

# Coating Selection and Important Properties of Coatings for Concrete

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**T**his article discusses the reasons concrete is coated and addresses important properties to consider when selecting coatings to meet varying exposure conditions.

## Reasons for Coating Concrete

Some reasons for coating concrete are unique to the structures in question while other reasons apply to coating any substructure. The major reasons for coating concrete include

- enhancing appearance with respect to colour, gloss, or texture for architectural purposes;
- reducing moisture permeability, which can otherwise lead to freeze-thaw damage, rebar corrosion, or other detrimental effects;
- controlling dusting related to routine traffic exposure by applying penetrating sealers;
- providing slip resistance, often in addition to other properties;
- achieving a hard, smooth, glossy surface that is easily cleaned and disinfected;
- improving the effectiveness of available lighting with light-reflective pigments;
- dissipating static electricity with coatings that contain conductive fillers, such as carbon, to the floors in microchip manufacturing facilities, hospital operating suites, medical research buildings, solvent storage handling areas, and aerosol or powder processing/filling plants;
- identifying aiseways that direct traffic flow, define certain areas, or designate the presence of hazards;
- improving thermal resistance with reflective or insulating coatings, provided exposure temperatures do not exceed the thermal resistance of the coatings themselves; and
- protecting the substrate from chemical and physical deterioration.

## Important Coating Properties for Concrete

Concrete is alkaline. Therefore, a coating must be chemically compatible with the alkalinity of the substrate and provide the proper combination of physical, chemical, and thermal properties for the intended service. For example, because underground concrete tanks or structures are often dampened by condensation, moisture tolerance during cure is an important consideration. Coating systems applied over rough concrete substrates must also include fillers/surfacers or linings that are easy to trowel and work into the substrate.

Key coating properties to consider are discussed here with a special emphasis on permeation and on chemical, physical, and thermal resistance because of their particular importance in avoiding coating failures.

### Adhesion

Coatings applied directly to concrete must have good wetting and levelling properties to bond well and provide a sufficient base for subsequent coating applications. Adhesion testing should precede large-scale coating work. Adhesion testing on concrete destroys the concrete (or coating) in the area tested, so it is always recommended to involve the owner in adhesion testing decisions.

### Alkali Resistance

Because concrete surfaces are alkaline, alkyds and other oleoresinous coatings should not be used, or saponification will result. Saponification is a hydrolysis reaction that occurs readily in oil-based coatings when the ester links that bond the fatty acids to the synthetic resins are broken down. The reaction produces alcohol and fatty acid salts called soaps.<sup>1</sup>

Alkali resistance in coatings has become increasingly important because fast-track construction often will not tolerate the 28-day concrete hydration period prior to coating. The 28-day rule is based on the fact that concrete typically

mix designs available today also develop the majority of their strength gain before 28 days.

Whenever a concrete structure, such as a tank, stores water or other liquids, it is strongly recommended that the 28-day hydration period be followed as a minimum before applying the lining. The reasons for this are that heavily reinforced concrete structures provide a great deal of restraint to concrete shrinkage and that such tanks are usually built from concrete with a relatively high cement content to promote early strength gain.

Thus, restrained drying shrinkage cracks associated with water loss may not be manifested in the first 28 days.

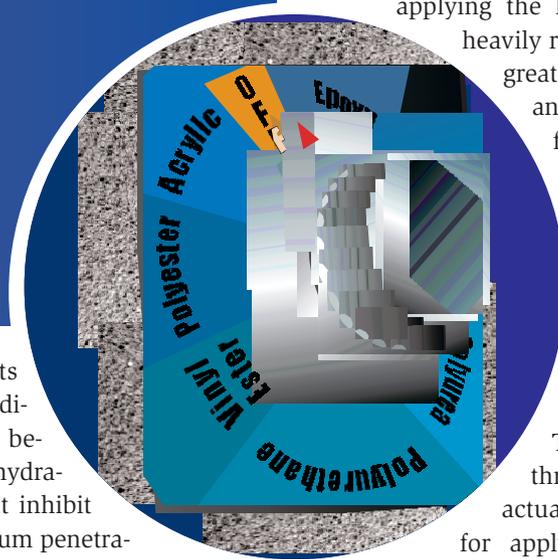
#### Resistance to Permeation

To some extent, moisture passes through all coating films. As such, the actual substrate conditions and the purpose for applying the coating must be weighed against the coating's rate of water vapour transmission (WVT). WVT is defined as "the steady water vapour flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface."<sup>2</sup>

Coatings used to protect concrete against water and aqueous chemical solutions should have a very low WVT rate. This is especially true for immersion-grade coatings or

achieves the majority of its strength during this period. In addition, after 28 days, excess water, beyond that volume necessary for hydration, has evaporated and will not inhibit the coating cure or prevent optimum penetration into the concrete's pores.

In recent years, moisture-tolerant and alkali-resistant acrylic and epoxy formulations have been developed to permit successful concrete coating before 28 days of hydration. This approach requires that the lowest possible water-to-cement ratios be used to minimise excess moisture release while ensuring good concrete placement and consolidation. Many of the low water-to-cement concrete



**Table 1: Physical and Thermal Properties of Various Coatings for Concrete**

Performance Property	Acrylic Emulsion Coating	Polyester	Vinyl Ester	Bis A Epoxy	Bis F Epoxy	Novolac Epoxy	Reactive Acrylic (MMAs)*	Elastomer Polyurethane/Polyurea	Furan
Adhesion	medium	medium	medium	high	high	high	high	low-med	low-med
Alkali Resistance	medium	medium	medium	med-high	med-high	med-high	medium	low-med	low-med
Resistance to Permeation	low	low	low	low-med	medium	med-high	low	low-med	low
Flexibility	medium	low	low	low	low	low	low-med	med-high	low
Coefficient of Thermal Expansion	medium	high (if not filled)	high (if not filled)	med-high	med-high	med-high	medium	high	medium
Chemical Resistance	low	medium	med-high	low-med	med-high	high	low-med	low-med	med-high
Abrasion Resistance	low	med-high	med-high	med-high	med-high	med-high	med-high	med-high	high
Heat Resistance	low	medium	med-high	low	medium	med-high	low-med	medium	high
UV Resistance	high	medium	medium	low	low	low	high	low-high	medium
Moisture Tolerance (during Application)	high	low	low	medium	medium	medium	low	low	low
Cure Shrinkage	medium	high	high	low	low	low	medium	medium	high

\* MMAs = methyl/methacrylate acrylics

**Table 2: Chemical Resistance Properties of Various Coatings for Concrete**

Chemical Resistance	Acrylic Emulsion Coating	Polyester	Vinyl Ester	Bis A Epoxy	Bis F Epoxy	Novolac Epoxy	Reactive Acrylic (MMAs)*	Elastomer Polyurethane/Polyurea	Furan
<b>Inorganic Acids</b>	low	med-high	med-high	low-med	medium	high	low-med	low-med	high
<b>Organic Acids</b>	low	high	high	low-med	medium	high	low-med	low-med	med-high
<b>Alkalis</b>	low	medium	high	med-high	high	high	medium	low-med	med-high
<b>Chlorinated Solvents</b>	low	low-high	med-high	low	medium	medium	low	low-med	high
<b>Oxygenated Solvents</b>	low	low-high	med-high	low-med	medium	med-high	low	low-med	med-high
<b>Hydrocarbon Solvents</b>	low	med-high	med-high	low-med	medium	med-high	low	med-high	high
<b>Salts</b>	medium	high	high	med-high	high	high	med-high	high	high
<b>Water</b>	medium	med-high	med-high	medium	med-high	high	high	med-high	med-high

\* MMAs = methyl/methacrylate acrylics

secondary containment coatings where aggressive chemical exposure is likely. The higher WVTs of exterior coatings, such as acrylics, actually prove advantageous since moisture passes from the concrete through the coating without causing blistering or delamination. This is also true for coatings used on the interior side of buried concrete structures with no “soil-side” waterproofing coating system applied.

ASTM E96, Test Methods for Water-Vapor Transmission of Materials (EN 1062-2), gives one way of evaluating the permeation of coatings. First, WVT is measured in grains per square foot per hour (grams per square metre per second). Permeance is measured from WVT in grains per square foot per hour per inch of mercury (grams per square metre per second per Pascal). One perm is defined as one grain per square foot per hour per inch of mercury, or  $5.72 \times 10^{-8}$  grams per square metre per second per Pascal.

Permeability is the arithmetic product of permeance and coating thickness. In contrast, permeance is a performance evaluation value of a material rather than a property of a coating of a specified thickness. It is defined as “the time rate of water vapor transmission through unit area of flat material induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.”<sup>2</sup>

As an illustration, a glass flake-filled vinyl ester lining 80 mils (2 mm) thick has a permeability value of 0.00015 perm/inch and a permeance of 0.0019 (0.00015 divided by 0.080 = 0.001875; approximately 0.0019 perms). These values show very low permeability and permeance for an immersion lining system. An 18-mil (450- $\mu$ m) thick glass flake-filled epoxy coating has a permeability of 0.0043 perm/inch and a permeance of 0.2389. These are good values for a coating used to protect substrates from intermittent exposure but not for immersion service in aggressive chemical solutions.

ASTM D1653, Standard Test Method for Water Vapor Permeability of Organic Coating Films, is another method

of assessing permeation resistance. To see the differences in WVT properties of coatings used on concrete, consider the following results of ASTM D1653 testing:

1. Acrylic emulsion coatings used on concrete for exterior architectural purposes need to be very breathable. A typical acrylic coating applied in two coats at 5 mils (125  $\mu$ m) of dry film thickness (dft) will exhibit a WVT between 300–350 g/m<sup>2</sup>/24 h and a permeance range of 9.70–10.50.
2. Epoxy polyamide coatings are often used as interior wall protection for aesthetic and ease of cleaning purposes in pharmaceutical or food plants. A polyamide-cured epoxy (bisphenol A) coating applied at 5 mils (125  $\mu$ m) of dft in one coat will have a WVT range of 9.50–10.50 g/m<sup>2</sup>/24 h and permeance value of 0.300–0.350. If the film is of good quality, without voids or holidays, for example, this range of permeability resistance properties is acceptable.
3. Polyester systems filled with silica flour and reinforced with glass mat applied at 100–125 mils (2.5–3.2 mm) of dft have been widely used for tank linings where dilute acids are stored. A system like this will have permeance values in the range of 0.0290–0.00400.
4. Cycloaliphatic amine-cured epoxy coatings can be used to protect concrete from acidic vapours. When applied in two coats at 18–20 mils (450–500  $\mu$ m) of dft, their permeance values are between 0.200 and 0.250.

Provided there are no other exposure condition problems, the permeance values presented here are acceptable and a good check for evaluating the coating system performance in the applications stated.

### Flexibility

Strong, hard coatings (e.g., most conventional epoxies) tend to bond well to concrete surfaces. However, these coatings are generally rigid and crack when the concrete cracks or existing cracks in the substrate move significantly. More flexible coatings, such as elastomeric polyurethanes, resist

impact well and can bridge some crack movement. Generally softer and offering good elongation properties, elastomers are often higher in permeability than other coatings but lower in chemical resistance.

Elastomeric coatings do not always bridge significant crack movement, whether cracks are existing or newly formed. Sometimes new cracks that form in concrete beneath cured elastomeric coatings telescope or transmit through the elastomer because the stresses that develop in the coating are exerted across such an extremely small area. Various methods of treatment are used to prevent or minimize this problem, including reinforcing the elastomeric coating with fiberglass cloth or other fabrics.

Elastomeric coatings will bridge some existing or new crack movement due to deflection, shrinkage, or thermally-induced substrate movement. Such flexibility can be very advantageous in parking garages or elevated floors in wet process environments.

### **Coefficient of Linear Thermal Expansion**

Coatings have a higher coefficient of linear thermal expansion (CLTE) than concrete, which can cause stresses in the coating that lead to a loss of adhesion, cracking, and, eventually, delamination of the coating film. Where concrete surfaces are weak, differences in CLTE may result in cohesive failure in the concrete and coating delamination. This type of failure can be most problematic when and where coated concrete is subject to rapid or cyclic temperature changes. Select a coating material with the lowest possible CLTE when changing or cyclic thermal conditions are expected. Coatings filled with silica sand or other aggregates rather than resin-rich coatings have CLTEs closer to that of concrete.

The CLTE for concrete is approximately  $5-6 \times 10^{-6}/F$  ( $9-11 \times 10^{-6}/C$ ). Heavily filled (silica) epoxy and vinyl ester linings can have CLTEs between  $10.0-11.1 \times 10^{-6}/F$  ( $18-20 \times 10^{-6}/C$ ). These linings work well with a concrete substrate provided there is not too much rapid and extensive thermal cycling in the coated structure. As comparisons, fiberglass-reinforced linings have CLTEs of  $15-16 \times 10^{-6}/F$  ( $27-29 \times 10^{-6}/C$ ) and steel rebar has a CLTE of around  $8 \times 10^{-6}/F$  ( $14 \times 10^{-6}/C$ ).

### **Chemical, Physical, and Thermal Resistance**

Coatings for concrete surfaces in industrial process environments must resist the chemicals to which they will be exposed as well as abrasion, erosion, physical wear, and high or low temperatures (or both).

Understanding and defining the actual exposure conditions—chemical type and concentration, duration and type of exposure (wet or dry), and temperature—are critical in selecting the proper coating and determining concrete's resistance to degradation. For physical resistance, the types of loading, traffic, and physical wear must be well understood.

Elastomeric coatings often provide good impact resistance, but because they are soft, their abrasion or wear resistance may be inadequate. In addition, chemical resistance decreases as elongation and flexibility increase. Harder coatings (epoxies filled with abrasion-resistant aggregates) perform better in many wet abrasive or heavy traffic exposure conditions.

Abrasion resistance and wear resistance vary widely among coatings and are dependant upon their formulations. A few elastomers may be flexible enough to resist abrasive particulates, while more rigid coatings like epoxies and vinyl esters are more resistant to abrasive wear from wet slurries or traffic loading. In general, abrasion resistance is a function of both the hardness properties of the resin used in the cured coating and the abrasion and wear resistance properties of the inert mineral or metallic aggregates used as fillers.

Chemical resistance is affected by a coating's cross-linking density and other factors. Most organic coatings used on concrete (epoxies, polyurethanes, polyesters, and vinyl esters) cure by polymerisation. Coatings polymerise by the chemical cross-linking of a monomer and one or more polymers to produce a resin film. Polymerisation occurs as a chemical reaction at ambient temperatures and when heat is applied to certain types of coatings.

The degree to which chemical cross-linking occurs during polymerisation largely determines the chemical resistance of coating systems. Cross-linking density is evaluated using a functionality numbering system. For example, bisphenol A epoxy resins typically have a functionality of 1.9 and bisphenol F epoxy resins have a functionality of 2.1. Thus, bisphenol F resins resist a wider range of chemicals than bisphenol A resins.

Thermal resistance also increases with functionality. Novolac epoxy resins have a functionality of 2.6-3.5, which means that their in-service temperature resistance is greater than that of bisphenol F epoxy resins. Novolac epoxies are more resistant to most chemical reagents than either bisphenol A or bisphenol F epoxies.

Chemical resistance is equally influenced by the curing agents used. Epoxy resins cured with cycloaliphatic amine curing agents provide much better chemical resistance to acids than epoxy resins cured with aliphatic amine or polyamide curing agents. Certain polyester and vinyl ester coating and lining systems are also highly cross-linked. Therefore, their chemical and thermal resistance properties are typically very good.

### **Ultraviolet Light Resistance and Gloss Retention**

Coatings exposed to exterior weathering must resist ultraviolet (UV) rays of sunlight. UV light degrades epoxies over a fairly short period, exposing pigment and causing chalking. Polyurethanes, polysiloxanes, and acrylic coating formulations have excellent resistance to UV light. UV resistance is

an important aesthetic consideration. It becomes less of a concern when corrosion protection is the primary purpose of the coating. For example, a concrete secondary containment coating system is chosen because of its resistance to stored liquid, not its ability to withstand the effects that UV light may have on its colour or gloss.

In many exterior and interior architectural coating applications for concrete, gloss and colour retention are also key aesthetic considerations. Polyurethane coatings provide excellent UV light resistance and long-term colour and gloss retention, while epoxies offer excellent gloss retention for most interior uses. Epoxies will discolour or yellow indoors; however, they do retain their gloss.

### Coating Systems Defined by Thickness

Currently, there are no industry-wide standard definitions of thin- and thick-film coatings for concrete substrates. For the purpose of this article, a thin-film coating can be defined as one that has a specified dft of up to 20 mils (500  $\mu\text{m}$ ) and is not reinforced, but may have aggregates or other filler materials in it; and is applied by airless or conventional spray or by brush or roller.

A thick-film coating can be defined as one that has a dft greater than 20 mils (500  $\mu\text{m}$ ) and may be heavily filled or reinforced; and can be applied by conventional spray, trowel, specialised plural-component spray equipment, or other non-conventional means.

#### Thin-Film Coatings

Low-viscosity penetrating sealers are used to prevent dusting. Acrylic coatings are used to add colour for aesthetics. Textured acrylic coatings or acrylic elastomers are popular for exteriors, and epoxies or polyurethanes are popular for interiors.

In architectural uses, the presence of some pinholes is not a critical defect. Epoxies, polyesters, polyurethanes, vinyl esters, and other linings are applied over bug hole fillers or surfacers to create a pinhole-free barrier of protection.

Most thin-film coatings are based on organic binders with the exception of some penetrating, often silicon-based, sealers. The organic binders are largely responsible for the coating's properties, including chemical and UV light resistance, substrate penetration, flexibility, and hardness.

Fillers and pigments may constitute up to 50% of the coating weight. Fillers such as silica or calcium carbonate are used to reduce cost and increase film build. Carbon is used to impart electrical conductivity. Pigments are added to create variations in colour, gloss, and texture in both thin- and thick-film coatings.

#### Thick-Film Coatings

Thick-film coatings are used mostly as linings for primary and secondary containment and floor toppings. Low permeability, void filling, and chemical resistance are the most

important properties for linings. For floors, traffic wear, loading, and impact resistance are also key.

Most thick-film coatings are based on thermosetting polymers with cross-linking densities that impart chemical, physical, and permeability properties. The polymer's cross-linking density is determined by the resin type and curing agent or hardener selected.

Fillers, reinforcements, cross-linked polymers, aggregates, and plasticisers that often constitute up to 80% of a thick-film coating can be used to further modify its resistance properties. Silica aggregates are the most common because of their low cost, relative chemical inertness, and availability in a large range of particle sizes. Metallic or carbon fillers are sometimes used to impart conductivity. Other fillers such as aluminium oxide are used to enhance abrasion resistance or other special properties.

Fibreglass, either in the form of hand-laid woven mats, or chopped strands or flakes spray-applied to the wet coating, is another reinforcing material. Other reinforcing materials include carbon fibre and veils to provide conductivity, special chemical resistance, or a thicker, more resin-rich corrosion barrier.

Thick-film coatings may shrink to some extent during solvent evaporation and cross-linking. Shrinkage varies with different formulations from less than 1% to more than 30%. Shrinking promoted by continuous cross-linking or other chemical reactions normally continues during ageing and produces stresses that may result in a loss of adhesion or cracking. Selecting the proper polymer, fillers, and reinforcement, and applying multiple layers of thinner coats can aid in inhibiting shrinkage-related stress problems.

### Conclusion

Coatings for concrete are selected because of their physical and chemical abilities to meet specific needs. This is especially true for those coatings that will come into contact with stored chemicals or other products that may interact with them. A variety of sources is available to assist the specifier in selecting coatings for concrete.

### References

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