However, currently there is no evidence that calcium chloride contributes to efflorescence. Alkali salts (sodium chloride, potassium chloride) contribute to efflorescence in large part due to the alkali content. Because cement is already calcium rich and calcium hydroxide is only slightly soluble, the use of calcium chloride does not have a deleterious effect as far as efflorescence is concerned.

Curing Process

The curing process is critical to producing efflorescence-free product. Moist curing with good air convection and a stable temperature yields the best final product. Good air convection is important in maintaining a homogeneous surface appearance. A common pattern of efflorescence is known as picture framing (Figure 9). This occurs when blocks are stacked (sometimes with a thin layer of silica sand between the individual blocks). Around the edges, there is good convection and in the center the product stays moist until final cure, so these two areas do not show efflorescence. However in the areas in between there are wet/dry cycles allowing formation of efflorescence.

Figure 9: *Concrete paver showing the efflorescence phenomenon known as picture framing; providing adequate convection during curing can prevent this. The efflorescence is composed of calcium carbonate.*

Another key factor is temperature control during cure. Efflorescence commonly appears during spring and autumn when there are relatively large swings between daytime and nighttime temperatures. Particularly when block is covered with a plastic sheet, water condensation (or dew) formed as the temperature cools can deposit on the block surface allowing salts to migrate to the surface. As the temperature climbs, the water evaporates leaving a relatively thick film of efflorescence (Figure 10). This phenomenon is aggravated by the fact that the solubility of calcium hydroxide in water decreases with increasing temperature.

Figure 10: *Portion of a concrete paver with a homogeneous thick film of calcium carbonate efflorescence resulting from water condensation and subsequent evaporation.*

Another strategy that has been shown to minimize visible efflorescence is the early introduction of a carbon dioxide atmosphere during curing. This promotes carbonation of the surfaces early in the curing process, which is generally not visible to the eye.

Removal of Efflorescence Salts

Efflorescence will often dissipate with time; however, if desired it can be removed. Sodium and potassium salts can easily be removed with a stiff brush or, if necessary, brushing with water. If the efflorescence is slight, a stiff brushing may remove it. If not, brushing with a dilute acid such as muriatic or sulfamic acid is recommended. If the concrete is pigmented, it is recommended that sulfamic acid in the 5 to 10% concentration range be used. Stronger acid may affect the color.

A good reference for masonry construction is the Concrete Masonry Handbook published by the Portland Cement Association (PCA).

Control of Efflorescence

Primary Efflorescence

To minimize the potential for primary efflorescence, it is necessary to determine the key factors involved and how the mix design or curing process should be adjusted. As discussed in this bulletin, the key factors include use of admixtures, cement content, water-cement ratio, alkali content, curing process, and permeability.

- Optimize mix design.
  - Cement – too little leads to low density and high permeability; too much increases soluble salts available as well as cost.
  - Water – enough to hydrate cement only.
  - Aggregate – proper gradation lowers permeability and produces best overall performance.
- Use low soluble-alkali cements.
- Use de-ionized (not softened by ion exchange) water.
- Use appropriate chemical admixtures.
  - Plasticizers to increase density and strength, lower permeability and water demand.
  - Water-repellent/efflorescence control admixtures to reduce water permeation, absorption, and color fading.
- Increase density and lower permeability by good mechanical compaction.
- Follow good curing practices.
  - Moist cure.
  - Even temperature.
  - Adequate air convection.
- Protect concrete from external water sources as long as possible.
- Use post-applied sealers if necessary.

Secondary Efflorescence

Control of water ingress, by production of low permeability products, is the best way to prevent secondary efflorescence – in terms of the concrete product itself.

Good building practices are essential for the prevention of secondary efflorescence. Factors that should be considered include:

- Mortar should contain a water-repellent/efflorescence control admixture and mortar joints must be properly filled, creating a tight bond between mortar and masonry unit.
- Good drainage must be placed, including flashing, weepholes and waterstops.
- Masonry units should be stored covered in well-drained locations at the job site.
- During construction, walls should be covered to prevent rain or snow from entering core sections.
- Plan roofing and installation of sprinklers to minimize exposure of walls to outside water sources.

Summary

Efflorescence cannot be prevented, but following the guidelines provided in this bulletin can help to minimize it. In particular, the use of admixtures such as the MasterCast series of plasticizers and the MasterPel series of water-repellent and efflorescence control admixtures can significantly reduce the potential for efflorescence in manufactured concrete products.

About Master Builders Solutions

Master Builders Solutions is a leading global manufacturer of concrete admixtures, as well as other sustainable solutions for the construction industry, focussed on delivering its vision: **Inspiring people to build better**. Master Builders Solutions provides value-added technology and market-leading R&D capabilities to improve the performance of construction materials and to enable the reduction of CO2 emissions in the production of concrete. Founded in 1909, Master Builders Solutions has ca. 1600 employees operating 35 production sites globally, supporting their customers in mastering their building challenges of today – for a decarbonised future.

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Concrete Technology in Focus

Efflorescence Guidelines

Introduction

In this technical report, primary and secondary efflorescence in concrete are defined and evaluated in detail. Many factors contribute to efflorescence, including cement content, alkali content, mix water, water-cement ratio, permeability, admixtures, and curing processes. Adjustments to one or more of these factors has an effect on the tendency towards efflorescence. Although efflorescence cannot be prevented completely, it can be controlled using recommended practices and MasterPel® water-repellent admixtures. Guidelines are discussed that provide the most advanced efflorescence-control methods available for concrete masonry.

What is Efflorescence?

Efflorescence is defined in ACI Concrete Terminology as "a deposit of salts, usually white, formed on a surface, the substance having emerged in solution from within either concrete or masonry and subsequently been precipitated by reaction, such as carbonation, or evaporation." Although efflorescence does not damage the integrity of the concrete, it does affect the aesthetic quality of the product and is a costly problem to the concrete industry.

Primary vs. Secondary Efflorescence

An arbitrary distinction is often made between primary and secondary efflorescence. Primary efflorescence generally occurs at the point of concrete masonry product manufacture and during curing. Efflorescence that occurs following use of the block in construction is referred to as secondary. There is not general agreement on when efflorescence stops being primary and starts being secondary. In this document, efflorescence that occurs in roughly the first 48 hours after production is considered primary.

Primary efflorescence occurs during production and initial curing of concrete masonry products, when excess water of manufacture is available for transport of soluble salts. These soluble salts are introduced primarily by the cement, but also may originate from the water and/or aggregates.

Secondary efflorescence occurs when water from an outside source (such as rain) is absorbed into the concrete product, dissolving any available salts within the concrete matrix. Efflorescence may then occur as these salts migrate to the surface.

What Causes Efflorescence?

For efflorescence to occur, three conditions must be present:

- There must be soluble salts available
- There must be a source of water that is in contact with the salts, forming a salt solution
- There must be a pathway for the salt solution to migrate to the surface and the water to evaporate

The minimization of efflorescence must address one or more of these conditions.

Mechanism

The most common efflorescence salts are calcium carbonate, sodium sulfate and potassium sulfate, although there are many others that have been observed – especially when unusual materials are present in the concrete. In practice, calcium carbonate is overwhelmingly the most common efflorescence product. As cement hydrates, calcium hydroxide, $Ca(OH)_2$, which is slightly soluble in water, is formed. The calcium hydroxide dissolves and migrates to the concrete surface where it may react with dissolved carbon dioxide (CO_2) from the atmosphere to form insoluble calcium carbonate ($CaCO_3$) that precipitates from solution:

$$\mathrm{Ca(OH)_2\ (dissolved) + CO_2\ (dissolved) \rightarrow CaCO_3\ (solid) + H_2O\ (liquid)}$$

As the surface of the concrete dries, the calcium carbonate remains as a surface residue that cannot be washed away by water but can be removed with a weak acid or abrasion. Calcium carbonate precipitates in small clusters as shown in Figure 1.

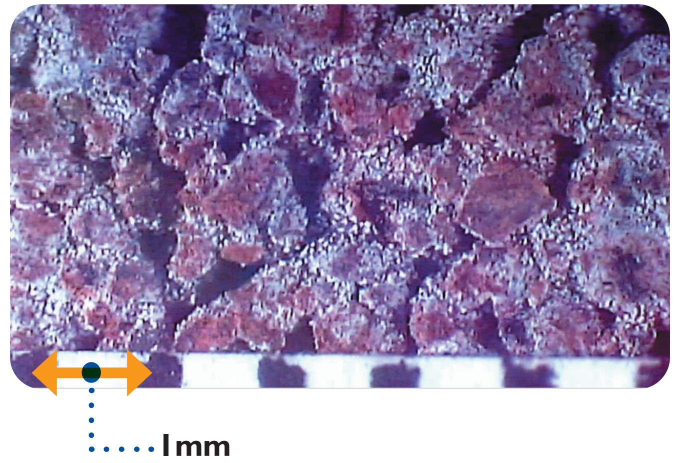

Figure 1: *Photomicrograph of calcium carbonate efflorescence on a red paver.*

Although calcium hydroxide has been used as an example, the same reaction that forms magnesium carbonate is possible but is seldom seen. The alkalis (potassium and sodium) initially present as sulfates may form carbonates via similar reaction sequences and precipitate once the surface dries out. The alkali sulfates and carbonates that precipitate on the surface are not usually of concern because they are very soluble and can be removed easily with water.

Evaluating Efflorescence

There are many analytical methods used in evaluating efflorescence. Infrared spectroscopy and X-ray diffraction are used in identifying efflorescence salts. Phenolphthalein (an acid-base indicator) and weak hydrochloric acid are useful to measure the location and depth of carbonation. A color photometer may be used to quantify the effect of efflorescence on the appearance of the concrete. Another useful tool is the artificial laboratory weathering chamber, which simulates environmental exposure.

Measurement of Efflorescence

The extent of efflorescence can be assessed using a hand-held photometer (Figure 2) to measure the color of a sample in the CIELab color system. In CIELab color space, every color is defined by three parameters: L*, a* and b*, where L* indicates lightness, a* is the green/red axis and b* is the blue/yellow axis. The photometer gives a reading in a few seconds. For flat, smooth surfaces, one measurement may suffice; however, because of the rough nature of concrete surfaces, measurements are generally taken at three to nine locations and averaged. For efflorescence evaluations, the whiteness or lightness of the surface is of interest and only L* needs to be measured. The values of L* range from 0 (black) to 100 (white) and no given value of L* is good or bad; it is the variation or change in L* (△L*) from a desired or reference value that is indicative of efflorescence.

Figure 2: *Byk-Gardner Color-Guide 45°/0° Photometer*

Accelerated Exposure Testing

Another tool used in the assessment of efflorescence potential is a artificial laboratory weathering chamber (Figure 3). One such chamber permits accelerated weathering of samples in a temperature range of 100-230 °F (40-110 °C), a humidity range of 10-100% relative humidity at two sun levels, and with-or-without water spray. Using an artificial laboratory weathering chamber, the efflorescence potential of different mixtures can be assessed for different environmental conditions.

Figure 3: *Weathering Chamber*

Factors That Influence Efflorescence

Efflorescence is affected by several factors including cement content, alkali content, mix water, water-cement ratio, admixtures, curing conditions, and permeability.

Cement Content

The major source of calcium, and particularly of Ca(OH)2, is the cement. So, increasing cement content tends to increase efflorescence. This is illustrated with four paver mixes in which the water-cement ratio was held constant at 0.35, while increasing cement contents.

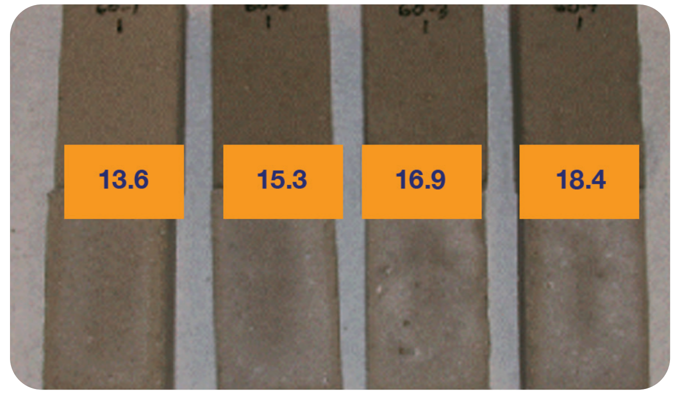

Figure 4: *Pavers produced with the same water-cement ratio, but increasing amounts of cement. The numbers on each set of two represents the percent cement in the mix. The increase in efflorescence with increasing amounts of cement is observed easily on the bottom row.*

The two rows of pavers in Figure 4 are duplicates with the top row showing the surface exposed to air and the bottom row showing the surface that was on the lab bench, thereby limiting air convection. Because of the limited air convection, the increase in efflorescence can be observed easily in the bottom row. The top row is more difficult to evaluate visually and requires the use of the photometer to examine the change in the lightness of each mixture. The difference in color between mixes is a function of the different sand-to-aggregate ratios and cannot be used as a measure of efflorescence. Therefore, to quantify an increase in efflorescence, the change in L* (△L*) following cure is measured (Figure 5).

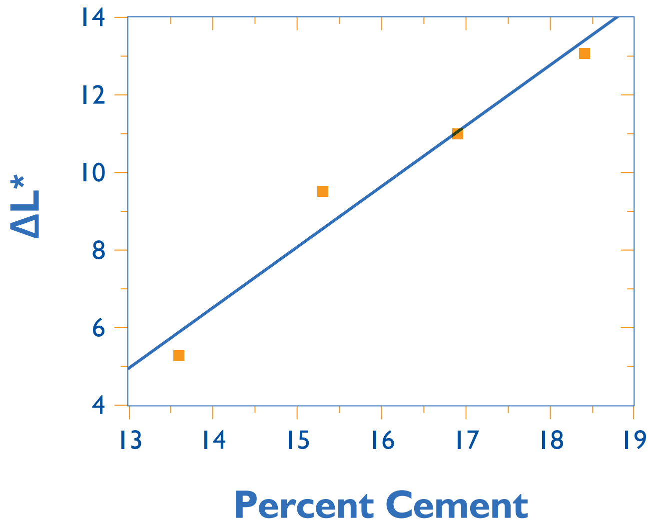

Figure 5: *Impact of cement content at constant water-to-cement ratio on efflorescence (△L* from 1 day to 7 days cure).*

Alkali Content

Elevated alkali content has long been associated with the tendency for concrete to effloresce. The alkali value reported on most mill sheets is total alkali. However, since efflorescence is the result of soluble salt migration, it seems reasonable that any correlation would be with soluble alkali, not total alkali.

In cementitious systems, the only Group I elements (known collectively as alkalis) present in significant concentration are the positively charged ions of sodium and potassium. Therefore, when alkalis are measured, sodium and potassium are the two elements analyzed. They are reported either as independent oxides or combined as the sodium oxide equivalent using the following formula:

$$\mathrm{Na_2O + 0.658K_2O = Na_2O\ equivalent}$$

Mortars were prepared with cements having a range of total and soluble alkali contents to examine the correlation with efflorescence. The four Type I/II cements had alkali contents as follows:

Total Alkali, % Alkali, %	Soluble
0.95	0.70
0.69	0.59
0.54	0.44
0.52	0.20

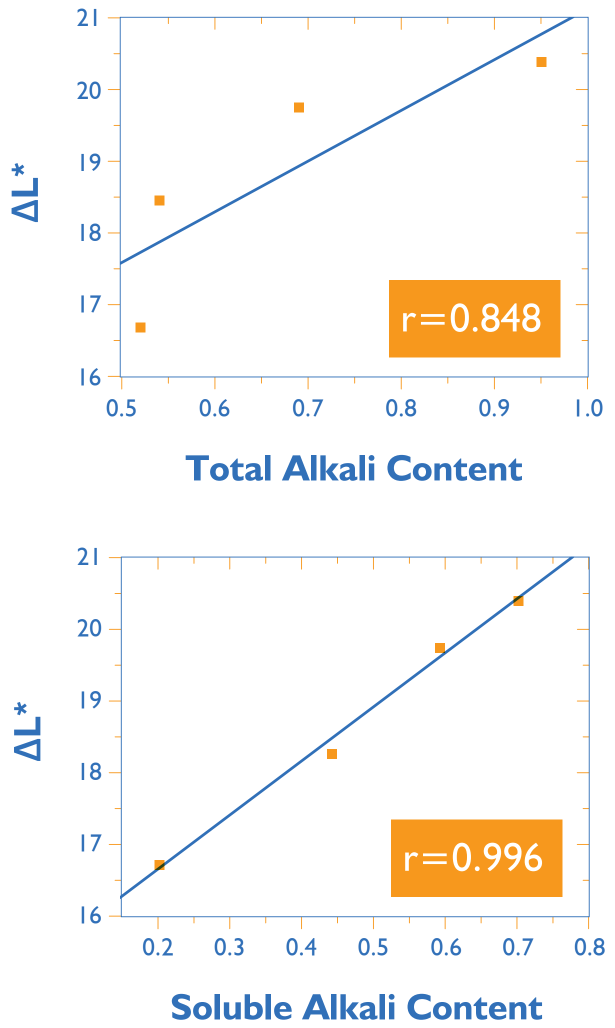

Figure 6: *Effect of Total Alkali Content and Soluble Alkali Content on Efflorescence*

The change in L* (△L*) values were computed for each sample, using the L* approximately 5 hours after removal from the curing chamber and L* after 3 days at ambient conditions (Figure 6).

Plotting the measured △L* vs total alkali content yields a correlation of 0.848; however, when the same △L* values are plotted vs the water-soluble alkali contents of the cements, the correlation is excellent (0.996).

One way that increased alkali content contributes to efflorescence is the common-ion effect, which states that a slightly soluble salt will become even less soluble if a more soluble ion is added to the solution. Calcium hydroxide is much less soluble in water, at all pHs, than are sodium and potassium hydroxides. Therefore, addition of the more soluble ions will make the calcium even less soluble. In addition, even if sodium or potassium carbonates form they can resolublize, whereas calcium carbonate is insoluble in water and will precipitate from solution.

Another factor to be considered is that increased alkali content increases the solubility of carbon dioxide, making more carbon dioxide available for reaction to form carbonates. The increased availability of carbon dioxide coupled with the equilibrium shift in favor of reducing calcium ion concentration is optimal for the formation of efflorescence.

Mix Water

Mix water also can contribute to alkali content. Water should be tested for calcium, magnesium, potassium and sodium. Water hardness is determined from the calcium and magnesium content: the higher the calcium and magnesium content, the higher the water hardness. When water is softened by means of ion exchange, each calcium (and magnesium) ion is replaced with two sodium ions. The added sodium can increase the potential for efflorescence.

Water-Cement Ratio

Because there must be moisture available for efflorescence to occur, minimizing the water-cement ratio helps reduce the potential for efflorescence. To illustrate this, two sets of pavers were prepared (Figure 7). One set of three contained 13.6% cement [a cement factor of about 335 lb/yd^3 (200 kg/m^3)]; the other set of three contained 18.3% cement [a cement factor of about 435 lb/yd3 (258 kg/m^3)]. Within each set, three water-cement ratios were tested (0.28, 0.35 and 0.42). These two sets show that as water-cement ratio increases, efflorescence increases. As in Figure 4 where the cement content was increased, the lightness of the individual mixtures cannot be compared because it is changing independently from any efflorescence – only the △L* within each mix is a valid measurement of efflorescence.

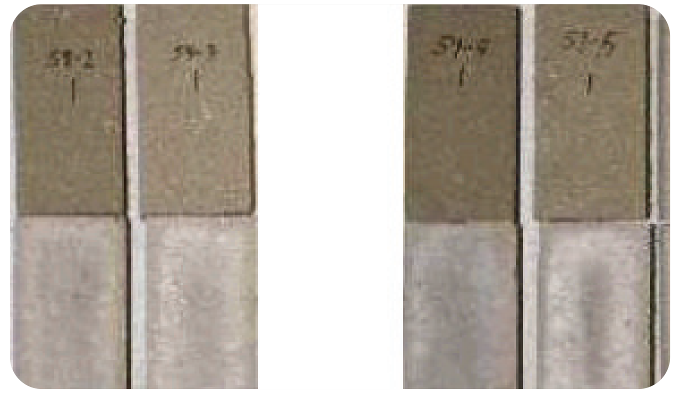

Figure 7: *Paver mixes with 13.6% (left) and 18.3% (right) cement. Water-cement ratios are 0.28, 0.35 and 0.42 from left to right in each set. Series across top shows surfaces that were open to the air during drying; series across bottom shows surfaces that were against the lab bench during drying.*

The water-cement ratio can be minimized by optimizing aggregate gradation and by using plasticizing admixtures that also increase density.

Permeability

To minimize efflorescence, permeability also should be minimized in order to prevent or slow the migration of soluble salts. The first step is to use well-graded aggregates – especially avoiding gap grading. Another approach is to increase density. This may be achieved by the use of plasticizing admixtures, which not only increase density, but also may increase strength, decrease cycle time (in block production) and reduce water demand. It has been demonstrated that pore-blocking admixtures decrease permeability by acting as water repellents and greatly reduce water absorption. The MasterCast® 700 series of plasticizing admixtures significantly enhance cement efficiency, lower water demand, and increase density – all of which reduce the permeability of manufactured concrete products.

Admixtures

Admixtures can reduce efflorescence potential in a variety of ways. Stearate-based water-repellent admixtures work as pore blockers and, thereby, reduce water transmission. However, they provide only minimal efflorescence control.

Polymer emulsion-based admixtures also work as pore blockers, reducing water transmission, and in addition, provide enhanced efflorescence control, increased color vibrancy, and some freeze-thaw protection. The specific materials and combinations of materials used in polymer emulsion-based admixtures vary significantly, as does their effectiveness, as seen in Figure 8.

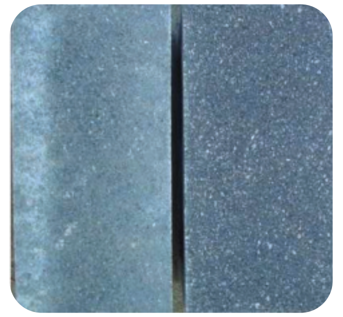

Figure 8: *Two,split-face concrete masonry units made with the same mix design, on the same machine,with back-to-back batches. A traditional water-repellent/efflorescence-control admixture was used in the block on the left,which shows efflorescence,while a patented, polymeric blend MasterPel admixture was used in the block on the right, with no efflorescence.*

The patented, polymer emulsion-based MasterPel technology provides superior concrete masonry performance compared to conventional water-repellent admixtures. MasterPel admixture has been optimized to provide the ultimate color vibrancy, color retention, efflorescence control, and freeze-thaw durability, all while maintaining excellent water-repellent properties.

Surfactant-based plasticizers and polycarboxylate-based plasticizers reduce efflorescence potential by increasing density, therby reducing permeability, and, in some cases, by reducing the amount of cement required for a given compressive strength. An added benefit is that often machine cycle times can be reduced with the use of these materials. The MasterCast® 600 and 700 series admixtures use a range of chemistries to provide the best end product for a variety of different mix designs.

Accelerating admixtures can sometimes help reduce a tendency to effloresce. This is because accelerating set reduces the time available for the migration of salts to the surface. One common accelerator, calcium choloride, has long been known to result in discoloration.