Calcareous and Cementitious Substrates—Basic Difficulties in Painting

by Clive H. Hare, *Coating System Design Inc.*

This month we will consider the painting of cementitious and/or calcareous substrates (Table 1). These include concrete mortar, stucco, stone, brick, and tile. Also included are other unitized masonry components that are not necessarily derived from the calcareous cements but, like calcareous substrates, require mortared construction. All such materials share characteristics that can adversely affect protective and decorative coatings. These characteristics are alkalinity; porosity; friability; and a propensity of the substrate to absorb, retain, and sometimes interreact with moisture.

This month, we will examine the above noted characteristics, and their effects on paint system application and performance.

Table I
Calcareous and Cementitious Substrates Definitions

Substrate	
Concrete	Cementitious matrix consisting of a dispersed coarse aggregate (e.g., stone) in a continuous phase of predominantly hydrated calcium silicates.
Mortar	Cementitious matrix consisting of a dispersed fine aggregate (e.g., sand) in a continuous phase of predominantly hydrated calcium silicates.
Concrete Block	An individual building unit prepared from a water-lean concrete mix. Used with mortar in building wall construction.
Cinder Block	A concrete block of lighter weight, produced from an aggregate of cinders or clinkers from well-burnt residues of coal from high-temperature industrial furnaces.
Masonry	A composite of individual building units (e.g., brick or concrete block) bound together with mortar in a regular, formalized pattern.
Brick	An individual, fired clay block building unit used with mortar as a building wall element.
Tile	Individual building unit of fired clay, stone, or concrete used on floors, walls, and roofs. May be finished with a decorative ceramic glaze.
Stone	An individual building element of natural rock (e.g., granite, limestone, marble). Used with or without mortar in wall or floor construction. May be polished, carved, or decoratively shaped.
Asbestos cement board	An asbestos-reinforced cementitious building unit in the form of a flat panel or tile.
Stucco	A cementitious plaster of hydrated calcium silicate, lime, and sand of workable consistency for application by spray or trowel onto the wire-reinforced exteriors of a new or old building as a finish.
Plaster	Coherent interior lining material, produced from a freshly mixed aqueous paste of a partially dehydrated gypsum (calcium sulphate dihydrate), applied by trowel, and allowed to set (rehydrate).
Drywall	Hydrated gypsum plaster core with paper laminate.
Gunnite	A fast-curing, spray-applied cementitious mortar.
Shotcrete	Fast-setting, spray-applied concrete.

Alkalinity

Most calcareous and cementitious substrates are alkaline in nature, at least immediately after placement, when most paint systems are likely to be applied. The alkalinity is usually derived from lime, which may be produced from the formation of the substrate[1,2,3], such as the case with the hydration of tricalcium silicate in concrete and mortar (Equation 1).

$$2\,(3\,CaO{\bullet}SiO_2) + 5.5H_2O \longrightarrow 3\,CaO{\bullet}2SiO_2{\bullet}2.5H_2O + Ca(OH)_2$$

Tricalcium Silicate — Calcium Silicate Hydrate — Calcium Hydroxide

Equation 1

Alternatively, the alkali may be deliberately added to the mix in the form of lime such as is often the case with gypsum plasters[4], or may also be generated from additives such as alum, which is used to extend the working time of plaster

continued

Copyright ©1999, Tecnology Publishing Company

substrates. Soluble salts may be inadvertently introduced through other ingredients (including water and other aggregates). In the presence of lime, the soluble salt (typically a salt of alkalimetal) produces strong alkali metal hydroxides, through a simple inorganic reaction (Equation 2).

$$\underset{\text{Calcium Hydroxide}}{Ca(OH)_2} + \underset{\text{Potassium Sulfate}}{K_2SO_4} \rightarrow \underset{\text{Calcium Sulfate}}{CaSO_4} + \underset{\text{Potassium Hydroxide}}{2KOH}$$

Equation 2

Alkali metal hydroxides such as sodium hydroxide and potassium hydroxide are more aggressive than the alkaline earth hydroxides (e.g., lime). These alkalis have been recognized as the major source of problems with these substrates and alkaline-sensitive paint binders.[5]

In the presence of moisture, alkalis such as these readily attack the ester groups of oil-based coating film binders, breaking the ester linkage and forming a soap. The process is known as alkali-induced hydrolysis, or saponification. The reaction is shown in Fig. 1. The moisture necessary for the reaction is readily available in newly placed substrates, because of the hydration process. As the reaction is completed and the substrate dries, the problem of alkalinity is lessened, although all of these substrates tend to be to some extent porous and may absorb water later in service. Problems with alkalinity thus may recur long after the coatings have been applied.

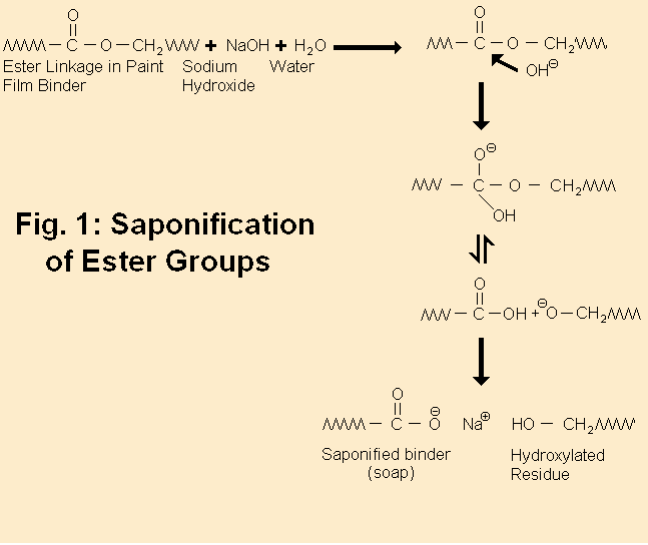


Fig. 1: Saponification of Ester Groups

Fig. 1 - Saponification of ester groups



Fig. 2 - Saponification deterioration (flaking and powdering) of an old oil paint composite on interior plaster subject to moisture.

The extent to which a paint will be attacked by an alkaline substrate will depend on the pH of the substrate, the composition of the paint (especially the type of ester linkages present on the polymer), the age of the paint at the time the film is subjected to wet conditions, and the dwell time of such wet contact. Effects may vary. Flaking and delamination are common when an ester-based paint is applied to green plaster that subsequently dries. When the plaster retains moisture, or humidity remains high, saponification on an alkaline substrate may be so extreme that the film becomes sticky. In this case, the oil film may become soluble in water. On drying, it will crack and lose adhesion. Loss in gloss and a brownish discoloration often occur. When a successfully coated plaster composite becomes moist later in service and is subject to repeated wetting and drying cycles, the coating film may flake or be reduced to a light, fluffy powder that crumbles from the substrate (Fig. 2).

Copyright ©1999, Technology Publishing Company

Oil-based coatings are best not employed directly over any of these substrates, although in the earlier and middle parts of this century, oil-based primer/sealers were widely used. The dangers of saponification were most severe when the films were new and cross-linking was not yet established along the fatty oil chains.

Sensitivity to ester groups varies greatly with the polymer type. Many ester-based systems show better performance than unmodified oils over alkaline surfaces. Flat alkyds were often successfully employed over dry plaster[6,7], as were ester gum and phenolic-based long-oil varnish-based coatings such as TT-P-47, Paint, Oil, Interior, Heavy-Bodied for Thinning, Light Tint and White (combines Sealer, Primer and Finish). The importance of keeping the substrate dry was always emphasized. Still more resistant to saponification are the ester groups on vinyl ester and polyester coatings, frequently recommended today for service over concrete.[8]

Latex paints based on vinyl acetate and acrylics have much greater resistance to alkali. Use of latex paints has reduced the sensitivity and problems of paint systems applied to alkaline surfaces. Primer/sealer coats based on these polymers are today successfully applied to new plaster and then topcoated with alkyds. Alkalinity may also induce color changes when alkali-sensitive pigments are used in coatings applied to "green" (incompletely cured) surfaces or to calcareous substrates, which after painting, become wet. Sensitive pigments include iron blue, which turns brown in the presence of even small amounts of alkali. Many of the lead chromates turn redder in hue. Chrome greens, lithol reds, manganese, barium, and calcium (BON) reds, and certain Hansa yellows are all alkali-sensitive. They will change color if applied directly to alkaline substrates and subjected to moisture.[9]

Porosity

Almost all cementitious surfaces are porous. Only glass, glazed tile, and some other tile and brick surfaces present truly non-porous substrates. Plaster, gypsum drywall, and interior spackle may be excessively absorptive. Concrete is less so, especially when hand-trowelled. Porosity presents many problems as well as some advantages for coating films.

Strong, porous surfaces, for example, present better bases for paint film adhesion than do hard, smooth surfaces, allowing good opportunity for mechanical adhesion. Properly

continued

Copyright ©1999, Tecnology Publishing Company

primed with a penetrating sealer, these surfaces constitute ideal substrates for a coating.

Porous surfaces contaminate easily when foreign liquids drain into the pores, allowing dust, dirt, and solid chemical species to become lodged within the surface pores. Oil contamination may extend for several inches into concrete. Removal of all the contaminated concrete and resurfacing may be required before painting.

Painting excessively porous substrates may itself give rise to difficulties. Fast-drying systems and those having limited flow properties may develop tiny blisters, pinholes, or blowholes within the coating, which generally result from the restricted flow properties of the partially dried film and the release of occluded air from the coating. When applied over porous surfaces, many paint films will lose a portion of their binder to the substrate as the newly applied system partitions. Large particle size resins such as certain latex binders and pigments may themselves be larger than the surface pores and cannot easily enter the porosities. Solutions of higher molecular weight thermoplastics do not easily enter finely porous surfaces because of the size of the binder molecules. In all these cases, the partitioning of binder solution (or dispersion) and pigmentation is difficult. Low molecular weight binders (e.g., oil paints, alkyds, epoxies), however, penetrate the substrate more easily. Latex binders of fine particle size will also penetrate such substrates, although the process is more hindered than it is with higher wetting, lower molecular weight binders.

The wicking of binder solutions into the pores of a surface changes the ratio of pigment volume concentration to critical pigment volume content (PVC/CPVC) of the applied film. Changes in both the aesthetics of the applied system and the performance properties (such as dirt pick-up and washability) often result. Gloss and semi-gloss films applied over such surfaces will tend to exhibit diminished sheen. Flat wall paints, formulated near the CPVC, may undergo even more dramatic changes.[10] Near the PVC, partitioning tends to maximize, and loss of binder may be more appreciable than it is at lower PVC value. If the interstitial binder of the film is substantially depleted, the effect will be to introduce porosities into the film itself.

While the increased porosity of the films may not cause much of an aesthetic problem in white and light tints, it will affect heavier tints and deep tone colors. The increased

continued

Copyright ©1999, Tecnology Publishing Company

voiding of the film surface will tend to result in a whitening effect because of additional light refractions at the increased binder/air interfaces. This lightening may be particularly disquieting where it is nonuniform, a condition favored when the substrate has areas of variable porosity or where film thicknesses vary significantly. Paint films will tend to appear lighter on the more porous areas and darker on the less open areas, thus giving rise to an unsightly patchiness.

The extent of partitioning will also depend upon the length of time the coating stays wet against the substrate. If the air space above the film becomes saturated in solvent, or if high humidity persists during drying of waterborne paints, drying will be delayed. The delay gives the binder more opportunity to partition from the paint to the substrate. Greater voiding and more lightening of color result. When applied directly to porous concrete in exterior environments, coatings suffering a similar shift in PVC/CPVC ratio will tend to weather faster, chalk more easily, and soil more readily than will those applied over non-porous surfaces.

To avoid these effects, primer/sealers are applied to porous substrates such as plaster, drywall, and stucco. These materials are generally large particle-sized latex paints of relatively low PVC/CPVC. Such alkali-resistant latex binders do not readily partition. Their relatively high surface energy reduces the tendency of the system to wet into the substrate too much. This material seals the surface of the porous substrate, normalizing areas of variable absorptivity and creating a more uniform surface for the subsequent adhesion of viable finish coats without gloss loss or color change.

A related phenomenon that may change the gloss and color uniformity of coatings applied to unsealed porous substrates by roller and brush is the effect of binder loss to the substrate on wet edge time. (The wet edge time is the period in which the paint film remains fluid and reworkable as painting in one area touches paint just laid down.) Good wet edge time means that the areas just laid down are still wet when adjacent areas are worked in, and is essential if good flow properties are to be maintained and lap marks are to be avoided. Humectants (glycols added to latex paints) and slow solvents in coatings such as alkyds and epoxies may extend this interval.

Because of excessive loss of binder to porous substrates, this wet edge time may be severely reduced. Poor flow and lap marks, roller pat-

continued

Copyright ©1999, Tecnology Publishing Company

terns, and brush marks may result, marring the job. Brush-applied "cut-in" areas around the peripheries of a wall and around light switches will be more obvious in a general background of spray or rolled wall under these circumstances. Difficulties will be compounded where opacities are marginal or film thickness is low. Sheen effects and differences relating to the manner in which the film orients itself against the substrate and reflects light may be apparent when viewed at low angle, or on long expanses of wall. High temperatures during application and/or air flow across the film may exacerbate these problems by decreasing dry times and wet edge intervals. Sealing the porous substrate with a properly designed primer/sealer before finishing will do much to mitigate all of these effects.

Overly porous exterior surfaces may be troublesome for latex paints applied under cold, humid conditions. Under damp, marginal drying conditions at low temperatures, the evaporation of water will be delayed. The delay causes the coalescent system to leave the film before the water. (The evaporation of the coalescent system is less affected by humidity.)

An elevation of the minimum film formation temperature of the film above the actual temperature of the substrate results. Film formation is thus prevented, and the dry paint assumes a friable, microcracked structure with no cohesion. The phenomenon is exacerbated on porous surfaces such as stucco.[11]

The reasons for such exacerbation are not clearly defined. It may be the result of simultaneous loss of coalescent or plasticizer to the porous substrate. Other theories suggest that the loss of the external (water) phase of the latex paint (into the substrate porosities) has a depressive effect on the mobility of the wet film and reduces the capillary forces within the film. In the normally drying film, the capillary forces bring about latex coalescence.[12] Where water is rapidly removed from the film by absorption before coalescence can begin, films will be non-continuous. The effects are discussed by Wicks.[13]

Friability

Many calcareous surfaces are or may become quite friable and poorly cohesive. Friability may be present throughout the substrate (such as in plaster that is not hydrated properly), or it may be confined to the surface only, as is the case with laitance (box, p. 28) on newly laid concrete. Surface deposits are generally re-

continued

Copyright ©1999, Technology Publishing Company

movable. Sub-surface layers that are strong, cohesive, and suitable for painting may be exposed by adequate preparatory procedures. Acid etching and mechanical scarification including sanding and abrasive blasting are common procedures.

Friable surface layers may be strengthened by applying penetrating sealers with low surface energy properties and low viscosities. Latex and waterborne systems in general should not be used in this way; their surface energy is too high and the latex particle size is too large to absorb into the surface porosities. Oil-based sealers (over non-alkaline surfaces), phenolic varnishes, and epoxies have been used in this way. Their success depends on the strength of the weak layer, its depth, and the depth to which the sealer penetrates. Removal of the surface layer is a safer option.

Substrates exhibiting more general friability can never be painted properly and must be removed. While the paint film will adhere to the surface layers of the substrate, areas of the substrate immediately below the limiting penetration of the film will remain cohesively too fragile to withstand any stress on the coating or the substrate. Lateral cohesive failure within the substrate is in-



Fig. 3 - Deterioration of old plaster beneath a paint composite as a consequence of water ingress to the coated substrate. Paint composite delaminates from crumbling plaster.

Copyright ©1999, Technology Publishing Company

evitable at some depth that the paint film does not penetrate. As the paint film delaminates, friable material from the substrate is clearly seen adhering to the undersurface of the paint. This phenomenon is not a paint failure and should be distinguished from cohesive failure in a sound surface (even glass) that has been coated too heavily. In this case, excessive internal stress build-up on curing of recoating causes the cohesive failure in the substrate.

The Effects of Water

All active calcareous cements and plasters, whether derived from portland cement (such as concrete or mortar) or gypsum (plaster), solidify through hydration of an anhydrous or partially hydrated powder. The quantity of water necessary for such hydration reactions is always far less than the amount of water that must be added to the practical mix for workability. The excess water must be released from the hardening mix after hydration is complete. For the most uniform gel framework and full cohesive strength generation from the mix, the rate at which water is desorbed must be carefully controlled.

A properly proportioned concrete will show considerable loss in strength (as much as a 50% reduction) if, during the early stages of cure, it is allowed to dry out too fast. Increased cure time as well as increased temperature reduces the amount of shrinkage on drying in concrete. Thus, a variety of approaches can be used to prolong some concentration of water within the mix. These approaches range from the continuous application of water to fresh concrete, to treating the wet surface with curing compounds that slow the evaporation of water. Similarly, gypsum plaster surfaces should not be allowed to dry out too rapidly (especially the slower drying anhydrite plasters). Dry out, which is a friable condition in the plaster surface (or in extreme cases, throughout the entire substrate)[14], can never be successfully repainted. It is caused by loss of water before hydration is complete, and results in a surface that is too weak to sustain paint films without cohesive failure. It may also be caused by incomplete rendering of the plaster during final trowelling.

A friable condition somewhat similar to dry out may be also caused by brittle failure in the plaster surface. This failure is caused by stresses from thermosetting coatings that cure on plaster that has already dried. Alkyd systems are among the coatings that may cause these failures.

continued

Copyright ©1999, Technology Publishing Company

In spite of these concerns, it is equally important that calcareous substrates be sufficiently dry before painting. Application of oil and alkyd systems to incompletely dried plaster and concrete will lead to adhesion loss, as is the case over any incompletely dried surface. Additionally, the likelihood of alkali attack in the presence of moisture will intensify the difficulties with ester-based systems.

Care is required even in the premature application of certain alkali-resistant waterborne paints to gypsum plaster.

It is reported[14] that the water tends to reinitiate the setting processes. The plaster surface expands beneath the newly applied paint films, producing stresses that cause surface irregularities and buckling. The phenomenon is known as delayed expansion. Hess[15] recommends allowing new walls and plaster to dry for at least six months before applying non-porous coatings. He recommends drying times of 3 to 12 months for masonry, stucco, and concrete. Modern practice in the U.S. is to reduce substrate drying intervals to 30 days or so before painting them. This figure is also somewhat arbitrary and will depend upon drying conditions, the paint specified, and the substrate. On concrete, epoxy coatings with good alkali resistance and good adhesion adhere to damp surfaces, so they may be applied more quickly. It is sound practice to examine all calcareous and cementitious substrates with a moisture meter to gauge moisture content before painting. Even concrete, which is strong and relatively non-porous compared to plaster and stucco, will allow the transport of water. Water ingress can induce interfacial problems at the paint film interface or behind the interface in the substrate itself.

Where the adhesion of an impermeable paint system is marginal, moisture below the film can induce blistering and delamination, especially in below-grade substrates where hydrostatic pressures may build. Where the adhesion is strong, water may accumulate within the substrate and cause other problems. On plaster and stucco surfaces, entrapped water may soften and destroy the substrate, leading to cohesive loss within the substrate and subsequent delamination of the paint film (Fig. 3). Water entrapped within a concrete substrate may also exacerbate the corrosion of reinforcing steel. Under freeze/thaw cycles, increased volume from ice formation may cause spalling of the stronger substrates.



Fig. 4 - Efflorescence on surface of a porous paint applied to newly laid block. Block was saturated with water from a leaky roof.

Laitance

Laitance is a fine, unbound, dusty layer that is often encountered on the surface of newly laid concrete. It consists of a layer of fine cement particles that are deposited from bleed water that tends to rise from the body of a newly laid mix. It is formed as a consequence of the inability of the solidifying contents of the mix to hold all of the mixing waters as they consolidate. It is neither cohesive nor adhesive to the body of concrete and must be removed before the coatings are applied. Light deposits can be removed through washing and scrubbing prior to wet vacuuming where service will be light-duty. For heavy-duty service or for areas where laitance is more copious, it must be removed by acid etching or mechanical cleaning before coating.

Where the paint film is very permeable to water (such as is the case with latex paints), the moisture below the film may pass through the film and escape to the environment safely. This latter model is itself, however, potentially problematic when the escaping moisture contains soluble salts.

Efflorescence

Soluble inorganic salts, most often derived from manufacturing or handling practices before construction can contaminate all types of cementitious materials. These salts include soluble residues from unwashed aggregates, cement and mixing water contamination, or materials deliberately entrained into the mix such as frost preventatives. Contaminating salts can also come from other sources: cleaning procedures, chemical and environmental exposures,

Copyright ©1999, Technology Publishing Company

chemical accidents and spills, and past uses of the areas involved.

Soluble sulfates (such as sodium sulfate) seem most common, although calcium and magnesium salts are also found frequently. The calcium salts often are the reaction products of lime and atmospheric components. After construction, water may enter a wall, ceiling, or floor; reach the salts; and redissolve them. The salt solution is then drawn to the surface of the substrate, and as the surface dries, the salts are redeposited on the surface as a fluffy white powder or crystalline film (Fig. 4). The phenomenon, known as efflorescence, is common in both painted and unpainted surfaces. On some substrates, such as brick, when the contaminating salts are iron-based, the deposits may be brown. White sulfate salts are equally common and disfiguring on brickwork, and around cracks where water can readily access and egress the substrate (Fig. 5).



Fig. 5 - White efflorescence crystals emanating from crack in concrete.

Although efflorescence is normally removable by washing the affected surface, the salts will often reappear as the surfaces get wet again and the extraction process continues.

Where coatings are present before efflorescence occurs, the effects of the salts will depend upon the type of coating. Salt solutions will penetrate the surface of porous films such as latex paints, and salts will be deposited on top of the film. When the film is impermeable, the salt will be deposited beneath the film and will often crack or dislodge the coating, causing efflorescent destruction of the coating surface and/or its delamination.

When adhesion is very high, the salts may be deposited in the substrate surface, directly beneath the film/substrate interface. The effect (known as cryptofluorescence) may cause crystalline pressure that then disintegrates the substrate itself.[16] In very humid environments, efflorescence may also cause osmotic blistering, especially on denser substrates. Removal of the finish will reveal the white efflorescence beneath the blister after the exposed substrate dries out.

One study[17] has shown that the degree to which the efflorescence disfigures surfaces painted with latex is related to the permeability of the latex film and its electrical conductivity: 100% acrylic latex paints at 35% PVC gave better resistance to surface deposits than did acetoxylated polyethylene and vinyl acrylic copolymer systems. Disfigurement increased as PVC was increased.

Efflorescence may be transferred if one substrate is built upon another. Where plaster is in contact with efflorescing brickwork, for example, mortar patterns originating in the masonry may appear on the plastered wall surfaces even after painting.

Water washes will remove soluble deposits; acids, such as muriatic acid or phosphoric acid, will remove water-insoluble deposits, however, efflorescence will continue as long as the water can access soluble salts beneath the paint film. The only certain way to stop efflorescence is to remove the source of water ingress from the wall. If moisture can be excluded, salt extracts can be eliminated. The surfaces can be dry abraded to remove the existing deposit and then waterproofed or painted with a coating impermeable to rain.

When acid washes are used, thorough rinsing and drying are necessary before the areas can be waterproofed or painted. This approach works only after eliminating the source of water producing the original disfigurement. The biggest problem with efflorescence can be the location of water ingress and its rectification. Expensive engineering remedies may be required. Sometimes, water is found to be ingressing the wall from the roof or guttering, for example. Expensive structural repairs may then be needed. Local build-up of efflorescence may signal other dangers caused by excessive water contamination of the substrate. Disfigurement or efflorescent-induced peeling of the paint work on ground level courses of coated stucco buildings may signal a problem, i.e., potential water-induced cohesive failure of the stucco if the access of water is not eliminated. In this case, water is usually being drawn into the wall from the lack or ineffectiveness of waterproofing in the foundation.

In some cases, the problem may be avoidable by taking precautions during construction. Hoffman[18] reports that the addition of 1 to 2% calcium chloride to gypsum plaster eliminates enough efflorescence to allow painting without the risk of disfigurement. Fiber-reinforced gypsum board is reported[19] to benefit from additions of 0.1% sodium methyl siliconate on the weight of the gypsum, reducing the tendency

Copyright ©1999, Technology Publishing Company

of the board to absorb moisture and, therefore, reducing efflorescence.

Other Stains on Porous Substrates

Other water-based stains may be problematic on porous surfaces, especially interior plaster ceilings of substrates, drywall, and insulative tile. Brown water stains from leaks in roofs, ice dams, burst plumbing lines, or radiators may saturate the substrate after finishing, either penetrating the permeable ceiling paints or cracking and disintegrating more impermeable films. As the affected surface dries out, the soluble iron or tannin extractives (from wood) are deposited upon the surface of the paint producing ugly brown stains, thus showing where the leak occurred. These stains will be readily transferred from one coat to the next if waterborne paints are applied in recoating. They must be sealed before such repainting, but only after the source of water is discovered and rectified. Sealing involves the application of non-waterborne barrier films over the stain. White shellac-based sealers, flat alkyds, and even aluminum paints have all been used successfully. After the stains have been sealed, the entire ceiling can be recoated with a suitable flat latex paint. Where the existing ceiling paint is poorly bound, the coating should be removed before impermeable sealers are applied. Failure to take this step will result in subsequent peeling from a cohesive break in the poorly bound system beneath the newly applied composite.

Conclusion

Next month, we will examine in detail the more common calcareous and cementitious substrates used in industrial structures, discussing specific problems that may apply to each substrate. ❑

References

1. *A.M. Neville,* The Properties of Concrete, Chapter 1 *(London, England: Pitman, 1977).*
2. *W.O. Nutt, "Concrete as a Substrate for Paint,"* JOCCA *(August 1968), 702.*
3. *I. Odler, "The Hydration, Setting and Hardening of Portland Cement," Chapter 6 in* Lea's Chemistry of Cement and Concrete, *ed. P.C. Hewlett, 4th Edition (London, England: Arnold, 1988), p. 241.*
4. *A.P. Mills, "Materials of Construction" Chapter VII in* Gypsum Plaster *(New York, NY: Wiley, 1931), p. 188.*
5. *A.J. Wandersleben, et al., The Cleveland Society, "The Painting of Plaster I,"* Official Digest *(No-*

Copyright ©1999, Technology Publishing Company

vember 1952), 718.
6. *H.F. Payne, "Architectural Paints,"* Organic Coating Technology *(New York, NY: Wiley, 1961), p. 1118f.*
7. *P.H. Walker and E.F. Hickson, #BMS105, Building Materials and Structures Report,* Paint Manual *(Washington, DC: National Bureau of Standards [Now the National Institute for Standards and Technology], U.S. Dept. of Commerce, 1945), p. 42.*
8. SSPC-TU 2/NACE 6G197 Informational Report and Technology Update—Design, Installation, and Maintenance of Coating Systems for Concrete Used in Secondary Containment, *SSPC 97-04. (Pittsburgh, PA: SSPC, 1997).*
9. *H.R. Hamburg and W.M. Morgans,* Hess's Paint Film Defects *(London, England: Chapman & Hall, 1979), p. 197.*
10. *F.B. Steig, "Flat Wall Paint," Chapter 6 in* Treatise on Coatings, *Vol. 4, Part I, Formulations, ed. R.R. Myers and J.S. Long (New York, NY: Marcel Dekker, 1975), p. 343.*
11. *G.P.A. Turner,* Introduction to Paint Chemistry*, 3rd Edition (London, England: Chapman & Hall, 1993), p. 149.*
12. *L.W. Beatty and I. Penbose, "Film Formation," Chapter 21 in* Surface Coatings*, Vol. I, ed. P. Parsons (London, England: Chapman & Hall, 1993), p. 325.*
13. *Z.W. Wicks, "Film Formation," Federation Series on Coatings Technology (Philadelphia, PA: Federation of Societies for Coatings Technology, 1986).*
14. *W.N. Lappen, "Decoration and Protective Coatings for Construction Materials," Chapter 1 in* The Application of Surface Coatings, *Part 4 of Paint Technology Manuals, Oil and Colour Chemists' Association (London, England: Reinhold, 1965), p. 11.*
15. *H.R. Hamburg and W.H. Morgans,* Hess's Paint Film Defects*, 3rd Edition (London, England: Chapman & Hall, 1979), p. 194.*
16. *F. Gale and T. Silva, "Masonry," Chapter 63 in* Paint and Coating Test Manual*, ed. J.V. Koleske (Philadelphia, PA: ASTM, 1995), p. 725.*
17. *M. Coffino, et al. (New York Society), "Studies of the Mechanisms and Control of Efflorescence Through Paint Films,"* Journal of Paint Technology *(November 1969), 615.*
18. *E. Hoffman,* JOCCA*, 45, 1962, 266.*
19. *G.A. King, M.J. Ridge, and G.S. Walker, "Efflorescence on Gypsum Glase Board,"* JOCCA*, (April 1974), 127.*

Copyright ©1999, Technology Publishing Company