Efflorescence in Manufactured Concrete Products
(Prevention Guidelines)

Overview

Countless papers have been written over the years and a great deal of research has been performed to analyze the age old problem of efflorescence in manufactured concrete products. This document summarizes some of the most recent information and gives best practices for avoiding the potential for efflorescence.

ACI 116R defines efflorescence 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.

The main difference between primary and secondary efflorescence is basically when it occurs. Primary efflorescence occurs with the excess water of manufacturing concrete and typically happens during the first 48-72 hours. Secondary efflorescence is due to an outside source of water (i.e. rain, condensation) traveling into the concrete and pulling the salts back out to the surface. Both types are formed by the same process.

The Mechanism

For efflorescence to occur three conditions must be present:

- There must be soluble salts available.
- There must be water available to carry the salts in solution.
- There must be a pathway for the solution to migrate to the surface (and the water to evaporate).

The most common efflorescence salts are calcium carbonate, sodium sulfate, and potassium sulfate. By far, the worst kind and most reported is calcium carbonate. During the cement hydration process, calcium hydroxide, $Ca(OH)_2$, which is slightly soluble in water is formed. The $Ca(OH)_2$ dissolves and is carried to the concrete surface, where it reacts with carbon dioxide, CO_2, in the air and forms calcium carbonate, $CaCO_3$, and water, H_2O (as shown below).

$$Ca(OH)_{2(dissolved)} + CO_{2(dissolved)} \rightarrow CaCO_{3(solid)} + H_2O_{(liquid)}$$

The water evaporates and leaves the insoluble $CaCO_3$ on the surface, which cannot be washed off with plain water (must be removed by using weak acid solution and/or abrasion). Efflorescence formed similarly by sodium or potassium salts is usually less of a concern because it is water soluble and can more easily be removed.

Measuring Efflorescence

Since efflorescence is a surface phenomenon and is typically white, one easy way to evaluate the extent of efflorescence is by using a photometer, using the CIE Lab color system (specifically using the L* value for lightness). When comparing two samples, a higher L* value may indicate a higher degree of efflorescence (lightness). Analytical methods, such as infrared spectroscopy and X-ray diffraction, may be used for analysis as well.

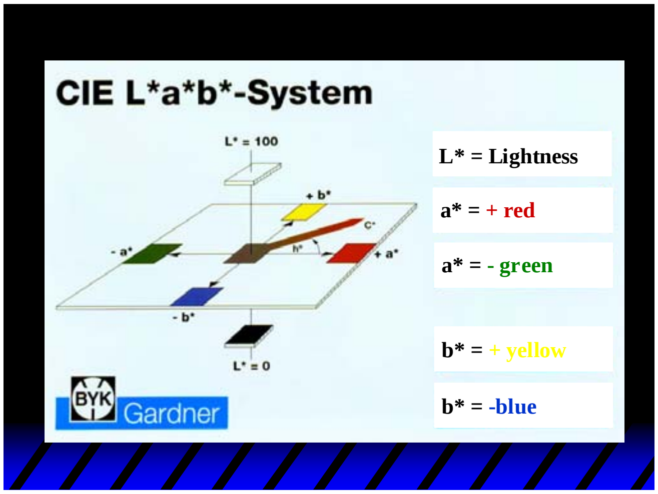

Figure 1 - CIELab Color System

Factors to Consider

There are many factors that affect the potential for efflorescence such as cement content, mix water, water/cement ratio, admixtures, curing conditions, and permeability.

As shown in Figure 2 & 3, an increase in cement content will tend to increase efflorescence potential. The samples were run with increasing levels of cement (bottom row is the bottom side of specimens, which were on lab bench and magnifies the efflorescence due to lack of air circulation). The water/cement ratio was held constant at 0.35 (along with all other factors).

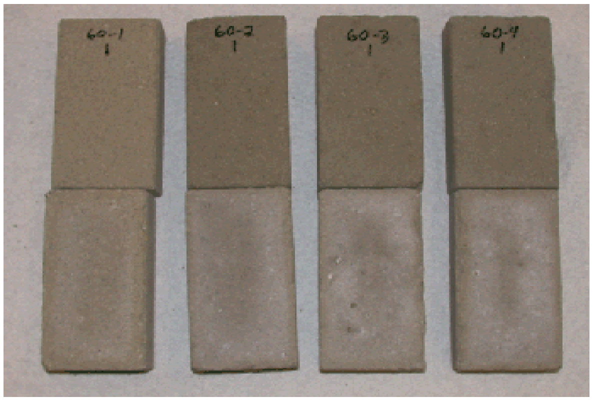

Figure 2 - Increasing cement contents (left to right)

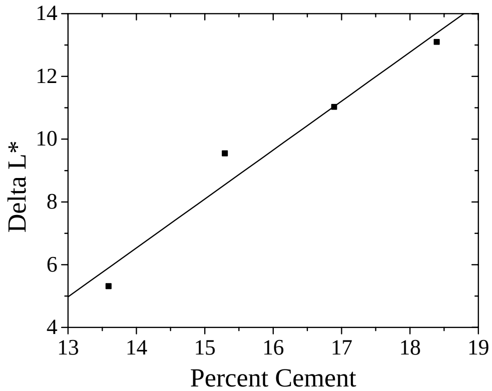

Figure 3 – Plotted change of L* from 1 to 7 days

Mix Water may contain various levels of calcium, magnesium, potassium, or sodium which can contribute to efflorescence potential. Sometimes water is softened by ion exchange, where each calcium (and magnesium) ion is replaced with 2 sodium ions (which are more soluble in water and may increase potential efflorescence).

Water/cement ratio is definitely a factor to consider. It is well known that increasing the w/c ratio leads to a more porous concrete matrix (Figure 4). This increases efflorescence potential by adding excessive water and creating easier pathways. Plasticizing admixtures have been shown to help optimize cement contents and water/cement ratios in manufacturing concrete products.

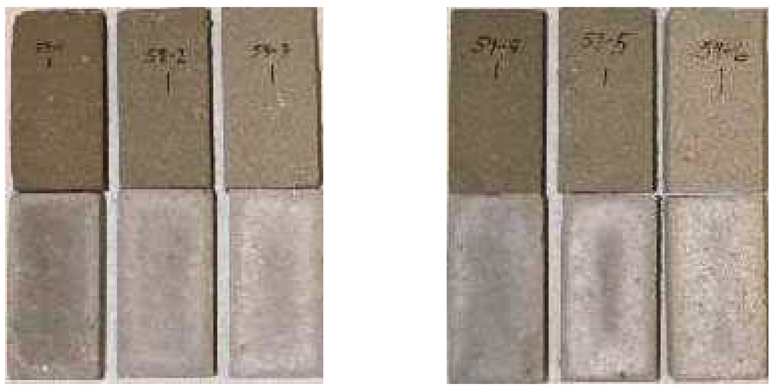

Figure 4 - Paver mixes with 13.6% (left set) and 18.3% (right set) cement
Water-cement ratios are 0.28, 0.35 and 0.42 from left to right in each set
Top row show surfaces that were open to the air during drying
Bottom row show surfaces that were against the lab bench during drying

Permeability is also a key factor in efflorescence potential, the less permeable the concrete matrix, the lower the efflorescence potential. Water-repellent (pore-blocking) admixtures have also been shown to decrease permeability by repelling water and reducing wicking potential (absorption) of concrete units.

Curing concrete products is essential for cement hydration and strength development. Typically steam is used (because of the high humidity and temperature) to accelerate the curing cycles. In some cases, carbon dioxide is forced into the concrete matrix, which theoretically forms efflorescence below the surface and blocks pathways for further efflorescence on the top surface (this process tends to be somewhat delicate to control due to several factors such as varying product densities, absorption rates, moisture contents, air circulation, humidity levels, etc.).

Conclusions/Summary

Unfortunately there is no" silver bullet" to totally eliminate efflorescence potential. There are the following steps that can be taken to avoid or greatly reduce the potential for efflorescence.

1. Optimize mix designs using quality materials
   a. Cement (too little leads to low density/high permeability, too much increases potential & expense)
   b. Water (keep water/cement ratios low, use plasticizing admixtures to assist)
   c. Aggregates (use well blended aggregates, optimization programs available that will help maximize cement efficiencies as well)
   d. Admixtures (plasticizers for enhancing production, increasing density, cement efficiency, and use water-repellent/efflorescence-controlling admixtures for lowering absorptions, enhancing color vibrancy, and improving overall water-repellency characteristics)
   e. Fly Ash (pozzolans or supplementary cementitious materials) typically help reduce efflorescence potential (color, consistency & early strength gain are usually concerns to evaluate)
2. Increase product density (by use of plasticizing admixtures or longer compaction times)
3. Properly cure concrete products (consistent temperature, moisture and air circulation)
4. Protect products from external water sources for as long as possible
5. Follow good construction practices (i.e. covering partial masonry walls, using low w/c mortar, & when cleaning walls don't use high-pressure)
6. Sealing of the external surfaces (if needed)

Following the above guidelines and maintaining a quality assurance program will greatly minimize the potential for efflorescence in manufactured concrete products.

References:

ACI Committee 116, :"Cement and Concrete Terminology, SP-19(90)" (ACI 116R-90), American Concrete Institute, Farmington Hills, MI

Technical Report – "Evaluation of the Causes of Efflorescence in Concrete Masonry Products and Recommended Guidelines for Efflorescence Control", Degussa Admixtures (Barbour, Culton, & Nmai), 2005

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