. One test kit placed over 1,000 sq. ft. does not provide the complete story. Usually a minimum of three tests over a 1,000 sq. ft. area is adequate.

### References

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# A firm foundation

Industry standards and guidelines set the bar for cleaning, preparation, and test procedures for concrete

*By Charles H. Holl, Dayton Superior Corp.*

**M**ost concrete surfaces will require repair, resurfacing, topping, overlayment, or coating at some point during their service life. The overall success and performance of protective coatings, linings, or patching materials applied to concrete or masonry substrates are highly dependent on the quality of the cleaning and surface preparation performed.

Here, in Part 2 of our review of industry guidelines and standards for cleaning, preparation, and test procedures for concrete, we focus on surface preparation and test methods.

As emphasized previously, referencing and following the appropriate guides and stan-

dards published by recognized industry organizations are strongly recommended, as is following cleaning and surface preparation instructions from the manufacturers of relevant coatings and repair materials. These industry guides and standards are listed on page 41.

## Preparation methods

Chemical stripping is a wet method of surface preparation, generally using alkaline chemicals based on methylene chloride, hydroxide, citrus, and soy to dissolve or soften cured coatings for subsequent mechanical removal. Chemical stripping of coatings and contaminated films from concrete is usually confined to small areas that cannot be prepared more effectively by other means. Chemical stripping requires additional cleaning and surface preparation before applying a coating. It should never be used as the sole cleaning method, because contaminants in the form of the removed material and/or the high-pH stripper chemical itself, are always left behind. To verify that the alkaline chemicals have been neutralized, pH should be tested per ASTM D 4262.

Shot blasting (ASTM D 4259; ASTM D 4258; SSPC SP13/NACE No. 6; and ICRI Guideline No. 03732). Centrifugal shot blasting is a very effective, clean, and dust-free method for removing contamination from hardened films and for texturing horizontal concrete without using water or chemicals. (Note: this is the method most commonly recommended by coatings manufacturers).



*Photo courtesy of Dayton Superior Corp.*

Shot blasting involves impacting the surface with high-velocity steel shot abrasive. The shot-blasting media, available in a range of sizes and shapes, are directed against the concrete from an enclosed, high-velocity, rotating paddle wheel. The abrasive, dust, and contaminants are then removed by a separate dust collector. The cleaned steel shot is then recycled to the blast wheel, where the cycle repeats.

Shot blasting provides a clean, physically sound substrate with a relatively uniform texture, ranging from fine granular to a coarse sandpaper finish. Shot blasting is particularly useful and cost-effective when used on large, unobstructed, horizontal surfaces. Preparing most concrete surfaces using shot blasting generally removes up to a maximum of 3 mm (0.125 in., or 1/8 in.) of the surface per pass.

If only laitance is to be removed, or if the surface is to be prepared for thin (<890 micron [35mil]) coatings, fine-grade steel-shot abrasive should be used. The profile made by this type of equipment can show through thin-film coatings as a track line. Using fine shot and/or fast travel speeds on the machine will produce a light etch, or “brush blast” on the surface, and can minimize the tracking lines. This brush-blast etch or surface profile breaks open the slick concrete surface to facilitate mechanical adhesion of



Photo courtesy of  
Dayton Superior Corp.

coatings, toppings, or overlays.

Although shot blasting is primarily used on horizontal concrete floors, specialized machines can be used for shot blasting vertical surfaces as well.

If a thick-film topping or overlay is to be installed, a much deeper etch must be achieved. This will require the use of coarse steel shot or setting the travel speed of the machine at slow, which will produce a surface that exposes the top of the coarse aggregate in the concrete. In some cases, multiple layers of thin-film materials require the use of angular steel grit. Grit punctures rather than fractures the coating without adversely affecting the substrate. The use of angular steel grit, however, increases the wear and tear on the equipment.

So called “working mixes” consisting of approximately 60% shot and 40% grit will provide an aggressive removal method and reduce the wear factor on equipment, as compared to using 100% angular grit. Care must be taken, however, to avoid contaminating the shot or grit abrasive with oil, grease, and dirt, or exposing it to water. Steel-shot blasting is not very effective for removing rubbery, elastomeric materials and some aliphatic urethane coatings; however, in some situations it can be used for this purpose.

Abrasive blast cleaning, or sand blasting (ASTM D 4259, D 4258, and D4285; SSPC SP13/NACE No. 6; and ICRI Guideline No. 03732). This type of blast cleaning is a method for preparing and texturing concrete surfaces by means of impact with a high-velocity stream of fine mineral-aggregate abrasives propelled by clean, compressed air. The blasting media usually consists of hard, angular mineral aggregates of a size range selected to be most effective. Blast cleaning with this method produces a textured, physically sound substrate that is free of surface contamination and fines.

The actual surface hardness of concrete should determine whether it is best to prepare it by abrasive blast cleaning. Test areas should be treated, using the same equipment, air pressure, hose lengths, nozzle size, and abrasive being considered for the job. Production rates, dusting, and cleaning profiling (roughening) effects should be noted for bidding



Photo courtesy of Dayton Superior Corp.

purposes. Generally, larger abrasive sizes are used for preparing concrete than are used in blasting steel surfaces. Sand abrasives having a diameter of 2,000 to 1,600 microns (8-12 mesh) size are recommended for heavy cleaning. If only the removal of concrete laitance is required, a diameter of 840-350 microns (20-40 mesh) sand gradation is sufficient.

Mineral abrasives should have a sharp angular shape and be at least a 6.5 on the Mohs Mineral Hardness Scale, where talc is a 1.0 and diamonds are a 10.0. Mineral abrasives having a Mohs hardness of less than 6.5 are too soft to clean at high production rates. Softer abrasives also are characterized by a very high breakdown rate, fracturing on impact and creating excessive dust and reduced efficiency.

Abrasives (sands) containing free silica should be avoided, as they can cause the lung disease silicosis. Wet abrasive blast cleaning and equipment may be used when dust abatement is required. Abrasive blast cleaning is not generally effective on rubbery, elastomeric materials, but it does lend itself to both horizontal and vertical concrete surfaces. The compressed air used in the blast cleaning must be

checked to make sure that it is oil free; ASTM D 4285 is the recommended test method to determine this.

Bush hammering (SSPC SP13/NACE No. 6 and ICRI Guideline No. 03732). Bush hammering is an impact method for roughening a concrete surface using a hammer device with a serrated face, with rows of round or pyramidal, hardened steel points. This tool can be used on either vertical or horizontal concrete. Bush hammering produces a much-roughened surface by removing the top layer of concrete; concrete mortar paste and aggregates are also removed. Bush hammering while removing deteriorated concrete can result in fracture damage to the sound concrete below and at the exposed surface. Concrete that has been bush hammered should be checked afterwards for its tensile strength in accordance with ASTM C 1583.

Scarifying (SSPC SP13/NACE No. 6 and ICRI Guideline No. 03732). Scarifying is a method for removing heavy concentrations of deteriorated concrete, surface contamination, or other substances from concrete floors. Scarifiers are heavy machines equipped with hardened-steel cutter wheels vertically aligned and arranged on a large horizontal cylinder that rotates at a high rate of speed. Scarification will remove the concrete surface in closely spaced parallel lines. Up to ½ inch of concrete can be removed in one pass.

High and ultra-high water blasting and jetting, and hydro demolition (ICRI Guideline No. 03732; ASTM D 4259 and SSPC SP13/NACE No. 6 and No. 5). This method employs water that is sprayed at pressures of 35–300 Mpa (5,000–45,000 psi). This method can be used to remove heavy dirt and loose, friable materials, and to remove concrete and some coatings. This preparation method is usually more difficult in practice than abrasive blast

cleaning, producing a more irregular surface profile. Water blasting or jetting, however, may be preferable if it is imperative to avoid airborne sandblasting media, cement particles, and dust.

High-pressure water produces a surface profile of varying degrees, free of all contamination. It is one of the most efficient methods for selectively removing and preparing



Preparation methods such as blasting with water or abrasives play a major role in the success of coating application to concrete surfaces. Photo courtesy of Dayton Superior Corp.

concrete. Hydro-demolition water jetting does not produce the bruised, fractured layer in the concrete work area that other impact methods can create. Consideration must be given, however, to what methods will be used to control and dispose of the spent water.

Power tool methods (ASTM D 4259; SSPC SP13/NACE No. 6). These methods include circular grinding, sanding, and wire brushing, and may be used to remove existing coatings, laitance, weak concrete, fins, and protrusions.

Etching with acid (ASTM D4260; ASTM D4258; SSPC SP13/NACE No. 6 and ICRI Guideline. No.03731). This method is applicable to horizontal concrete floors only. Acid etching works fairly well on non-surface-hardened floors, but is difficult or impossible on vertical surfaces. (Note: This method is *not* recommended by most coatings manufacturers.) Acid etching does roughen the surface, but does not remove laitance or other loose material.

Acid etching often employs a 5-10% solution of muriatic (hydrochloric) acid in clean water. The concrete should be pre-wet, and all oil, grease, paint, sealers, gum, tar, and any other foreign materials must be removed to assure uniform etching of the surface.

Many products containing surfactants are readily available at commercial contractor centers for degreasing the surface of concrete/masonry substrates. Scraping or freezing, then impact scraping can remove gum, tar, and other thick and soft contaminants. After the surface is free of contaminants, one gallon of acid solution is spread on 5 to 7 m<sup>2</sup> (50 to 75 sq. ft.) of concrete and allowed to stand for two to three minutes. The surface should be immediately rinsed with fresh water to avoid the formation of salts. This procedure should be repeated until the concrete exhibits the texture of medium sandpaper. It is advisable, whenever possible, to use a pressure-wash rinse with a minimum pressure of 13,800 KPa (2,000 psi), using a 15° tip for good results.

Pressure washing forces the fines out of the pores in the surface and assures removal of the acid-weakened and etched surface layer of the concrete; thus, pressure washing will greatly reduce the potential for adhesive bond failure of any subsequent coating system. In environments where pressure washing is not possible and rinsing may not be thorough enough, it is advisable to use a neutralizing agent dispersed in water to ensure that the acid has been neutralized. A diluted ammonia solution of 3–5% in water, mixed at a rate of one quart concentrate to five gallons water and flooded over the surface of the concrete will generally be sufficient for neutralizing.

Baking soda can also be used to neutralize acid. Here, the powder is broadcast onto the wet concrete and scrubbed in with a synthetic bristle broom. This is left to dwell for 10 minutes, then flushed completely with clean rinse water. Baking soda is often the preferred method because it eliminates the strong odors associated with ammonia.

After the neutralizing solution is left to soak for about five minutes, the surface is rinsed with clean water. If it is not possible to rinse to drains, all standing water is vacuumed and the rinse is repeated. This procedure must be repeated until no particulate is visible in the rinse water. After rinsing, the surface should be checked with pH paper in accordance with ASTM D 4262 to assure that it has been neutralized. Acid etching should only be used when no other methods of preparation are possible. Again, acid etching is only suitable for horizontal concrete or floor slabs.

Vacuum cleaning/air blast cleaning (ASTM D 4261; ASTM D 4258; ASTM D 4285 & SSPC SP 13/NACE No. 6). Vacuum cleaning or air blow-down with clean, oil-free compressed air is a final cleaning step used to remove loose dust or dirt on a prepared surface immediately before applying a coating or patching material. Vacuum cleaning is preferable to air blow-down when the dispersion of dust must be controlled and limited.



Floor grinders such as the machine shown here are used to remove surface laitance and contaminants, and reduce waviness in concrete floors. Photo courtesy of Blastrac Corp.

### Field testing and inspection

Before, during, and after cleaning and surface preparation, tests and inspections may be conducted, if desired, to help establish the quality and general acceptability of the substrate for the application of coatings. Some of these tests are described as follows.

ASTM C 1583 (Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete), and ACI 503R. This test method, sometimes referred to as the pull-bond or pull-out test, enables the in-situ evaluation of the tensile strength of concrete and/or the adhesive bond strength of applied toppings, mortars, and coatings over concrete. A detailed description of how to conduct the test is provided in ACI 503R, Appendix A.

This field test facilitates the following assessments.

- Evaluation of the in-place bond strength between a repair overlay and the concrete substrate
- Evaluation of the in-place tensile strength of the repair mortar and the concrete itself
- Evaluation of the effect of surface-preparation methods on the tensile strength of the concrete substrate before applying a repair material, overlay, or coating

This test is conducted by epoxy gluing a disc to the prepared concrete testing surface. The disc is then pulled off after a partial core is cut around the disc. The pull-off force is then measured and provided in psi units. General industry consensus holds that pull-off values or tensile strength of the system should be around a 200 psi average. It should be taken into consideration that the tensile strength of concrete usually falls between 8% to 12% of the concrete's compressive strength.

Moisture (determining moisture in concrete by the Plastic Sheet Method ASTM D 4263). Here, a heavy-gauge, 102-micron- (4-mil)-thick plastic sheet approximately 156 cm<sup>2</sup> (18 sq. in.) in size is taped to the concrete surface around its perimeter. The plastic film acts as a moisture barrier and traps moisture migrating through the concrete. If the concrete appears dark, damp, or wet under the sheet, the presence of moisture in the concrete is indicated. If this is the case, additional drying or curing time may be required, and the test procedure can be repeated. Sheets of test film should be placed at various locations throughout the surface area to be coated, particularly in areas that are likely candidates for moisture presence, such as below-grade, low-spot sections, inside corners, and lower-wall areas where "rising damp" may occur. The test film should be completely sealed using approximately 51mm

(2-in.)-wide duct tape and left in place from eight (8) to sixteen (16) hours. A minimum of one test every 46 sq. m, or 500 sq. ft., should be conducted.

Determining pH of chemical rinse water on the concrete surface (ASTM D-4262). With this test, a strip of pH test paper should be dipped in the rinse water and remain on the surface. After the paper changes color, it should immediately be compared with the color chart accompanying the paper to determine acidity or alkalinity. The pH reading of the final rinse water should also be taken. The pH reading from the rinse water on the concrete surface should not be more than 1.0 pH unit lower or 2.0 pH units higher than the fresh rinse water; if it is, the surface should be further neutralized with fresh water and re-tested until the pH is acceptable. Two readings should be taken on random sections of every 50 square meters (about 500 sq. ft.) of concrete, and in corners, along the (wall to floor) interface, and in areas that are difficult to properly flush and rinse. This pH testing is appropriate for gauging the neutrality of concrete that has been acid etched or cleaned with an alkaline detergent.

Oil in air supply (ASTM D 4285). This test method is used to check for the presence of

oil in the compressed-air supply used for abrasive blast cleaning, air blow-down, and coating operations. This method employs a white blotter paper that the compressed air source is directed at for a continuous, one-minute period; the paper is then checked for the presence of oil contamination.

**Oil, grease, and gum.** Oil on the concrete surface may be detected by conducting a water break test. Here, clean, potable water should be lightly sprinkled or sprayed (fine mist) onto the surface. If the water wets and spreads out instead of beading up, the surface may be considered relatively free of oil and grease. Gum may take on the appearance of an oil spot and will cause problems in the form of coating delamination if not properly removed.

**Dust.** Dust or airborne fallout may be detected by wiping the concrete surface with a clean, dry cloth and inspecting the cloth for any contamination. A black cloth works best for showing up dust and fine-particulate dirt. A more critical dust test involves the use of transparent tape, which is applied to the surface, removed, and then visually inspected for dust pick-up.

### **Summing up**

Most concrete surfaces will require repair, resurfacing, topping, overlayment, or coating at some point during their service life. The first steps taken in carrying out these functions is extremely critical. The best, state-of-the-art materials, correctly mixed and applied, can nonetheless be doomed to failure unless the concrete surface is properly cleaned and prepared. Unsound concrete and deleterious surface contaminants must be removed and the surface roughened and properly cleaned.

Many different techniques, methods, and equipment can be used to effectively clean and prepare concrete. With this review, we have covered some of the more common cleaning and preparation techniques and procedures that are designed to ensure successful application and maximize the service life of coatings and patching materials applied to concrete and masonry. Any shortcomings in these critical cleaning and preparation methods will compromise the performance of even the highest-quality coating, topping, or patching system.

### **Referenced documents**

Documents referenced in this article can be obtained from the following organizations.

- The American Society of Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428—tel: 610-832-9500
- American Concrete Institute (ACI), 3800 Country Club Drive, Farmington Hills, MI 48331—tel: 810-848-3700
- International Concrete Repair Institute (ICRI), 1323 Shepard Dr., Suite D, Sterling, VA 20164-4428—tel: 703-450-0116
- National Association of Corrosion Engineers (NACE), P.O. Box 218340, Houston, TX 77218-8340—tel: 713-492-8254
- The Society for Protective Coatings (SSPC), 40 24<sup>th</sup> St., Pittsburgh, PA 15222—tel: 412-281-2331

# Effective formulas for the polymer floor

Performance success is driven by optimum mix of chemistry, composition, and application

*By Robert Cain and Eric Borglum, Key Resin Company*



*(Facing page): An epoxy terrazzo floor at Spring Wood High School, Houston, TX. The terrazzo is composed of 100% solids epoxy resin binder with marble chip aggregate. Photo courtesy of Southern Tile & Terrazzo.*

Over the last 40 years, the protection of concrete floors has evolved from essentially ground zero to a fairly sophisticated process involving some type of protective polymer resin coating or surfacing. The main purpose of installing or applying these types of materials, of course, is to provide protection to the slab from deterioration or contamination, or to provide some added benefit such as aesthetics, wear resistance, non-slip functionality, chemical resistance, ease of maintenance, physical performance, and a myriad of other properties.

Without question, no other surface in a building takes more abuse than floors, regardless of the

type of building—industrial, institutional, or commercial. Concrete floors are inherently porous and tend to generate dust from wear and abuse, and they are subjected to just about every kind of abuse—impact, abrasion, chemical attack, and thermal shock. Concrete floors, without some sort of treatment or coating, are not designed to withstand this continual abuse.

It is for these reasons that virtually all concrete requires some sort of protection, regardless of where the floor is located. The challenge, in the overall picture, is to determine what type of protective material to choose to respond to the given conditions.

This article will focus on fluid-applied polymer resinous floor systems and coatings that are bonded directly to the concrete surface, offer long-term protection, and may or may not add aesthetic value.

## **Decisions, decisions.**

The problem facing most design, building, and facility decision makers—whether they are architects, designers, or facility managers—is to choose the most effective material and application that will result in the best performance and lowest lifecycle cost. It is increasingly clear that these individuals must rely on knowledgeable professionals to assist in the proper selection, application, and maintenance of the floor system. The polymer resin flooring specialist can guide the owner in proper material

selection, application, and long-term performance, thereby reducing the long-term cost of floor maintenance.

Total floor protection should be part of any study or evaluation for new or old concrete floor protection. The thorough process for selecting a resin flooring system, the writing of a detailed specification, and the preparation of detailed application procedures and final acceptance criteria will give the owner a basis for choosing the right system.

A comprehensive selection process should be followed to narrow the search for the right product and application for floor coatings. Remember, the task is not just selection of the material, but a total system in terms of application, total thickness, and aesthetics.

### The material-selection process

#### Surface evaluation

The polymer flooring specialist must be able to provide a complete program from conception to long-term maintenance. The process should include the following:

- Evaluate the existing concrete surface to determine what you are working with. The surface must be structurally sound, clean, and must not be contaminated with any foreign material that could interfere with the bond of a new resin flooring system.
- Is the concrete surface distressed in any way? Are cracks, spalls, or unevenness present? Does the resin flooring system require a level floor or one that slopes to a drain?

Patching, repairing, and leveling are as important as the polymer flooring system and would require a whole separate discussion to address thoroughly. It is important to state, however, that any material used to level, patch, or slope must be compatible with the total flooring system. A cheap, low-performance patching and leveling material can ruin an otherwise excellent polymer floor.

It is also good practice to allow the same contractor that is doing the polymer-floor installation to make any needed repairs to the concrete substrate.

- What type of surface preparation is needed for the area in question? Surface preparation is the most important step in the installation process and is critical to long-term performance of the total system.

Unfortunately, no single “best way” to prepare the surface exists. The resin flooring selection (thin-film coating or thick, aggregate-filled surfacing) will have a bearing on the type of preparation. Or, to put it another way, the required surface prep can dictate the type of system from a thickness standpoint. A thin-film coating requires preparation that will not leave a heavy profile or texture. A heavy profile may require a leveling or fill coat before the thin-film material installation. This could double the estimated material cost.

It is also important to remember that new concrete requires proper preparation, as does an old concrete surface. Curing compounds must be removed, a proper profile or texture achieved, and any surface laitance removed.



*A 100% solids epoxy coating with broadcast colored vinyl chips produced this garage-floor treatment. The surface was sealed with a clear aliphatic urethane. Photo courtesy of Elasto.*



### ***Consideration of performance conditions***

Four major types of abuse will dictate the performance requirements of a polymer resinous flooring system.

- **Chemical exposure.** Severity of exposure and types of chemicals are both important. Resin materials differ widely in chemical-resistance capabilities, making identification of the exposure highly important. Common splash and spills also are far less problematic than constant immersion.
- **Abrasion.** The amount of wear or traffic a surface will be subjected to is an important criterion. The presence of steel-wheeled traffic as opposed to rubber-wheeled traffic must be taken into account. Any surface exposed to steel-wheeled traffic requires special treatment for long-term wear resistance.
- **Impact.** Heavy loads and direct impact require a thicker, aggregate-reinforced resin floor system.

- **Thermal shock.** Temperature fluctuation, or thermal shock, can have a significant impact. Thermal shock caused by steam cleaning of the floor surface may result in a loss of bond due to differential thermal expansion if the polymer floor system is not chosen properly. The coefficient of expansion of most polymer floor systems is much higher than for concrete and must be carefully considered when selecting a material.

Once the degree of severity of the major sources of abuse to the polymer floor is identified, these sources must be ranked in order of importance for the particular project. This will provide a major focus for what is needed in terms of type of material and applied thickness.



*This colorful floor design at Children's Hospital at Fitzsimmons, Aurora, CO, was created using epoxy terrazzo composed of 100% solids epoxy resin binder with marble chip aggregate. Photo courtesy of Hawk-eye Flooring.*

### ***Other selection considerations***

Other considerations are often overlooked when selecting or specifying a polymer floor system. These lesser considerations don't necessarily contribute to the function of the system, but are important in successful installation of a particular system and assurance of owner satisfaction.

- **Aesthetics.** The final appearance of the floor surface is more important than many people perceive it to be. An owner's thinking on how the floor was going to look versus the final appearance is sometimes quite divergent. In the current marketplace, identical performance characteristics can be obtained with a variety of decorative appearances and surface textures.
- **Installation parameters.** In many cases, a flooring project is up against a very tight installation schedule. This places limits on some systems, depending on how long it takes to install a given material. In occupied areas, the odor of some solvent-based systems or the inherent odor of the material itself will limit its use.

Temperature of the surface at the time of installation is critical in selecting a material. Some systems, such as epoxies, are quite temperature sensitive; lower temperatures also can affect cure time greatly.

- **Life expectancy.** Owners want a flooring system that will last forever, and will be guaranteed. In actuality, a given system will require periodic maintenance. Maintenance procedures must be clearly outlined and understood in order to provide a significant life expectancy.



*This coffee-shop floor was transformed with a high-build, 100% solids epoxy coating sealed with a clear aliphatic urethane. Photo courtesy of Key Resin Company.*

- **Economics.** The system's economics must be considered a major factor, perhaps the single most important factor. At times, low-cost systems will prevail at the expense of more durable systems. Generally, all other considerations aside, the old axiom that "you get what you pay for" holds a great deal of validity. Another generally accepted maxim is that the thicker the applied system, the better the performance.

### **Material properties and application procedures**

The primary reason to go through a material-selection process is to make the right call on the proper resin material for the application being planned. It is critically important to review technical data, performance characteristics, and installation procedures for the materials that have survived the elimination process thus far.

The technical data and performance review can be difficult for most architects, engineers, specifiers, and owners because no standard form of data presentation exists. The following discussion, however, identifies differences in technical data and performance based on applied thickness. Various ASTM test methods, Federal Standard test procedures, Corps of Engineers test methods, and other guidelines are used by resin formulators to represent the capabilities of their products. In many cases, the reviewer must compare test method to test method to determine the differences in the reported values. Professional assistance is suggested to completely understand the data. To ensure optimal performance, it is necessary to keep in mind the key service conditions the materials will be subject to.

### **Resin type and thickness**

At this point in the selection process, it's time to settle on the type of resin material, application, and applied thickness.

Polymer resin flooring for concrete can be classified by:

Thickness.

Thin-film: 110 mils

High-build: 10-30 mils

Slurry/broadcast: 40-125 mils

Topping/overlay: 125 mils-1/2 inch plus

Polymer type.

Epoxy, polyurethane, polyester, vinyl ester, acrylic, methyl methacrylate (MMA), or other.

Appearance. Functional, decorative, or both.

Finish. Is a smooth or textured finish preferred?

The selection process can narrow the thickness and the appearance requirements. Consideration of polymer type, however, can prove more difficult and may require professional assistance in reviewing data and comparing performance.

Thousands of formulations exist for polymer resin flooring systems for concrete, and each is different from the next. While epoxies and polyurethanes are the most commonly used polymers, performance and data vary significantly. In a general comparison, however, it can be stated that urethanes are used for thin-film to high-build coatings, and are characterized by excellent abrasion and wear resistance, excellent gloss retention, and good to excellent stain and chemical resistance. Some urethanes also exhibit excellent

elastomeric properties and, due to low permeability, are used extensively where water-proofing capabilities are important.

Urethane resins are also used as binders in urethane cement systems. These materials offer unique performance properties that include excellent resistance to thermal shock, chemical resistance, tolerance to moisture-vapor transmission, and rapid cure. Historically, most urethanes were solvent-based coatings. Regulatory and environmental mandates, however, have made it necessary for manufacturers to reduce VOC (volatile organic compound) content. Many formulators now offer ultra-high-solids and water-based urethane resins that are VOC compliant in all states.

Epoxy formulations used in resin floor systems typically are 100% nonvolatile (no solvent), and are characterized by excellent adhesion, good to excellent chemical and abrasion resistance, and excellent mechanical properties. Applications include bonding adhesives, crack repair, concrete coatings, aggregate-filled toppings, and overlays.

Specialized epoxy formulations are used as flexible crack-isolation membranes and moisture-vapor control primers, among other applications.

MMA—methyl methacrylate—is a unique type of acrylic resin that is 100% reactive (no VOC). MMA resin is characterized by very rapid cure (typically one hour for full cure), and offer cold-temperature cure (down to minus 20 F), UV resistance, and good chemical resistance. These resin floor systems are used in food plants, sports stadiums, freezers, or projects where very limited time is allowed for the installation and curing. In spite of the 100% reactive nature of MMA, however, it generates a strong odor that requires good ventilation.

Vinyl ester resin systems offer excellent chemical resistance, and are typically used for secondary containment dikes where chemicals are stored and in other severe chemical processing areas such as metal plating where a variety of strong acids may be continuously spilled. Vinyl ester generates a strong odor that requires good ventilation during application.

More detailed comparisons of polymer resin types would require discussion of individual thickness classifications, which goes beyond the scope of this article.

### **Installation and inspection**

Once the polymer floor system has been chosen, the material must be applied and the job inspected and approved. The choice of an appropriate specialty flooring contractor to install the system is just as important as the material used. A contractor trained to install a particular polymer resin floor system (e.g., thin-film coating versus thick overlay) is critical. Once the system and the contractor have been selected, coordination among parties must be maintained to ensure the best performance and user satisfaction.

The job does not end with the application of material. A long-term review, maintenance, and repair program should be established for continued performance and satisfaction. Floor surfaces are punished by continuing wear, abrasion, and impact. Even the most durable surface will show areas of distress that require attention. Still, attention to selection and application details prior to installation will prolong the life of a flooring system. As years go by, the success of the project will depend on the coordination between the flooring specialist and the facilities manager. The payback will be a trouble-free floor at lower cost.

# Creating decorative concrete: Methods and materials

Use of colors, textures, patterns, and other artistry heralds dawning of the age of expressionism in cement

*By Jamie Farny, Portland Cement Association*

Using concrete for enhancing a property's appearance and value has opened the door to a wide variety of new materials and techniques, including integral coloring, staining, coating, and texturing. Concrete is the world's most used construction material and occupies a long and storied place in the history of building and design. But recent developments have helped to give this ancient technology new and original applications and appearances. A general upsurge is taking place in the use of concrete and other ce-

ment-based products for decorative finishes on residential and commercial projects.

This article will examine some of the products that come under the heading of decorative concrete and some of the applications for these products. In addition, the article will describe the technology behind these decorative methods and why some methods are more suited to certain applications. Particular attention is given to the use of integral coloring, stains, paints and coatings, and other applied technologies.

## **The concrete canvas spans broad realm**

Known for its durability and low maintenance, concrete also is gaining repute for its aesthetic versatility in applications involving flatwork and walls. It can be cast on-site or assembled from items pre-cast in a factory-like facility.



*Powdered pigments are available in a wide range of colors.*

## **Flatwork**

Flatwork was one of the first areas of concrete in which people began to experiment with decorative techniques. Imprints of cans, leaves, and scored patterns represented the first "baby steps" of experimenting with patterns. The use of colors followed. Then came metal tools designed for stamping, which eventually led to rollers (for repeating patterns) and rubberized mats.

From very basic shapes available on the earliest stamps to today's ultra-realistic mimicking of natural stones such as slate, pavement imprinting has grown into an art form.

Interior floors constitute an exciting creative area for concrete contractors, owners, and artists. Protected from weathering, interior concrete floors are not restricted by limitation on textural treatments. For instance, rock-salt finishes produce small holes in the concrete and add visual interest, but this type of finish is not recommended for areas that will undergo freezing and thawing when the concrete is wet.

Concrete floors have long been a workhorse in warehouses (burnished floors), but quite recently, concrete has come into fashion in malls, restaurants, and retail spaces.



*A series of form liners on one wall panel shows various textures that can be further enhanced with colors.*

Homeowners are starting to embrace polished and waxed colored surfaces for their architectural appeal—from sleek contemporary appearances to old-world rustic charm. Architectural variety is easy to achieve, and designers can make an entire surface a single color or multiple colors in intricate patterns.

In cold climates, combining concrete with radiant heating makes for homes that are ultra-clean and comfortable. The floors become radiators, warming more efficiently than forced air and reducing dust recirculation.

Coloring concrete slabs will be reviewed in detail further along in this discussion. Methods range from the incorporation of integral mineral pigments, to chemical stains that react with the cement matrix, to pigmented tints or dyes that carry finely dispersed pigments and deposit them on the surface. Colored waxes enhance the surface color and appearance. Paint offers another option.

Concrete pavers, often tinted with integral pigments, give the impression of bricks. To create pastels, vibrant colors, and bright white, pavers

can be produced with white portland cement and white aggregates. They are great for high-traffic public areas, can be used to delineate crosswalks, and are easy to install. They do not require concrete finishing skills.

### **Walls**

Walls represent another opportunity for using concrete decoratively. For buildings, precast panels have been in use for several decades. Both the Portland Cement Association ([www.cement.org](http://www.cement.org)) and the Precast/Prestressed Concrete Institute ([www.pci.org](http://www.pci.org)) offer documents that detail placing, finishes, and panel construction.

Exposed aggregate panels are one of the most common finishes for walls. Aggregate to be exposed in the panels is selected on the basis of appearance. Rather than relying on pigments for color, the paste is removed from panel surfaces to let the beauty of the aggregates show through.

SRWs, or segmental retaining walls, are formed from concrete units stacked together. Like pavers, they are concrete products, often contain pigments for coloring, can be textured for different finishes, and are made in various sizes.

### Other applications

Two interesting categories of decorative applications are tilt-up walls and concrete countertops. Tilt-up is a cast-on-site precast slab [??], using the floor or a dedicated casting bed to construct slabs that will be hoisted by a crane for assembly as walls of the building. Countertops made of concrete have found a home in retail establishments and residences, gracing cabinet tops with “stone” of the intended shape, size, color, and finish.

The following grid presents several of the applications for decorative concrete as they relate to flatwork and walls, and whether they are cast-in-place or precast.

**Table 1: Roofing Material Radiative Properties**

	Cast-in-place	Precast
Flatwork	<ul style="list-style-type: none"> <li>Exterior pavements (walks, driveways, patios, pool and spa surrounds)</li> <li>Intersections</li> <li>Interior floors</li> </ul>	<ul style="list-style-type: none"> <li>Paver plazas and walkways</li> </ul>
Walls	<ul style="list-style-type: none"> <li>Form liner surfaces</li> <li>Stucco finishes</li> </ul>	<ul style="list-style-type: none"> <li>Precast panels for buildings</li> <li>Precast panels for barrier walls</li> <li>Segmental retaining walls (SRWs)</li> </ul>

### Coloring and texturing technology

Concrete is a combination of portland cement, sand, stone or gravel, and water. In effect, it is a man-made stone that hardens due to a chemical reaction of cement and water. The paste of cement and water surrounds and bonds aggregate into a mass. The chemical nature of the paste affects how concrete accepts color, either in the fresh or hardened concrete.

Decorative techniques include coloring, texturing, and combinations of two or more techniques. The concrete is simply a starting point. Certain finishes are not recommended in freeze-thaw climates for durability reasons. Smooth finishes are not recommended for slabs where slip resistance is required.

### Mineral Pigments for Colored Concrete Finishes

Color desired	Materials to use
White	White portland cement, white sand
Black	Iron oxide
Brown	Burnt umber or brown oxide of iron (yellow oxide of iron will modify color)
Buff	Yellow ocher, yellow oxide of iron
Gray	Normal portland cement
Green	Chromium oxide
Blue	Cobalt oxide
Pink	Red oxide of iron (small amount)
Rose	Red oxide of iron
Cream	Yellow oxide of iron

### Integral coloring

Originally, pigments were mineral oxides of iron derived from natural deposits that were then purified. Unfortunately, these were not always the purest or strongest coloring agents. Instead, pigment manufacturers “cook” iron in various chemical baths to collect a precipitate.

These colorants are produced in many earth tones, ranging from buffs and yellows to reds, browns, and black. Greens and blues are also offered. ASTM C 979, Specification for Pigments for Integrally Colored Concrete, is the specification that covers these pigments. Pure white finishes are also possible; these employ no pigment, but rather, white portland cement and white aggregates.

Color is integral when pigments are mixed throughout the fresh concrete. To save money on materials, a two-course method can be used for slabs on ground or for precast panels by using color only in the outer layer of concrete. Here, color is not integral. Another option is to use a proprietary dry-shake material. Here, a colored powder is spread over the surface of fresh concrete and “floated in” as part of the finishing process. While this helps harden the surface and make it more resistant to abrasion, it is a surface-only coloring. If the concrete becomes damaged, the color of the underlying concrete can be exposed.



*Finished example of a sandblasted stencil pattern*



*Stains were used to create this main floor and its border.*

### **Stains**

Stains provide another option for coloring concrete. These materials have a long history of use on concrete, and were quite popular in the early 1900s. The basic types are chemically reactive stains and water or solvent-based dyes and tints. Several applications may be required to get the desired effect, especially on coarse-textured surfaces.

Chemical stains are water-based acidic solutions. They contain metallic salts that react with calcium hydroxide in the cement paste to produce insoluble colored compounds of blue-green, black, brown, or gold. Stains typically only have to penetrate about 1/32 inch to 1/8 inch to achieve the desired effect. Stains react with concrete with a degree of variation, and can result in a non-uniform effect. To some observers, that adds to the natural appearance of stains. In fact, it can be difficult to get a uniform color with stains (or dyes for that matter), so if a uniform appearance is the desired effect, it is worthwhile to consider another coloring method.

Stains can be used on old or new concrete. The inorganic stains are most effective on relatively new concrete because they react chemically with lime, which is liberated by cement hydration. Surfaces should be dry and clean and free of contaminants such as oil, grease, paint, curing compounds, and wax.

Concrete is typically prepared for stain application by washing with water, followed by a muriatic acid (10% solution) wash to etch the surface layer and open up

the pores. Some stains are formulated with the acid wash in the first coat, so following manufacturer instructions is important. Proper safety precautions should always be followed, particularly when working with acids or other strong chemicals.

Stains also react with calcium-based aggregates such as limestone. Stains should be avoided with lean concrete mixtures (low cement contents). Prior to staining, concrete should age at least 14 days; blue, green, and gold colors require 30 to 60 days of curing.

### **Dyes, tints, and waxes**

Dyes and tints do not react chemically with concrete. They often produce colors that are not available in chemically reactive stains, namely the reds and yellows. They help intensify colors when used in successive applications, or can soften or “even out” the appearance of slabs that have been chemically stained. They are water- or solvent-based materials, and must be applied to concrete that accepts penetration of materials. The slab should be treated with a degreaser and a mineral acid solution to reach a surface pH of about 7 or 8 before dyes and tints are applied.

To protect the color, concrete needs to be treated with a sealer following application of these materials.

Some manufacturers formulate waxes to work with many of the colored concrete finishes. The best results are generally obtained when products from one company are used, because they represent a system known to be compatible. Waxes may be color-matched to the stain to heighten or increase the sharpness of the slab's color. They not only improve concrete appearance, but help a colored slab retain its appearance. After stain has dried for at least 24 hours, a wax can be applied. The wax is allowed to dry, typically 30 to 45 minutes, then is buffed to a nice finish. A second coat of wax will increase the surface gloss.

Waxed finishes require maintenance. Periodic reapplication is necessary. Care should be taken not to create too much build-up, however, as that could lead to a more slippery surface and the tracking of wax onto adjoining surfaces. With both the application and maintenance of waxes, it is important to follow the manufacturer's instructions.

### ***Paints and coatings***

Paints and coatings for concrete represent a broad category of products. In general, even though formulations are many and varied, paints can be defined as pigmented coatings that form opaque films. Paint mixtures contain minute, solid particles of pigment suspended in a liquid that is referred to as a vehicle. Paints come in every imaginable color, with the pigment providing color and hiding of the substrate, or surface beneath the paint.

The paint vehicle includes a solvent to give the material the desired consistency for application, and a binder to bond the pigment particles into a cohesive film during drying and hardening. Some paints dry and harden by evaporation of the solvent, some by oxidation. Other types involve chemical reactions as well as evaporation of the solvent.

Some paints "breathe," meaning they are characterized by a degree of permeability and allow passage of water vapor. These types include portland cement-based paints and latexes. Other paints are water-vapor impermeable or non-breathing.

Impermeable paints should be applied to the side of a wall where moisture enters, while permeable paints should be applied to the side where moisture exits. If the surface from which moisture is attempting to leave is coated with an impermeable paint, blistering will occur and the paint will peel. Rubber-based paints are nonbreathing and are good for wet or humid locations or areas that are frequently washed. Other nonbreathing formulations, like the oil-based paints and oil-alkyd paints, are affected by alkali content, and therefore, are not generally recommended for concrete surfaces.

While paints are used on both horizontal and vertical surfaces, some are not well suited to areas where foot or tire traffic will occur. As a surface-applied material, they do not become part of the cement matrix and might be a source of future maintenance needs, unlike some other coloring methods.

Varnish- and rubber-based paints are also used on floors. Varnish bases require dry, aged floors not subject to dampness, although rubber bases can be used where the concrete is damp. Other coatings that are well suited for floor application are epoxy-based materials. These floor coatings may also contain aggregates for slip resistance.



*Dry-shake coloring compound is broadcast onto the surface by hand.*



As a general rule, concrete should be cured first and allowed to air dry for anywhere from 28 days to 6 months before paint is applied. One exception is portland cement paints, which may be applied after the concrete has aged three weeks.

### **Textures**

Concrete textures can be what the artist or contractor makes them. Finishes that look as smooth as polished marble can be created. Terrazzo, one highly familiar material of this type, consists of polished concrete. Terrazzo is designed for use on high traffic floors, such as office lobbies and airports. It is used mostly indoors because the finish is very smooth and might pose a slip hazard if used outdoors.

Portland cement-based terrazzos normally contain white portland cement and decorative aggregates. In some cases, pigment is used to color the matrix. As a result, terrazzo can be crafted in any color, with either complementary or contrasting tones positioned between the matrix and aggregates.

When installing terrazzo, thin steel strips are laid as joints to create appropriately sized panels. The fresh concrete is deposited into the forms and struck off, finished, and then cured. Afterwards, it is polished to a smooth finish using planetary grinders, first with coarse grit pads, then progressing to finer pads.

Terrazzos are easy to maintain. They should be waxed periodically to provide a protective and attractive finish, and cleaned regularly to remove surface debris that otherwise might wear away the wax and even abrade the surface.

Terrazzos are also offered in epoxy-based versions, but these are not addressed within the scope of this article. These products are supplied in an excellent range of color choices, but may pose concerns during installation due to strong chemical odors. In service, these materials can bubble if not properly adhered to the base.

Exposed aggregate finishes range from very fine textures all the way to large cobbles approaching 8 inches in diameter. The smaller and medium-sized aggregates work well for both horizontal and vertical applications. Pattern-stamping tools imitate slate, cobblestone, brick, repeating decorative patterns, or even wood. Sandblasting or grit blasting are effective ways to add decorative touches, especially in border patterns. Stencils are placed on the surface before blasting to impart the pattern.

Timing of the texturing depends on the technique employed. For exposed aggregate, the work involves freshly placed concrete. Concrete surface retarders delay the setting of the surface paste so that the underlying concrete can stiffen and bond the aggregates with the base concrete. The surface is then washed to expose the colored aggregate, typically within a few hours after concrete placement.

Burnishing is done on fresh concrete by passing over it repeatedly with a trowel during finishing. Polishing also produces a smooth, glossy surface, but finishing is done by repeatedly sanding the hardened concrete with progressively finer grit abrasives. Sandblasting is also done on hardened concrete, but generally at an early age before it has gained too much strength. This allows the surface paste to be removed without as much work. Other tooling methods, primarily for vertical surfaces, were more common in the past but have become less frequently used as a result of higher labor costs and the availability of numerous form-liner options.

Form liners are a counterpart to pattern stamping, except that walls are the surface being finished. Here, too, the concrete can take on just about any appearance. Fractured fins were a popular pattern for quite a long time, but an endless variety of fin-



*Dark green, white, and pink aggregates are combined to create a granite-like appearance on this exposed aggregate panel.*

ishes exists currently.

Some form-liner patterns can be colored to heighten the realistic appearance of the concrete, such as the impression of a stacked-rock wall by means of staining in various colors. Form liners are made from different grades of plastic and can serve as single- or multiple-use tools; some are practically indestructible.

### **Decorative concrete: Limitless possibilities**

Concrete is a versatile design medium. It is a well known product, is long-lasting, and is only now beginning to come into its own in terms of decorative possibilities. Many materials and techniques can be used alone or in combination with others to create interest-ing and attractive finishes. This article has sought to provide an introduction to these materials and methods. The following references and Web sites are provided for further reading.

### **References**

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4. Panarese, W.C., Kosmatka, S.H., and Randall, F.A. Jr., Concrete Masonry Handbook for Architects, Engineers, Builders, 5th ed., EB008, Portland Cement Association, Skokie, Illinois, 1991, 64 pages.

### **Links**

<http://www.nrmca.org> / National Ready Mixed Concrete Association  
<http://www.aci-int.org> / American Concrete Institute  
<http://www.ntrma.com> / Roof Tile Institute  
<http://www.ascconline.org> / Newsite / decorative.htm / ASCC/DCC  
<http://www.archprecast.org> / Architectural Precast Association  
<http://www.bca.org.uk> / British Cement Association  
<http://www.caststone.org> / Cast Stone Institute  
<http://www.csinet.org> / Construction Specifications Institute  
<http://www.decorative-concrete.net> / Decorative Concrete Network  
<http://www.icpi.org> / Interlocking Concrete Paving Institute  
<http://www.ncma.org> / National Concrete Masonry Association  
<http://www.precast.org> / National Precast Concrete Association  
<http://www.nspi.org> / National Spa and Pool Insitute  
<http://www.ntma.com> / National Terrazzo & Mosaic Association Inc.  
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<http://www.tilt-up.org> / Tilt-Up Concrete Association