PCI Plant Quality Talk Series 4
Quality Enhancement Committee

NPCA National Precast Concrete Association

PCI Precast/Prestressed Concrete Institute

Series 4, Issue 1 – Efflorescence Basics

Series 4, Issue 2 – Removing Efflorescence

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SERIES 4, ISSUE 1 - EFFLORESCENCE BASICS

What Is Efflorescence?

Efflorescence is a whitish, powdery residue on the surface of concrete. It occurs due to the presence of soluble salts, such as calcium hydroxide, in the materials used to make concrete.

In concrete at early ages, the hydrated cement contains a substantial amount 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, where it reacts with carbon dioxide in the air to form the whitish deposit.

After stripping, efflorescence may appear within a few days. It sometimes does not appear until weeks, months, or (in rare cases) years have passed. Although efflorescence is generally harmless from a structural viewpoint, its initial appearance can be extremely detrimental to the appearance of a finished structure.

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 alkalis that contribute to efflorescence will vary depending on the cement source.
- Second, moisture must be present to dissolve the substances.
- Third, evaporation or hydrostatic or capillary pressure must cause the solution containing the dissolved substances to move toward the surface of the concrete. There must be a pathway through the pores or cracks in the concrete for the solution to move. Frequent wetting of the concrete surface helps facilitate this path.
- Fourth, the solution must evaporate once it reaches the surface of the concrete, leaving these soluble substances behind as efflorescence.

If any one of these conditions is eliminated, efflorescence will not occur. In most good-quality concrete, the efflorescence tendency will decrease 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.

Minimizing Efflorescence

- Use a low-alkali cement, or a cementitious materials combination low in alkalis.
- Use sand that meets the requirements of ASTM C33/C33M, ASTM C144, or CSA A23.1. Never use unwashed sand containing soluble alkali sulfates or sand contaminated from soil runoff, plant life, or decomposed organic compounds.
- Use clean mixing water that is free from harmful amounts of acids, alkalis, organic material, minerals, and salts.
- Consider using additives and/or surface sealers.
- Use ingredients and methods to reduce concrete permeability and produce a concrete with a low water absorption (5% to 6% by weight or 12% to 14% by volume). Concrete permeability and water absorption are the key factors that the producer can influence to minimize efflorescence. It is therefore important to ensure the following:
  - Properly graded aggregates
  - A minimum cement content for stripping and service strength requirements
  - A low water-cementitious material ratio
  - Good consolidation techniques
  - Thorough curing

Pigment Considerations

- 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 an efflorescence problem by making efflorescence more visible.
- Efflorescence deposited on the surface may mask the true color of the concrete, so that the pigment seems to be fading, even though the pigment itself has not changed.

Other Resources
Additional information on efflorescence can be found in PCI Technical Note TN-3, *Efflorescence on Precast Concrete*.

Note: Please complete this form and return to the Quality Control Manager. All crew members should be observant and report to their foreman anything out of the ordinary on a project. See something, say something.

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SERIES 4, ISSUE 2 – REMOVING EFFLORESCENCE

Efflorescence is a whitish, powdery residue on the surface of concrete. It occurs due to the presence of soluble salts, such as calcium hydroxide, which can be in the materials used to make concrete. When efflorescence occurs during or immediately following construction, your first impulse may be to immediately wash it off with water or an acid cleaning solution. This is *not* advisable, particularly in cool or damp weather, because such action can introduce more water into the concrete. The water or cleaning solution will wash some of the alkali salts from the surface, but it will also dissolve and carry the salts back into the concrete, thus causing a reoccurrence of the efflorescence. In almost all cases, if you can wait a year or two before acting, most of the salts will migrate 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 because it forms a hard white crust. After weathering to calcium hydrogen carbonate, it may be easily removed; otherwise, acidic cleaners may be necessary.

Efflorescence Test Area

Before beginning efflorescence cleaning operations on a large scale, a small area (at least 1 square yard) of the concrete surface should be cleaned and checked to be certain there is no undesirable effect on the concrete surface finish or adjacent corrodible materials such as glass, metal, or wood. A strip-off plastic can be sprayed onto glass and aluminum frames to protect them. The effectiveness of the method on the sample area should not be judged until the surface has dried for at least one week. If possible, concrete should be cleaned when the weather conditions, including temperature and relative humidity, allow for rapid drying. Slow drying increases the possibility of recurring efflorescence and discoloration.

Suggested Testing Process

When choosing a cleaning method to remove efflorescence from precast concrete, the least-damaging option should be tested first. The following is a suggested order for testing efflorescence removal procedures (beginning with the least damaging technique):

1) Dry scrubbing with a stiff fiber brush (particularly if the surface is brushed shortly after appearance of efflorescence).
2) Abrasive blasting with industrial baking soda. This abrasive will minimally affect the concrete surface. Residues should be blown, vacuumed, or brushed from the surface. Do *not* use water to remove residue on the surface—the water could dissolve salts and carry them into concrete, causing additional efflorescence.
3) Vigorous dry scrubbing of the finish with a stiff fiber brush followed by low-pressure washing of the surface.
4) Chemical cleaning compounds such as detergents, hydrochloric (muriatic) or phosphoric acid, or other commercial cleaners used in accordance with the manufacturer's recommendation. To prevent the chemicals from being absorbed deeply into the surface of the concrete, areas to be cleaned chemically should be thoroughly saturated with clean water before the cleaning material is applied. Surfaces should also be thoroughly rinsed with clean water after application so that no traces of detergents or acid remain on the surface of the concrete. Cleaning solutions should not be allowed to dry on the concrete surface. Residual salts can flake or spall the surface, or they may leave difficult-to-remove stains. Misapplication of hydrochloric (muriatic) acid can lead to corrosion of adjacent or embedded metals with shallow cover. Care should be taken to use diluted solutions of acid to prevent surface etching, which may reveal the aggregate and slightly change surface color and texture. Apply the solution to just one small area (less than 4 ft^2) at a time, and then wait about 5 minutes before scouring off the salt deposit with a stiff bristle brush and moving on to the next small area.

Any of the following diluted solutions of acids will effectively remove efflorescence:

- 1 part hydrochloric (muriatic) acid in 9 to 19 parts water
- 1 part phosphoric acid in 9 parts water
- 1 part phosphoric acid plus 1 part acetic acid (vinegar) in 19 parts water
- 1 part acetic acid in 5 parts water

Hydrochloric (muriatic) acid may leave a yellow stain on white concrete. Therefore, if an acid solution is needed to clean white concrete, a solution with phosphoric or acetic acid should be used.

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Safety Precautions

- Materials used in chemical cleaning can be highly corrosive and are frequently toxic. Therefore, rubber gloves, safety eyewear, a respirator, and other protective clothing should be worn, in accordance with the manufacturer's recommendations, when using acid solutions or strong detergents.
- All precautions on a product label should be followed as these cleaning agents can affect eyes, skin, and breathing.
- Materials that can produce noxious or flammable fumes should not be used in confined spaces unless adequate ventilation can be provided.

Other Resources

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SERIES 4, ISSUE 3 – WATER-CEMENTITIOUS MATERIAL RATIO

The water-cementitious material ratio (*w/cm*) is the ratio of the mass of water to the mass of the cementitious material in a concrete mixture, expressed as a decimal. It is a key factor affecting the properties of concrete, such as strength, workability, durability, and consistency.

The water-cementitious material ratio is calculated as follows:

w/cm = Mass of water / Total Mass of cementitious materials

The mass of the water used in the calculation includes the mass of the water directly added to the mixture as well as that added indirectly, such as in the aggregates. The total mass of the cementitious materials includes the mass of the cement as well as the mass of any supplementary cementitious materials such as fly ash, silica fume, and slag.

Instructions for a concrete mix design will specify the *w/cm*. The *w/cm* is used to determine the maximum amount of water to add to the mix including free water in excess of the saturated surface dry (SSD) condition of aggregates. If too much water is added to the concrete, the actual *w/cm* will be higher than the specified *w/cm*. That is a problem because adding too much water can weaken concrete: The excess water creates a diluted paste that separates cement particles. Then, when the cement and water chemically react to form crystals, the crystals are too far apart to form a strong bond. Concrete with a higher *w/cm* ratio is more susceptible to dry shrinkage cracking.

The water content requirements for a concrete mixture can be influenced by any or all of the following:

- Cementitious material types and content
- Aggregate size and shape
- Air content
- Admixtures
- Environmental conditions

Water demand can be lowered by the following:

- Increased air content
- Increased aggregate size
- Use of a rounded or cubical aggregate
- Use of a high-range water-reducing admixture

On the other hand, water demand is increased by the following:

- Increased concrete temperatures
- Increased cementitious material content
- Increased aggregate angularity
- An increase in the ratio of fine aggregate to coarse aggregate
- Use of lightweight aggregates

Per MNL 116 and MNL 117, the maximum allowable *w/cm* ratio for normal weight concrete is 0.45. During production, the *w/cm* is not allowed to vary from the ratio specified in the mixture design by more than 0.02.

Example:

Assume a batch with 30 gallons of water, 550 lb of cement, and 150 lb of fly ash. Each gallon of water weighs 8.33 lb. Aggregates are at SSD condition.

30 gallons × 8.33 lb/gallon = 250 lb of water

w/cm = 250 lb water / (550 lb cement + 150 lb fly ash) = 0.36

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SERIES 4, ISSUE 4 – REDUCING EMBODIED CARBON

Embodied carbon in a construction project is the amount of carbon dioxide equivalent (CO_2e) associated with the extraction, processing, manufacturing, transportation, and installation of building products. Embodied carbon is also referred to as global warming potential (GWP).

For concrete, embodied carbon includes the CO_2e associated with the extraction, handling, and processing of the concrete materials, and the CO_2e involved in batching the concrete and operating the production facility. In an environmental product declaration (EPD), embodied carbon is qualified as the mass of CO_2e per unit mass of concrete. Although portland cement production is a relatively energy-efficient process, more than 80% of the embodied carbon in concrete is typically from cement. Using supplementary cementitious materials such as fly ash to replace a portion of the cement content can reduce embodied carbon.

A maximum GWP limit for each concrete mixture may be specified. These GWP values may be derived from benchmark values for varying strength levels of typical mixtures. Factors that affect baseline embodied carbon, such as design strength, low water-cementitious materials ratios, and high reinforcing steel ratios should be considered, and adjustments made to stay below the specified maximum GWP.

Optimizing Concrete Mixtures for Lower Embodied Carbon

When concrete mixtures are optimized for performance and economy, their embodied carbon content will generally be lowered. The GWPs of individual materials and concrete production practices will affect the embodied carbon content of the concrete mixture. Consider local sources to reduce GWPs when optimizing mixture proportions.

Reducing the Paste Volume of Mixtures

Because of the high percentage of embodied carbon associated with cement, reduction of paste volume can be considered. Reducing paste volume involves reducing the content of mixing water and cementitious materials while maintaining the same water-cement ratio. The paste volume can be reduced by implementing some or all the following options:

- Use a larger-size coarse aggregate.
- Use low-water-demand fine aggregate, such as gravel, and rounded, clean, or very well graded sand.
- Combine the aggregate in appropriate percentages to increase packing density.
- Use cementitious materials that reduce water demand.
- Use high-range water-reducing admixtures.
- Use cement hydration–enhancing admixtures.

Using fly ash or slag cement as a portion of the cementitious materials will reduce the required mixing water content for the target slump. Replacing portland cement with an equal weight of fly ash or slag cement will increase the volume of cementitious materials, but the lower mixing water content will have a net effect of a reduced paste volume.

Structure design

The design of a structure can affect its carbon footprint. The use of higher-strength concrete can reduce component size and the amount of required reinforcement, and the reduced quantity of materials thereby reduces the structure's embodied carbon. Higher-strength concrete can be designed with reasonably low quantities of cementitious materials.

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SERIES 4, ISSUE 5 – MATH FOR PRESTRESSED CONCRETE: CONCRETE YIELD

Concrete is ordered by volume (per cubic yard) and batched by weight. If concrete ingredients are not accurately batched and combined, the materials may produce either more or less than the desired volume.

Yield refers to the actual volume of concrete produced from the batched materials.

- *Over yield* occurs when the weight of the materials batched provides a volume of concrete that is more than what was originally calculated and ordered. An over yield of concrete can increase the risk that the concrete may be rejected because it fails the project acceptance criteria for fresh concrete, strength, or durability requirements. If over yields are due to batching inaccuracy, that can also cause problems with inventory control of ingredients.
- *Under yield* occurs when the weight of the materials batched provides a volume of concrete that is less than what was originally calculated and ordered. An under yield of concrete can negatively affect the resulting properties of the mixture. For example, 2% under yield may result in 2% more cementitious material content per cubic yard than what was ordered. Under yield can also increase the standard deviation of strength, thereby reducing the quality of the concrete and increasing the cost of all concrete produced. An under yield can also lead to the need to order an additional, partial load because there is insufficient concrete to complete the casting operation.

Calculating Density (ASTM C138/C138M) (see Note 1)

- Select a container whose volume is known.
- Weigh the dampened, empty container.
- Fill the container with concrete, as described in ASTM C138/C138M.
- Weigh the full container; record the value to nearest tenth (0.1) of a pound
- Subtract the empty container weight from the full container weight to get the weight of the concrete.
- Divide the weight of the concrete by the known container volume to get the density (unit weight) of the fresh concrete.

Calculating Yields

Calculate the following using the total weight of all materials batched (aggregate, water, cement, etc.):

- Yield per batch in cubic feet = Total weight of all materials (lb) / Fresh density (lb/ft^3)
- Yield per batch in cubic yards = Total weight of all ingredients batched (lb) / [Fresh density (lb/ft^3) × 27]
- Yield per cubic yard in ft^3/yd^3 = Yield per batch in ft^3/Number of cubic yards delivered
- Yield as a percentage = (Actual volume of concrete/Reported volume) × 100

Example Problem

Assume a concrete batch with the following properties:

Volume of concrete targeted = 4 yd^3

Weight of materials batched = 15,930 lb

Cementitious materials = 2800 lb

Sand = 5520 lb

Stone = 6627 lb

Water = 118 gal x 8.33 lb/gal = (983 lb)

Density (unit weight) of the concrete = 147.52 lb/ft^3

Yield = 15,930 / (147.52 × 27) = 3.99 yd^3 in the actual batch

Yield per batch = 15,930 lb/147.52 lb/ft^3 = 107.98 ft^3

Cubic yards delivered = 4

Yield per cubic yard = 107.98 ft^3/4 yd^3 = 26.99 ft^3/yd^3

Yield (%) = (3.99 yd^3 4 yd^3) × 100 = 99.8%

Gravimetric Air Content Calculation

ASTM C138/C138M provides a method for calculating the air content of freshly mixed concrete using the gravimetric method.

The formula for calculating gravimetric air content is as follows:

$A = (B - C) \times 100/B$

where

A = air content as a percentage by volume

B = theoretical air-free density of the concrete in pounds per cubic foot

C = density (unit weight) of the fresh concrete in pounds per cubic foot

For example, if the theoretical air-free unit weight is 151.7 lb/ft^3 and the measured density (unit weight) is 141.4 lb/ft^3, the air content would be 6.8%:

$A = (151.7 \text{ lb/ft}^3 - 141.4 \text{ lb/ft}^3) \times 100/151.7 \text{ lb/ft}^3 = 6.8\%$

Notes

1. This is a summary of the steps involved. Be sure to review ASTM C138/C138M for a full description of the process and requirements.
2. The suggested tolerance for yield is ±1% for non-air-entrained concrete and ±2% for air-entrained concrete. (NRMCA TIP-8, Concrete Yield)

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SERIES 4, ISSUE 6 – PROPER USE OF PNEUMATIC POWER TOOLS

Pneumatic tools are powerful and efficient, but unsafe use of them can cause serious injuries. Treat pneumatic tools with the respect given to any power source, and maintain awareness of stored energy. Air pressure can be as dangerous as electricity; respect it, control it at all times, and never bypass safety devices.

Safe habits prevent accidents.

General Safety

- Always inspect pneumatic tools, hoses, and fittings before use for wear, cracks, leaks, and moisture.
- Inspect air hoses for wear before use. Keep air hoses out of the paths of vehicles and areas with high foot traffic.
- Only trained personnel should operate pneumatic tools.
- Follow manufacturers' instructions and OSHA/ANSI standard 29 CFR 1926.302 (b), Pneumatic Power Tools.
- The tool operator and all persons in close vicinity to pneumatic tools in operation must use appropriate personal protective equipment.

Air Supply and Pressure

- Use a regulator to ensure the air pressure is at the manufacturer's recommended air pressure and never exceed the maximum pressure rating. A perceived lack of air pressure could be caused by an inadequate volume of air or a kinked hose. Ensure that all hoses and fittings are properly sized and are not kinked to provide the proper air volume, which is usually measured in cubic feet per minute.
- Install safety devices such as pressure relief valves.
- Bleed pressure from hoses before connecting, disconnecting, or servicing tools.

Hoses and Connections

- Use hoses and couplings rated for at least the maximum allowable pressure of the pneumatic tool.
- Secure hose connections with safety clips and restraints to prevent hose whipping.
- Route hoses to avoid trip hazards, sharp edges, pinch points, and hot surfaces.
- Never carry tools by the hose.

Tool Handling

- Use only accessories that are intended for pneumatic tools. **DO NOT** use chrome sockets on air wrenches or impact wrenches.
- Disconnect tools from the air supply when changing cutting accessories (for example, chisels, drill bits, blades) or when not in use.
- Keep hands clear of rotating, cutting, or impact points.
- Maintain a firm grip and stable stance during operation.
- Do not use compressed air to clean skin, clothing, or hair, and never direct air toward yourself or others.

Work Environment

- Ensure good lighting and clean, dry surfaces to prevent slips.
- Use proper ventilation where dust, fumes, or exhaust may be generated.
- Keep bystanders at a safe distance during operation.
- Secure tools with lanyards when working at heights.

Maintenance and Storage

- Perform regular maintenance (for example, lubrication, after-coolers, filter checks, O-ring replacement) per manufacturers' guidelines.
- Tag and remove defective tools from service immediately.
- Do not modify tools except as allowed by the manufacturer.
- To prevent damage, store hoses coiled and store tools in designated areas.

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