EFFLORESCENCE – The White Whiskers of Winter

By Joseph "Cris" Crissinger, CCS, CCCA

Scientists say that approximately 75% of the earth's surface is covered with water. With that water-to-dry-land ratio, it's obvious that the water "gets around"; and when it does, it usually means mischief. For this discussion, that mischief is efflorescence.

One of the first signs of a moisture problem in cementitious materials is efflorescence. Depending on its source, it is usually a white powdery substance (*Figure 1*). If efflorescence has any purpose in life, it is to sound the moisture alarm.

Efflorescence forms on different cementitious and clay construction when internal restless moisture dissolves free water-soluble salt deposits in the masonry and carries these dissolved deposits to the surface (*Figures 2* through *8*). The moisture and salts can also promote galvanic action. When the moisture containing the dissolved salts evaporates, masonry "makeup" appears.

Unlike ASTM A36 carbon steel that consistently turns a rusty color when exposed to moisture, there is nothing consistent about efflorescence. Depending on the type of salt compound in the structure, it can be the familiar white to light gray, or it can range from shades of light to dark brown and green. Alkali salt compounds such as those of sodium or potassium, usually found in mortar and cement products, generate the more common white to light gray deposits. It can also be powdery, crystalline, dull, hazy, or bright, and it can cover large surface areas, individual masonry units, or partial units. These reactions bring the salts to the surface in a solution that forms

Figure 1 – Efflorescence caused by cold, damp weather. Very severe efflorescence can make masonry appear as if being observed through a frosted glass. The wall was clear by late spring.

Figure 2 – Moisture migrating through the brick cap of a brick retaining wall produced traces of lime run and efflorescence.

Figure 3 – Free salts in the mortar combined with moisture produced efflorescence and galvanic action of bare mill-finish aluminum.

Figure 4 – Efflorescence caused by improper drainage and no waterproofing behind the retaining wall.

crystals when it combines with the carbon dioxide in the air. If allowed to progress, efflorescence may produce spalling that can affect the masonry's structural and durability properties. However, according to ASTM C1364, *Standard Specification for Architectural Cast Stone*, efflorescence alone on manufactured units is not a reason for rejection.

According to the Brick Institute of America and to PROSOCO, a leading producer of masonry cleaners and sealers, metallic salt compounds from vanadium, manganese chromium, and molybdenum tend to produce discoloration (stains) other than white or gray. These compounds are often used as colorants in specialty brick. Some discolorations are often referred to as stains because they usually occur during chemical cleaning, are more difficult to remove, and can be permanent. For instance, vanadium stains are greenish, and manganese stains tend to be

Figure 6 – Efflorescence on shaded clay pavers over an unprotected base.

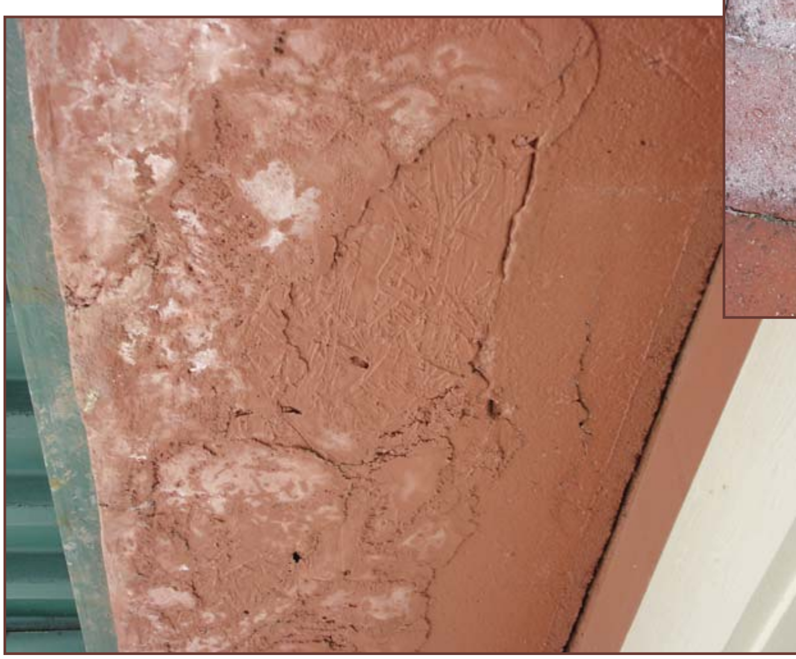

Figure 5 – An improper metal canopy tie-in directed moisture to the concrete lintel, causing efflorescence, spalling, and deterioration of attempted repairs.

Figure 7 – Efflorescence mixed with traces of mildew on shaded concrete pavers caused by moisture migrating from unprotected base.

Figure 8 – Moisture mixed with the salts in a clay pot planter that was kept in the shade and formed a heavy crust of efflorescence.

brown streaks that can resemble tobacco stains (*Figures 9* and *10*).

Lime run is another discoloration similar to and often confused with efflorescence. Lime run usually forms in the joints and runs down the face of the masonry units during cleaning (*Figure 11*). The salts and resulting colors are different, but the production processes are basically the same.

The simple equation for visible efflorescence consists of four components as follows:

Efflorescence
= salt deposits + moisture
+ moisture path to the surface
+ evaporation.

Efflorescence is supported by the four mentioned components (*Figure 12*). It is analogous to a four-legged table where eliminating any one of the legs will cause the table to fall down. Thus, eliminate any one of efflorescence's legs, and efflorescence is stopped and the efflorescence problem is solved.

Hidden efflorescence can be present in masonry when the salts are dissolved by moisture but the moisture has not yet migrated to the surface. For instance (*Figure 13*), sprinkle some table salt (sodium chloride) in a clear glass, add water, and watch the salt disappear (dissolve). Pour out the water and let the residual moisture in the glass evaporate. After evaporation, a cloudy white salt film is left on the glass. The glass on the left represents salt compounds in a structure. The center glass represents added moisture, and the right glass represents evaporation.

Efflorescence is not just a cosmetic problem. During freeze-thaw conditions, efflorescence can cause the brick to weak-

Figure 9 – Vanadium metallic stain leaves varied shades of yellow to light tan to light green splotches. (Courtesy of PROSOCO.)

Figure 10 – Manganese metallic stain leaves its dark mark that often resembles tobacco stain. (Courtesy of PROSOCO.)

Figure 11 – A form of lime run beginning at the mortar joint and trailing down the face of the masonry.

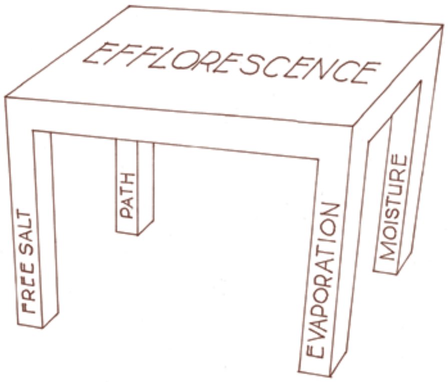

Figure 12 – Efflorescence requires four legs to form. Removing any one leg will prevent its formation. (Courtesy of Charlie Martin.)

en, spall, or crumble. It can be a slow process, but it does occur.

There are two kinds of efflorescence: powdery and crystalline.

Powdery efflorescence. This is the simple kind just described, which can usually be brushed away.

Crystalline efflorescence. This is produced by powdery efflorescence that is allowed to go through repeated cycles of being deposited on the surface, dissolved from rain, and then redrying again. The repeated cycles create small crystals that are tightly bonded to the surface and cannot be brushed away.

It is not always possible to predict whether masonry will effloresce. Soluble salt components may be present in the concrete, mortar, brick, concrete masonry unit (CMU), cast stone, Portland cement stucco, or earth. They may be carried into the wall with any form of precipitation, fog, condensation, or sprinkler systems, or they may be absorbed by groundwater.

When this author tested the pH of masonry construction, areas void of efflo-

Figure 13 – Efflorescence begins with a salt deposit, combines with moisture, and then saline solution evaporates and leaves the characteristic white film.

Figure 14 – New-building bloom during winter construction usually disappears after everything dries out, especially after the interior acclimates.

rescence had pH ranging from 8 to 12, while areas exhibiting efflorescence were above 12. Most paint manufacturers recommend that masonry have a pH of less than 12 before painting. It is also prudent to use an alkali-resistant primer when painting masonry. Since efflorescence can cause paint to delaminate, perhaps the paint manufacturers know something about efflorescence.

Most efflorescence is temporary and, as such, should be left alone. It most commonly occurs shortly after building wash down and in the fall and winter months when vapor transmission slows and masonry stays damp for extended periods of time. Most masonry cleaners tend to be acidic, and acid rain tends to be a natural remover of efflorescence. The very wet and cold fall and winter of 2009-2010 produced monumental proportions of efflorescence in the Southeast. Buildings that were 12 to 15 years old and had never had their first particle of efflorescence were turned white. It was mostly gone by the end of summer with no human intervention.

PREPARING A BATCH OF EFFLORESCENCE

Beginning with calcium chloride that usually comes from lime, the following four salt compounds and their characteristics are required to prepare a batch of efflorescence:

1. Calcium oxide: Soluble in water
2. Calcium hydroxide: Soluble in water
3. Calcium carbonate: Insoluble in water
4. Calcium bicarbonate: Soluble in water

Calcium oxide is soluble in water and, when mixed with water, forms calcium hydroxide. As moisture moves within the structure, the calcium hydroxide is carried to the surface, where it mixes with carbon dioxide in the atmosphere to form calcium carbonate. Calcium carbonate is the first visible white indicator of efflorescence. The calcium carbonate begins to react with carbon dioxide and moisture to form calcium bicarbonate, which is soluble in water. Converting the insoluble calcium carbonate to soluble calcium bicarbonate is slower than converting the soluble calcium hydroxide to calcium carbonate. Therefore, there is an accumulation of calcium carbonate on the surface that is the familiar white powder. To simplify this process:

Calcium oxide + water = calcium hydroxide

Calcium hydroxide + carbon dioxide = calcium carbonate + water

Calcium carbonate + carbon dioxide + water = calcium bicarbonate

The most common efflorescence salt compounds are calcium carbonate, sodium sulfate, and potassium sulfate. Of these three salt compounds, calcium carbonate is the most common. After concrete is poured, mortar is laid, or plaster is applied, the hydration (hardening) process begins, and calcium hydroxide is formed.

When weather is warmer or dryer and humidity is low, moisture usually evaporates before it reaches the surface, leaving salt deposits internally. Conversely, when weather is wet and cold and humidity is high, evaporation can be slow to nonexistent, and conditions are ripe for visible white whiskers. As a building becomes enclosed during construction, efflorescence usually disappears.

Efflorescence is sometimes called "new building bloom" because it frequently appears on new construction. However, it is one bloom that we want to go away and not to come again another day. Efflorescence can occur during or shortly after construction and can disappear shortly after or can remain for a year or more. It can occur during construction (often confused with mortar scraping from a distance) or during any type or combination of cold, damp, or rainy weather (*Figure 14*). These conditions are usually temporary and suggest that the building is drying.

Cold concrete and cold ambient temperatures encourage efflorescence because evaporation is slower during these conditions, and the moisture has more time to react with the salt compounds. Additionally, concrete tends to bleed more during cool weather.

Contrary to what might be expected, wet-curing concrete tends to reduce efflorescence, even though more water is introduced. When concrete is kept moist during a wet cure, more capillaries and pores are filled to form a denser matrix that resists moisture migration. Concrete that has a higher slump or that is not properly cured tends to have more open pores and capillaries to promote moisture migration in all directions.

Efflorescence is least likely to occur on the south and west walls because the warm sun moves the evaporation point from the surface to deeper in the wall. Think dew point: The interior part of the wall is usually cooler and has a higher moisture content than the surface. North- and east-facing walls tend to experience the most efflorescence because they are usually cooler, thus permitting the evaporation point to remain on the surface. Any type of moisture, including humidity, supports formation of efflorescence. Thus, efflorescence activity tends to increase after a rainy winter season, seems to moderate with warmer spring weather, and then practically disappears in summer. When weather is warmer or dryer and humidity is low, moisture usually evaporates before it reaches the surface, leaving internal salt deposits. Conversely, when weather is wet and cold and humidity is high, evaporation can be slow to nonexistent and conditions are ripe for visible white whiskers. When efflorescence persists or disappears and reappears, then there are internal problems, and investigations should be considered. Obviously, efflorescence is often considered to be a seasonal event.

Until the structure is dry, efflorescence can occur even on an interior wall (*Figure 15*). Drying will occur from the inside

Figure 15 – New construction efflorescence from residual moisture that usually disappears after the building dries out.

out and efflorescence can occur on both sides of a wall until the drying is complete. Dark moisture spots and white efflorescence suggest that the building is drying out. It usually goes away after the building dries and ambient conditions stabilize. If it doesn't, there is probably more to be concerned about than efflorescence because it may be signaling that something is amiss, such as moisture intrusion, inadequate drainage, nonfunctional flashing, etc.

In most instances, the tendency of brick to effloresce can be determined by a test prior to laying. Simply place a brick on end in a pan of distilled water for seven days. Allow water to migrate upward and evaporate on the surface. If the brick is prone to efflorescence, soluble salts will be deposited on the exposed brick surface during evaporation. Distilled water ensures that additional impurities are not introduced into the test.

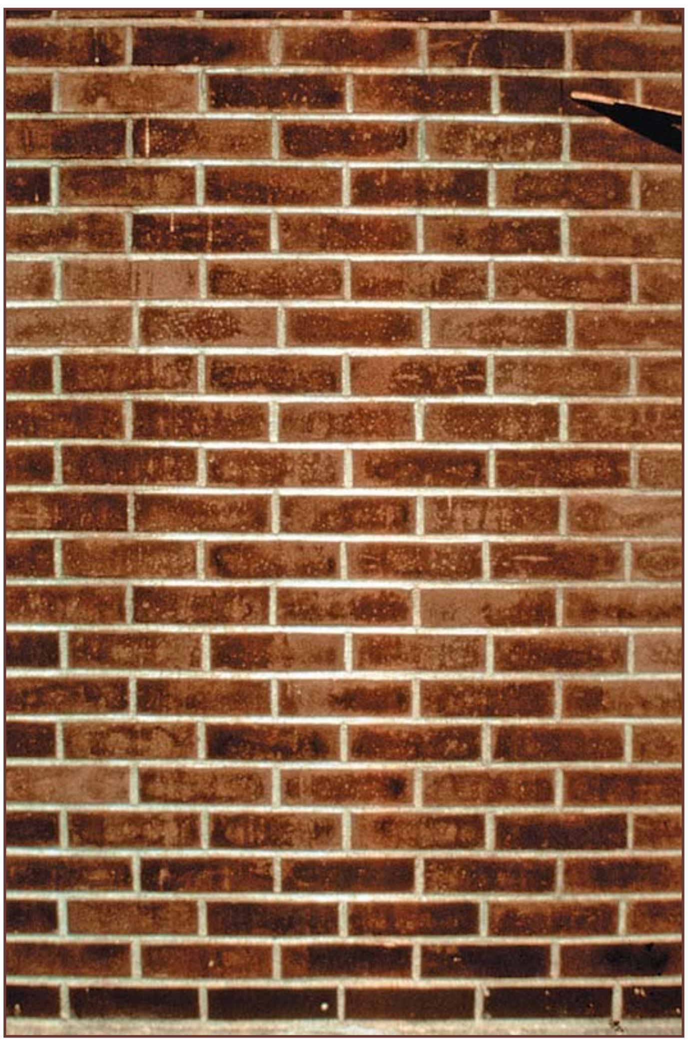

Figure 16 – Acid burn caused by improperly used hydrochloric acid (muriatic acid) that can react with the naturally occurring iron salts in the clay and produce iron oxide (rust). (Courtesy of PROSOCO.)

SOURCES OF MOISTURE

Water sources are either from exterior or interior sources or from construction activities. Exterior sources include weather events (rain, fog, condensation, humidity, snow, etc.), landscaping irrigation, and groundwater. Interior sources include cooking, showering, breathing, plumbing failures, drainage failures, missing or damaged vapor retarders, groundwater through the foundation, and failed or missing internal flashing. Construction sources include concreting, mixing mortar, plastering, fireproofing, drywall installation, etc.

Common installation problems that can cause or enhance efflorescence include the improper use of through-wall flashing, lack of sufficient weep holes, masonry without vented cavities, use of incorrect brick below grade or at planter type areas without proper moisture barrier, failure of joint materials that allow water entry, and the use of hard mortar joints where sealant joints should be used. Cementitious soffits are particularly susceptible to efflorescence because their horizontal plane tends to hold moisture and they are usually shaded. Grout in CMU cells should be consolidated with a mechanical vibrator to densify the grout and eliminate voids.

Efflorescence is affected by the permeability of construction materials. The more porous the materials, the more they can transport moisture. Thus, smooth brick is less porous than textured brick, tooled mortar is less porous than untooled mortar, standard-weight CMU is less porous than lightweight CMU, and concrete with a steel trowel finish is less porous than a float finish. Architectural precast concrete panels with 6,000 to 7,000 psi compressive strength are less permeable than 3,000-psi concrete. Proper tooling of masonry joints causes the cement paste to encapsulate the fine aggregate in a smooth, dense matrix that forms a water-resistant joint. When masonry is pressure-washed, the chemical cleaner applied under pressure can damage or remove the cement matrix along with the joint's water resistance.

Rain can easily enter a masonry wall of a building under construction through the exposed tops of the wall. Water can fill the cells in the brick and CMU units and then feed the walls long after the wall is complete. If the walls are reinforced, the pools of water in the cells can affect grout pours.

CATEGORIES OF EFFLORESCENCE

Efflorescence can occur within the first 48 hours of manufacture or installation. It is generally associated with the initial cure during manufacture of stone, cement, and brick masonry units and masonry construction. This produces a construction-induced moisture that moves through the cementitious structure and picks up the free salts along the way. If the moisture makes it to the surface and evaporates there before it evaporates internally, white salt crystals form on the exterior surface. This is sometimes referred to as "primary efflorescence."

Moisture induced from construction activities often causes efflorescence to occur after construction. This is sometimes referred to as "secondary efflorescence." Considering these possible sources, it can be surmised that secondary efflorescence tends to occur randomly, affecting some masonry units or portions of the structure but not others. The chemistry and formation of both are the same. The difference is when they occur.

Salt Sources

The salts usually associated with efflorescence are alkali sulfates such as sodium sulfate and potassium sulfate. Sources of these salts include Portland cement, lime, sand (source may be from seashore), clay used in the brick (may come from saline earth), and any admixture that contains chlorine. Even water that was in contact with sulfate-containing soil can produce efflorescence.

REMOVING EFFLORESCENCE

Cleaning efflorescence only removes the visible symptoms, but it does not necessarily cure the disease. Efflorescence is often masked, but the causes are still present, and it often reappears unless one or more of the formula components is removed. Cleaning can involve water during preapplication of cleaners, application of cleaners, and rinsing; and water is one of the components of the formula. Thus, efflorescence can recur–sometimes with a vengeance.

Frequently, natural weathering, including acid rain, can remove efflorescence. When using cleaners, the procedures often require presoaking the masonry and then flushing after cleaning. If the efflorescence is removed and then returns, it suggests that moisture is entering the building and carrying the salts out.

Soft Dry Brush

If the efflorescence salts are water-soluble, a dry brush with bristles stiff enough to remove the efflorescence but not stiff enough to damage the surface of the substrate may remove it. Brushing actually removes the salts and prevents them from reentering the structure, as is often the case with fresh water and chemical treatment. This should be the preferred method because there is no detrimental effect on the surfaces.

Fresh Water

Fresh water is the next method. However, since water is one of the elements of the efflorescence formula, a freshwater wash introduces more moisture into the wall. The paths the salts take to the surface are not one-way. Consequently, some of the partially dissolved salts may be carried back into the structure through the same path that took them to the surface. Keep in mind that water may hide the efflorescence, but it is still there.

Manual washing can often draw additional salts to the surface. Repeat washing may be necessary, but when all of the salts have come to the surface naturally and have been washed off, there will be no more trouble from this cause. It is imperative that all efflorescence mechanisms are reduced or eliminated prior to sealing. If efflorescence does not return, chances are that the moisture or salts or both were construction-induced.

Chemical

This is probably the most common removal method and will receive the most attention. Chemical cleaners can contain acids and/or detergents that dissolve the salts so that they can be washed away with fresh water. The acids in the cleaner can react with pigments that may be in the brick, concrete, mortar, etc., producing color variations.

Usually, chemical cleaning cannot remove crystalline efflorescence because of the crystals' attachment to the surface. That is why chemical cleaning can look great for a few hours, but when it dries, some efflorescence deposits remain. They are not new deposits coming out, they were just temporarily disguised by the darkening effect of the initial treatment. The reappearing efflorescence is crystalline and is bonded to the surface. These deposits will "fizz" on contact with strong acids such as pool acid or muriatic acid, which should not be used to clean masonry.

Chemical cleaning can produce acid burn (accompanied by heartburn) if not properly performed by trained professionals (*Figure 16*). Strong acids such as muriatic acid usually cause acid burn. The brick's porosity causes the acid to be absorbed before it can be properly rinsed. Improper chemical cleaning can also activate any metallic salts that may be dormant in the structure, resulting in stubborn brown and

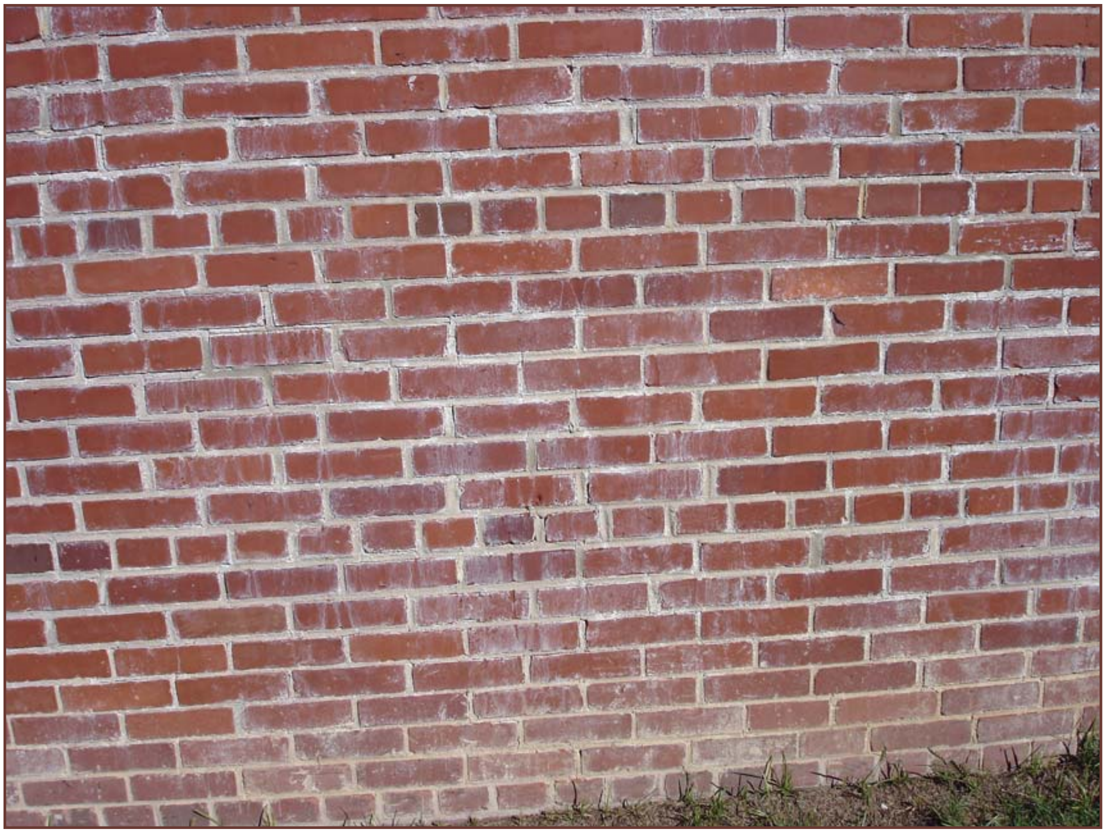

Figure 17 – Lime scum on old brick laid with restoration mortar that had a high lime content, which reacted with aggressive chemical cleaning that was not properly prewetted and rinsed.

green stains instead of a stain-free structure. Therefore, these stains are not normally visible until after chemical cleaning. Proper prewetting and then rinsing are imperative. Chemical cleaning often produces stains from the previously mentioned metallic salts. Lime (white) scum can be a byproduct of chemical cleaning and is usually caused when the masonry units are not adequately prewetted during washing. The strong cleaning acids can dissolve some of the Portland cement matrix, which is then absorbed by the dry masonry and then runs down the joints and walls to form a thin white film scum. (*Figure 17*).

Chemical cleaners are often formulated for certain types of salts and substrates. Some formulations may be for common alkali salts (calcium carbonate, sodium sulfate, potassium sulfate) that produce the usual whitish/grayish appearance. Cleaners may also be formulated for metallic salts from vanadium, manganese, and molybdenum. Cleaners used for metallic stains can be more aggressive than those used for alkali stains, and there is a risk of damaging or discoloring the brick. The type of salt and the color of the masonry units the cleaner can be used on are usually stated in the manufacturer's product data sheets. Cleaners should be compatible with the various substrates. The wrong cleaners can destroy the Portland cement matrix of precast stone.

Before chemical cleaners are used, all loose efflorescence should be removed according to the previously mentioned soft brush removal procedure. Chemical removal must be done carefully, and the cleaner and procedures should be tested in an inconspicuous area before proceeding. Also, some removers may contain chlorine, which is also a salt and may contribute to the efflorescence problem. The cleaning instructions usually state to flush with plenty of fresh water, which puts moisture and possibly some of the partially dissolved salts back in the wall, thus creating an efflorescence loop. It is best to minimize the amount of cleaner used in order to minimize the amount of fresh flush water.

Mechanical

Mechanical methods, such as brush blasting, will definitely remove the efflorescence, but they are the most aggressive. These methods can also remove some of the substrate along with the efflorescence; roughen the surface, making it more porous to trap and hold moisture; and remove mortar matrix around the fine aggregate, which reduces water repellency of the mortar and causes spalling.

CONTROLLING EFFLORESCENCE

It has been said many times that wood floors crack because they are made from a natural material. Similarly, cementitious construction effloresces because it is constructed of natural materials. Ultimately, it is best to execute all available precautions to prevent efflorescence. When it does appear and stays or comes and goes, there may be some hidden problems that need attention.

We can't build all the walls facing south or west; neither can we build all of our buildings in the desert. Efflorescence may not be completely eliminated, but there are steps that can be taken during design and construction to reduce the possibility of its occurring. Unfortunately, many of the recommendations may be subject to a cost-cutting surgical knife during "value engineering." Specify the best for given situations and let someone else be responsible for design revisions. Efflorescence prevention is shared by both design and construction, of which design comes first. Ensuring the design provisions are incorporated is an even more important and difficult challenge. The following suggestions are divided into two phases–design and construction–and will probably elicit additional ideas.

Design

- Use sill pans in all openings.
- Use slumps in the 4-in range.
- Use low-alkali Portland cement.
- Provide overhangs at roof line and sills.
- Use vapor retarder under slabs and in walls.
- Use durable, preformed end dams at openings.
- Keep the water/cement ratio low, approaching 0.45.
- Use waterproof liners in planters and fountains.
- Waterproof below-grade spaces, including elevator pits.

- Use proper drainable weeps spaced a maximum of 24 inches on center.
- Use durable through-wall flashing turned up the back and sealed.
- Fortify Portland cement with recommended proportions of fly ash.
- Specify brick with additives that neutralize alkaline sulfates or are free of such.

Construction

The following are good construction practices that should be followed.

- Use wet-curing methods.
- Use clean, potable water free of salts.
- Keep sprinkler systems off the walls.
- Cover brick cubes until ready for use.
- Provide drainage away from structure.
- Use aggregate that is washed in potable water.
- Follow ACI 306 for cold-weather concreting.
- Do not clean masonry with pressure washers.
- Consolidate grout pours with a mechanical vibrator.
- Cover the tops of unfinished masonry walls and sills.
- Don't pour grout or concrete in cold or damp weather.
- Do not use sea sand or aggregate washed in salt water.
- Perform an efflorescence test on brick units prior to laying.
- Tool mortar joints to a smooth, dense, and concave surface.
- Use clean fine and coarse aggregate washed with potable water.

Sealers

Generally, sealers are either film-formers or penetrating (pore-plugging). Just as a jar lid keeps the fruit juice in the jar, film-formers create a thin layer over the surface of the substrate to keep the salts in. These film-formers stop the salt-laden moisture just below the surface. When this happens, moisture will usually evaporate and deposit the salts behind the sealer where they crystallize. During crystallization, the salts expand and can cause brick to spall or deteriorate. On the positive side (no pun intended), film-formers can prevent moisture from entering the substrate from the exterior. Since the film-formers are on the surface, they are exposed to weather, ultraviolet rays, dirt, abrasion, etc., that shorten their life; and they also may form a vapor barrier that prevents the structure from drying to the exterior.

Penetrating sealers are formulated to penetrate the substrate and plug the pores to prevent the salts from ever reaching the surface. These pore-pluggers are usually breathable, allowing the walls to breathe without carrying salt deposits to the surface. In cold-weather climates, freeze/thaw cycles can cause moisture trapped below the surface to expand and spall or otherwise damage the masonry or joint.

HOW LONG WILL IT LAST?

It has been said that as long as the "law of fermentation" is in effect, there will be liquor. Similarly, as long as there is moisture, there will be efflorescence.

There is no definitive answer as to how long efflorescence will hang around. It stays until it is done. Its life span is tied to weather conditions during and after construction, moisture induced during construction, and design and construction details. To some folks, it just seems to suddenly appear and then just as quickly disappear. In reality, it can appear any time from three to six weeks to three to six months or more after construction, hang around for a few months (up to six or more), and then take another three to six months or longer to disappear. Of course, if conditions are conducive, it may make annual pilgrimages back to the surface. Efflorescence does not occur on every project. When it does occur, the building owner, designer, and contractor have two options – live with it, or try to get rid of it.

SUMMARY

It has been said that efflorescence is controllable and should not be a problem in modern masonry. The key word is "controllable." That does not necessarily mean eliminated. If that were the case, we would not need masonry cleaners. Cementitious materials come in various textures and finishes and usually have some degree of porosity that is a good source of capillary action to transport moisture. That leaves the alkali salts. Considering the various salt sources, it is virtually impossible to ensure our buildings are on a "salt-free diet." We can effectively reduce the various salts, but we can't completely eliminate them. Efflorescence can be present but invisible, lying in a dormant state just waiting for the right conditions to grace a building's face with "masonry makeup."

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ANSI/SPRI STANDARDS TO BE UPDATED

SPRI, the association representing single-ply roofing manufacturers, has announced its intention to revise ANSI/SPRI FX-1, *Standard Field Test Procedure for Determining the Withdrawal Resistance of Roofing Fasteners*. The standard was first approved in 1996 and revised and reapproved in 2001 and 2006.

ANSI/SPRI WD-1, *Wind Design Standard Practice for Roofing Assemblies*, is also being updated to reflect 2010 updates to the American Society of Civil Engineers' (ASCE) standard *Minimum Design Loads for Buildings and Other Structures*. Revisions include reinstating Exposure Category D for hurricane-prone areas, simplified procedures for determining wind pressures for buildings, and new wind speeds using a 700-year return.