

EFFLORESCENCE ON PRECAST CONCRETE

What could be more frustrating? You just know you have done everything right! You used quality materials, had a good mix design, exceeded strength requirements, met production schedule, produced the surface texture that the owner asked for, and yet there it is again ... the telltale white, crystalline, splotchy deposits of efflorescence.

Efflorescence, if not the major problem suffered by the architectural precaster, is definitely one of the most frequent. Often it appears just after the structure is completed — when the architect, owner, and contractor are most concerned with the appearance of the new structure. However, the length of time that elapses before efflorescence occurs may vary greatly; it may appear after only one day, or within a few days of stripping, and sometimes not until weeks, months or (in rare cases) years have passed. Though generally harmless from a structural viewpoint, the initial appearance of efflorescence can be extremely detrimental to the appearance of a finished structure, but should not cause undue concern. Recurrent efflorescence, on the other hand, indicates a chronic moisture problem, and efforts should be taken to prevent and eliminate recurrent efflorescence.

While little attention is given to efflorescence on white or light-colored surfaces, the contrast on darker colored concrete surfaces is obvious and attention getting.

What is Efflorescence

Efflorescence occurs due to the presence of soluble substances in the materials used to produce concrete. The chemical components of efflorescent salts are usually alkali and alkaline earth sulfates and carbonates. The most common salts found in efflorescence are sodium and potassium sulfate; sodium bicarbonate; and calcium carbonate. The sulfates and bicarbonate are readily soluble in water, while calcium carbonate is not.

Water-soluble salts present in concrete materials as

only a few tenths of 1 percent are sufficient to cause efflorescence when leached out and concentrated at some point on the surface. The amount and character of the deposits vary according to the nature of the soluble materials and the atmospheric conditions.

In concrete at early ages, the hydrated cement contains a substantial amount (15 percent by volume of the cement paste) of calcium hydroxide as a normal product of the hydration reaction between cement and water.

Some of the calcium hydroxide that has dissolved in the mixing water migrates to the surface of the fresh concrete. The solubility of the calcium hydroxide increases with decreasing temperature, and the greater the solubility, the greater the likelihood of efflorescence. It is not the water in the concrete which migrates to the surface with the calcium hydroxide; rather, the calcium hydroxide moves through the aqueous solution in the capillary pores of the concrete to the surface, where it reacts with carbon dioxide in the air to form water-insoluble calcium carbonate. which then appears as a whitish deposit (primary efflorescence). Primary efflorescence can only occur if the capillaries are filled to the top with water. Precipitation of the calcium carbonate reduces the calcium hydroxide concentration, thus creating a concentration difference in relation to the interior of the capillary system. New calcium hydroxide is then supplied to the surface. Since calcium hydroxide is much more soluble in water at cold temperatures than at warm temperatures, such deposits are more common in damp winter months.

In a subsequent, slower reaction over a period of one to three years, calcium carbonate can react with additional carbon dioxide and water to form calcium hydrogen carbonate (calcium bicarbonate) which is soluble in water. This type of efflorescence can be partially washed away by rain. The acid constituents of the atmosphere (e.g., sulfur dioxide) can result in transformation of the calcium hydroxide deposits on the concrete surface to calcium sulfate. Efflorescence, therefore, disappears faster in areas with acid rain than in the purer air of a marine or mountain climate. Other causes for the migration of calcium hydroxide to the surface include rain water, which penetrates or comes in contact with the concrete, or water of condensation, which may occur within or on the concrete. Such water is initially free of dissolved calcium ions, but as a result of a concentration gradient, the calcium hydroxide migrates out of the concrete to the water on the surface, where it eventually reacts with carbon dioxide. Such efflorescence, which can occur during the continual curing of hardened concrete, is referred to as **secondary efflorescence**. Secondary efflorescence will not usually occur if the concrete surface has had time to carbonate to any appreciable depth.

No clear distinction can be made between primary and secondary efflorescence, particularly as the transition between the two is not clear-cut.

The identification of efflorescence is sometimes of use. X-ray diffraction analysis, petrographic analysis and chemical analysis are techniques some commercial laboratories use to identify efflorescence deposits. In some instances, it is useful to know both the type of salts present and their relative quantity. For example, very soluble efflorescence salts such as alkali sulfates and bicarbonates indicate possible material problems. Whereas, relatively insoluble efflorescence deposits may indicate problems related to too much moisture movement into the concrete or unfavorable curing conditions.

What Causes Efflorescence

A combination of circumstances causes efflorescence. First, soluble substances must be in one or more of the materials. An abundance of calcium hydroxide is always present in concrete, but the quantity of soluble alkalies will mainly vary depending on the cement source. Second, moisture must be present to dissolve the substances. Third, evaporation, hydrostatic or osmotic pressure must cause the solution to move toward the surface. And fourth, the solution must evaporate to leave these substances behind as efflorescence. If any one of these conditions is eliminated, efflorescence will not occur

The efflorescence tendency of most good quality concrete decreases with increasing age, and this decrease is assisted by rapid drying and carbonation of the surfaces. However, concrete that is constantly or frequently saturated with water can continue to develop efflorescence for years. Many factors affecting the occurrence of efflorescence on concrete surfaces interact with one another. These factors are relative humidity, temperature, and air movement (these affect the rate of surface drying), and permeability and texture of the concrete surface. Some types of efflorescence occur most frequently when temperatures are low and humidity is high since calcium hydroxide has greater solubility at low temperatures. In the North this happens most often in the early spring or fall when there are intermittent rains, and the temperatures are still only in the 30s to 50s. These conditions rarely occur in some Southern regions, consequently these regions rarely, if ever, have any problems with this type of efflorescence.

High evaporation rates always reduce the degree of efflorescence, whereas low evaporation rates need not necessarily result in high efflorescence levels. In the summer, even after long rainy periods, moisture evaporates so quickly that comparatively small amounts of salt are brought to the surface. Usually efflorescence is more common in the fall or early spring when a slower rate of evaporation allows a greater migration of salts or calcium hydroxide to the surface.

Fresh concrete should be imagined as a system riddled with capillaries which are filled with an aqueous solution of the water-soluble components of the cement — mainly calcium hydroxide and alkali sulfates. As the concrete hardens, the calcium hydroxide at the mouth of the capillaries reacts with atmospheric carbon dioxide to form calcium carbonate. Due to the formation of calcium carbonate. the concentration of calcium hydroxide at the mouth of a capillary is lower than inside it. For this reason, calcium hydroxide is continuously diffused from the lower layers of the concrete to the surface. It is always true that visible efflorescence can only occur if the capillaries in the concrete are wet to the very ends. Only then can the calcium hydroxide and alkali salts reach the surface. The capillaries are gradually blocked with calcium carbonate, and the whole process normally comes to a halt. However, if the surface of the concrete is covered with a film of condensation, the calcium hydroxide can spread over the entire surface area and react to form a layer of calcium carbonate which is insoluble in water. In this case, efflorescence will be more severe than when no water film is present on the surface of the concrete and calcium carbonate is only found at the capillary mouths.

Well designed and correctly made concretes contain capillary systems in which water not needed for hydration of the cement paste can make its way by diffusion into the atmosphere. The size of these capillary pores is of decisive importance with regard to the formation of efflorescence; the finer and more elaborately branched the capillary pore system is, the more intensively is the diffusible water held back by capillary forces, and the drier the ambient air must be to induce the water to evaporate from the pores. Also, the smaller the capillary diameter, the more rapidly the outlets of the capillaries at the surface of the concrete are blocked by calcium carbonate from the reaction of the calcium hydroxide with carbon dioxide in the air. As the concrete surface becomes more dense and less permeable, the further formation of efflorescence is stopped.

If the capillary pores in hardened concrete could be limited to a minimum, it would be a step forward in dealing with the efflorescence problem. When good quality concrete is thoroughly hydrated, its pore structure changes, and its permeability decreases dramatically, so that such concrete will as a rule not be affected by efflorescence.

Secondary efflorescence can appear on the surface of concrete during weathering, even if the concrete has cured properly. What is remarkable is that secondary efflorescence usually occurs for roughly as long as there is a marked increase in the strength of the concrete during weathering. It is therefore likely to be a consequence of further hydration of the cement. During this process, calcium hydroxide is deposited on the surface and then reacts with carbon dioxide. Secondary efflorescence appears to reach a maximum within a year. The maturity of the concrete, defined as the product of the curing temperature in $^{\circ}C$ and curing time in hours, has been related to secondary efflorescence. At maturity values above 1300 ($^{\circ}C x h$), efflorescence is usually minimal.

The more common causes of moderate amounts of secondary efflorescence do not lie in transport processes from deeper layers of concrete to the surface, but are thought to be more a question of localized happenings on the surface. This is backed up by the point that the efflorescence would otherwise have to be very pronounced, since there is a much larger quantity of calcium hydroxide available in the concrete as a whole. When the surface of concrete is sandblasted, retarded, or acid etched, the quantity of secondary efflorescence can be greater than it would have been for a densely formed or finished surface under the same environmental conditions.

The weathering away of a thin layer of secondary

efflorescence in one to two years can be due to the slow formation of water-soluble calcium hydrogen carbonate from calcium carbonate. Once this occurs, all that is needed is rain to wash it away. In areas with little rain, (Arizona, for example), secondary efflorescence is particularly long-lasting. The amount of rainfall is not the decisive factor in efflorescence and may even be counter-productive as a great deal of rain will wash the calcium hydroxide from the surface of the concrete before it has a chance to react and form insoluble calcium carbonate. It is very rare for secondary efflorescence to reappear on wellcompacted concrete.

Minimizing Efflorescence

Since many factors influence the formation of efflorescence, it is difficult to predict if and when it will appear. This fact is evident in the lack of any accepted standard test method for measuring the efflorescence potential of concrete. Several experimental methods have been proposed, but none has been accepted as effectively predicting the performance of concrete in actual use. However, the efflorescence test described in ASTM C67 for brick and structural clay tile may also be used for concrete samples. A concrete cylinder can be placed in one inch of distilled water for seven days. After 48 hours of drying, the cylinder is observed at a distance of 10 feet for efflorescence. The test, however, will unlikely predict a potential for calcium carbonate efflorescence.

Conditions that increase the penetration of water into the concrete must be avoided. A dense concrete that absorbs as little water as possible after curing is desirable.

In the selection of materials, all ingredients should be considered for their soluble-salt content. To reduce or eliminate the potential for efflorescence:

O Use a low-alkali cement. Portland cements vary appreciably in their total (acid soluble) alkali content, (typically 0.02 to 0.90 percent by weight of the cement), as well as their water-soluble alkali contents depending on the raw materials used and the temperature of the kiln. The total alkali content should be limited to less than 0.35 percent as Na₂O and the water-soluble alkali content to less than 0.13 percent as Na₂O. These severe limitations on alkali content can be met only by a few cements, other than portland blast-furnace slag cement. Modern cement manufacturing methods, which attempt to achieve energy conservation, have led to increased concentrations of

alkali sulfates, sometimes as much as 1.5 weight percent, usually present as soluble sulfates such as K_2SO_4 or $Ca_2K_2(SO_4)_3$. It is suspected that the sulfate content may be as significant as the alkali content in contributing to efflorescence.

❷ Use sand that meets the requirements of ASTM C33, C144, or CSA A23.1. Never use unwashed sand containing soluble alkali sulfates. Water-soluble salts, generally chloride and sulfates, may be deposited in, or on, sand and gravel deposits by evaporation of groundwater, or by evaporation of sea or salt-lake water on beaches. Sands may also be contaminated from soil runoff, plant life, and decomposed organic compounds. These salt contaminated materials may cause efflorescence and should be avoided.

A feature of limestone aggregates is their tendency to exude self-produced efflorescence when used for exposed aggregate finishes. On white or near-white aggregates this is of little consequence, and on white finishes it might, on occasion, even bring some slight improvement to the final result. On dark surfaces, however, the white film will not only show, but will significantly dull the original color of the aggregate. After cleaning the surface, treatment with a clear sealer can normally be relied on to prevent a recurrence.

• Use clean mixing water free from harmful amounts of acids, alkalies, organic material, minerals, and salts. Do not use drinking water that contains quantities of dissolved minerals and salts sufficient to cause efflorescence. Some city drinking water supplies may require treatment as they may have as much as 215 ppm of sodium, 20 ppm of potassium, 550 ppm of bicarbonate, 120 ppm of sulfate and 280 ppm of chloride. Do not use seawater.

O Additives which reliably prevent efflorescence when added to the concrete are the dream of every precaster. However, no panacea for the prevention of efflorescence has been found.

Both fly ash and microsilica consume large quantities of calcium hydroxide, (although not generally used in architectural precast concrete because of color problems). The reaction of fly ash with calcium hydroxide is rather slow, so that significant reductions in calcium hydroxide are seldom seen before 30 to 60 days. With microsilica additions greater than 20 percent, it is possible to almost completely eliminate calcium hydroxide. Additions of five to 10 percent microsilica can produce large decreases in permeability and alkali content in the pore structure. Trial mixes should be run to evaluate the effect of these materials on air content and other mix properties and most importantly on color and color uniformity.

Using an integral water-repellent or dampproofer, such as butyl stearate, may reduce the rate of penetration of water in its liquid state through the concrete. The butyl stearate is added as an emulsion at a rate of one percent stearate by weight of the cement. These additives function by blocking capillary action, thus providing an internal barrier to the transmission of water through the matrix. These additives have performed very well in some instances, particularly when the concrete contains paste with relatively high porosity, but only marginally in others; their major shortfall is generally the limited amount of time over which they provide protection. A relatively recent improvement in this technology is the development of polymer stearate dispersions. Polymer stearate dispersions are liquid emulsions of stearates and polymers, the combination of which offers improved adhesion in pore walls and capillaries. The polymer particles coalesce into a continuous film that reduces permeability by sealing air voids and blocking microcracks. This results in greatly improved long term effectiveness. These additives have no effect on the condensation of water vapor in the capillaries and pores of the concrete. On the other hand, the condensation of water vapor on and in the surface of the concrete is of considerable importance for secondary efflorescence, in particular. When considering the use of an efflorescence controlling agent, the producer should run trial mixes to determine the effect a given product may have upon air content and its compatibility with other admixtures which may be in the mix.

• The reduction of concrete permeability and a concrete with a low water absorption (five to six percent by weight or 12 to 14 percent by volume) are the key factors that the producer can influence to minimize efflorescence. To accomplish these will require properly graded aggregates, a minimum cement content for stripping and service strength requirements (a cement-rich concrete mix increases water absorption), a low water-cement ratio, good consolidation techniques, thorough curing and possible use of efflorescence controlling agents.

By reducing the amount of available water beyond that required for hydration, voids and capillaries in the matrix are reduced. The reduction of total water content by means of a water-reducing admixture should reduce the total porosity slightly, but there are no adequate data to demonstrate that permeability is reduced materially. However, decreased permeability through the use of high-range water reducers at equivalent water-cement ratios has been reported. However, reducing or limiting the water-cement ratio and total water content to the minimum feasible will greatly aid in reducing the propensity for efflorescence.

The compound composition of cement of a given fineness affects permeability of a paste of a given water-cement ratio at a given age only insofar as it influences the rate of hydration. The greater the degree of hydration, the lower the permeability. The ultimate porosity and permeability are unaffected. However, for a given water-cement ratio, coarse cements tended to produce pastes with higher porosities than finer cements.

The permeability of concrete depends on the permeability of the paste as well as that of the aggregate, and on the relative proportions of each. It also depends greatly on placing, finishing, particularly consolidation, and curing procedures. Permeability of concrete to liquid water or water vapor is not a simple function of its porosity, but depends also on the size, distribution, and continuity of the pores in both the cement paste and aggregate. The pores in cement paste are of two kinds. Gel pores, constituting about 28 percent of the paste volume, are interstitial spaces between the gel particles. They are very small (between 1.5 and 3.0nm in diameter). Capillary pores are larger (of the order of 1µm) and are irregularly distributed throughout the cement paste. Because capillary pores represent the remains of originally water-filled spaces, their volume can vary between zero and 40 percent, depending on the original water-cement ratio and the degree of hydration. As hydration progresses, the permeability decreases. Thus, normally, the higher the strength of a given paste or concrete, or the longer it has cured, the lower will be its permeability.

Air entrainment might be expected to increase the permeability of concrete. However, since air entrainment reduces the mixing water requirement and bleeding, and since entrained air voids interrupt the continuity of capillary pores, the overall effect of air entrainment will usually be reduced permeability.

• Other factors to consider. Coloring pigments usually have no positive or negative effect on efflorescence. Synthetic pigments are water insoluble and do not contain noticeable amounts of water soluble salts. Pigments may appear to aggravate any efflorescence problem by making it more visible. Also, efflorescence deposited on the surface may mask the true color and give the appearance of pigment fading, even though the pigment itself has shown no change.

It is important to prevent inadequate hydration of cementitious materials caused by cold temperatures or premature drying of the concrete during curing. These conditions will prevent the occurrence of primary efflorescence, but increase the likelihood of secondary efflorescence.

Precast concrete units should be protected against extraneous water for as long as they are stored. During storage of the precast concrete, the units should not be stacked too closely so that air circulation can lessen the occasion of surface condensation. Water repellency can be achieved by sealing the concrete surface with acrylates, silanes or siloxanes. The use of a concrete sealer will reduce the absorption of moisture into the surface, thereby minimizing or eliminating the wet-dry cycle and, therefore, the migration of water and salts to the surface. A sealer generally lasts five to six years, but beneath it, the surface of the concrete carbonates, thus preventing or lessening efflorescence after the sealer becomes less effective. A combination of a base coat application of a penetrating sealer with a top coat application of a methacrylate based sealer may be most effective.

If a sealer is used, all the manufacturers' recommendations should be followed on when and how to apply the sealer. For example, application of the sealer to a cold, damp panel may discolor and/or streak the panel.

Removal of Efflorescence

Since efflorescence often occurs during or immediately following construction, the first impulse is to immediately wash it off with water or an acid cleaning solution. This is not advisable, particularly in cool or damp weather when the primary result of such action will be to introduce more water into the concrete. The water will wash some of the alkali salts from the surface but will also dissolve and carry the salts back into the concrete, thus causing a reoccurrence of the efflorescence.

If you can wait for one to two years before doing anything to the building, 95 percent of the time, the salts will work themselves to the surface; thus the problem may solve itself by normal weathering. The water soluble alkali salts will gradually weather away. Heavy calcium carbonate efflorescence, although less common, is extremely difficult to remove as it forms a hard white crust. After weathering to calcium hydrogen carbonate, it may be easily removed, otherwise acidic cleaners may be necessary.

It is often helpful to determine the type of efflorescent salt so that a cleaning solution can be found that readily dissolves it without adversely affecting the surface finish. Before cleaning precast concrete, a small (at least a square yard) inconspicuous area should be cleaned and checked to be certain there is no effect on the concrete surface finish or adjacent corrodible materials such as glass, metal or wood, before proceeding with the cleaning. A strip-off plastic that is sprayed-on can be used to protect glass and aluminum frames. The effectiveness of the method on the sample area should not be judged until the surface has dried for at least one week.

If at all possible, cleaning of concrete should be done when the temperature and humidity allow rapid drying. Slow drying increases the possibility of recurring efflorescence and discoloration.

A suggested order for testing appropriate procedures for the removal of efflorescence from precast concrete (beginning with the least damaging) is:

• Dry scrubbing with a stiff fiber brush (particularly if surface is brushed shortly after appearance of efflorescence).

• Abrasive blasting with industrial baking soda. This abrasive will not affect the concrete surface. (Any residue on the surface must not be removed by water as salts will be dissolved and carried into concrete causing additional efflorescence.) Residues should be blown, vacuumed, or brushed from the surface.

• Vigorous dry scrubbing of the finish with a stiff fiber brush followed by low pressure washing of the surface.

• Chemical cleaning compounds such as detergents, muriatic or phosphoric acid or other commercial cleaners used in accordance with the manufacturer's recommendation. If possible, a technical representative of the product manufacturer should be present for the initial test application to ensure its proper use.

Areas to be cleaned chemically should be thoroughly saturated with clean water prior to application of the

cleaning material to prevent the chemicals from being absorbed deeply into the surface of the concrete. Surfaces should also be thoroughly rinsed with clean water after application so that no traces of acid remain in the surface layers of the concrete. Cleaning solutions should not be allowed to dry on the concrete finish. Residual salts can flake or spall the surface or leave difficult stains. Misapplication of hydrochloric acid can lead to corrosion of adjacent or embedded metals with shallow cover.

Care should be taken to use dilute solutions of acid to prevent surface etching that may reveal the aggregate and slightly change surface color and texture. Application should be to small areas of not more than four sq. ft. (0.4 m^2) at a time, with a delay of about five minutes before scouring off the salt deposit with a stiff bristle brush. Any of several diluted solutions of acids are effective ways to remove efflorescence:

- one part hydrochloric (muriatic) acid in nine to 19 parts water
- one part phosphoric acid in nine parts water
- one part phosphoric acid plus one part acetic acid in 19 parts water
- one part acetic acid (vinegar) in five parts water

Hydrochloric (muriatic) acid may leave a yellow stain on white concrete. Therefore phosphoric or acetic acid should be used to clean white concrete.

Rubber gloves, glasses, and other protective clothing must be worn by workmen using acid solutions or strong detergents. Materials used in chemical cleaning can be highly corrosive and frequently toxic. All precautions on labels should be observed because these cleaning agents can affect eyes, skin and breathing. Materials which can produce noxious or flammable fumes should not be used in confined spaces unless adequate ventilation can be provided.