So, what about chloride chemicals applied to concrete surfaces too soon?

# Some Truths and Fantasy About Chloride De-icing Chemicals

By Bernard Erlin & Dipayan Jana

Concrete must be one year or older before de-icing chemicals are applied. Or does it? Our experience is that a one-year waiting period is not needed for concrete that is well made, well finished, of adequate strength, has undergone a short period of air drying, and has an effective air-void system. Concrete that does not meet these criteria is always vulnerable to scaling when it becomes saturated and freezes. De-icing chemicals increase that vulnerability and may lead to scaling in concrete that might otherwise have performed acceptably despite being marginally air-entrained or having surface defects caused by improper finishing.

To make our point, we present three case studies. The first, a residential concrete driveway, survived 20 years without scaling until calcium chloride de-icing chemicals were applied. The second case study, a residential concrete sidewalk, deals with slightly different entrained air-void systems and the effects of sodium and calcium chloride de-icing chemicals. The final case study is a residential driveway that illustrates how gross variations of air-void systems affect scaling resistance whether or not chloride de-icing chemicals were used.

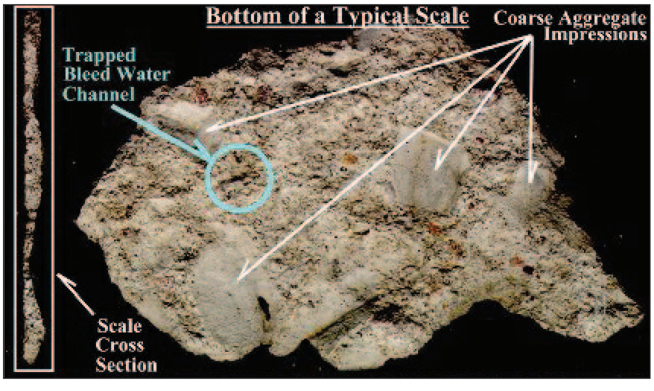

**Figure 1. Features on the bottom of a scale.**

### Case study 1

A 20-year-old residential driveway in the northwestern United States had never been exposed to de-icing chemicals. The owners of the property decided to use a proprietary calcium chloride de-icing chemical that was warranted to not cause scaling of properly made concrete that had been suitably designed to withstand cyclic freezing. The de-icing chemical was applied—and, to the dismay of the owners, the concrete scaled during the winter in which it was applied. The owners angrily contested the non-scaling claim by the manufacturer of the chloride de-icing chemical, noting that the concrete had withstood 20 years of exposure to cyclic freezing without a surface blemish.

From a non-legal viewpoint, that seemed valid to the owners, and they demanded replacement of the driveway under the manufacturer's warranty. Disregarding the legalities, as petrographers we wish only to look at the facts that led to the scaling.

Petrographic studies of scaled concrete from the driveway (performed according to ASTM C856, "Petrographic Examination of Hardened Concrete") (see Fig. 1) revealed that:

(a) the scales are up to 1¾ inches in diameter and ⅛ inch thick

(b) rather than having a lenticular configuration (lens-shaped), as is typical for scales that result from inadequate air-void systems, the scales' thickness is relatively uniform from edge to edge

(c) impressions of the topsides of aggregate particles are embossed on the undersides of the scales

(d) several telltale vertical channels created by bleed water terminate just inside the bottom of some of the scales

(e) the paste has features that led us to estimate the water-cement ratio to be 0.57, and is carbonated (as normal), and

(f) the scales contain a handful of small, discrete, spherical voids characteristic of entrained air voids.

These features led us to conclude that the driveway had been improperly

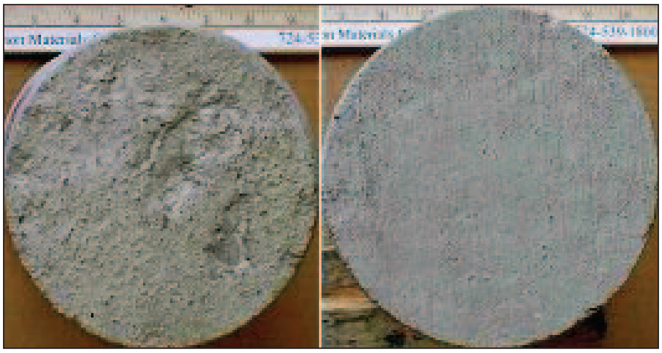

**Figure 2. Scaled and unscaled surfaces from adjacent sidewalk.**

finished. The petrographic data demonstrates that:

(**a**) although the concrete had been improperly finished 20 years before the de-icing salt was applied, it was not sensitive to the effects of cyclic freezing, and

(**b**) the de-icing salt took advantage of the surface-deficient concrete and created a harsher environment than the previous exposure, which was enough to cause the scaling.

The fact is that the concrete did its best for 20 years—even with its inherent surface imperfections—until the chloride de-icing salt finally did the surface in. Perhaps this case is a tribute to the vigor of concrete, to the innate nature of concrete to sustain, and to the forgiving nature of concrete that, up to a point, will perform well even though it is mishandled in construction.

## Case study 2

Sidewalks that had been placed during July, August, and September were exposed to sodium and calcium chloride de-icing chemicals in November. The sidewalks were about 4 inches thick, had a finely broomed finish, and were in 4 x 5 foot panels separated by saw-cut control joints.

Some of the panels had scaled to depths of ⅛ inch so that coarse and fine aggregate particles were prominently exposed; panels on the other side of a joint, however, were unscaled (Fig. 2). The concrete appeared to be from the same or similar concrete batches and both had been exposed to the same environmental conditions that included chloride-deicing chemicals.

Cores taken from adjacent scaled and unscaled panels were examined using standard petrographic methods, air-void analyses were done using a standard modified-point count method (ASTM C457, “Microscopical Determination of the Parameters of the Air-Void System in Hardened Concrete”), and chloride analyses were done using a standard chemical method (ASTM C1152, “Acid-Soluble Chloride Content of Mortar and Concrete”). These examinations of the scaled and unscaled concretes revealed that both:

(**a**) are air-entrained

(**b**) contain crushed limestone-dolomite coarse aggregate and natural siliceous-calcareous sand fine aggregate

(**c**) have cementitious materials contents estimated to be equivalent to 7½ bags per cubic yard, of which 20 percent is estimated to be fly ash, and

(**d**) have water-cementitious materials ratios estimated to be 0.42 to 0.46.

Thus, the scaled and unscaled concretes outwardly have similar compositions, and there is no evidence of improper finishing. The chloride contents both at the surface of the concretes and in the middle are also similar: 0.07 and 0.06 percent by mass at the top and 0.02 percent by mass in the middle (see table). The higher chloride contents at the top are consistent with the reported application of chloride de-icing chemicals.

Since chloride de-icing chemicals had been applied to the scaled and unscaled concretes, something other than the de-icing chemicals is responsible for their different performances. The difference we found was the air-void systems.

In addition to the industry-recognized air content requirement of 6±1½ percent obtained using an acceptable air-entraining admixture (for concrete with ¾- to 1-inch aggregate that is in a severe weathering environment), the industry also recognizes two other requirements of air-void systems that are usually not specified. These requirements are related to the size of entrained air voids and the distance between them, expressed as specific surface and void spacing factor.

The specific surface relates to the size of the air voids—the greater the number, the more small bubbles there are in the concrete. The void spacing factor is half the distance between air voids, in other words, the farthest distance water would have to travel to enter an air void. For an air-void system to be effective, the specific surface should be at least 600 ($in^2/in^3$), and the void spacing factor should be 0.008 inch or less. The determined air contents, calculated specific surfaces, and void spacing factors of the scaled and unscaled concretes are given in the table.

The air contents of both concretes are within the 6±1½ percent requirement, but their specific surfaces and void spacing factors are significantly different. The specific surface and void spacing factor of the unscaled concrete are acceptable—for the scaled concrete they are not. Air voids in the scaled

### Scaled versus unscaled concrete sidewalks—Case study 2

| | Air-void parameters | | | Chloride (% by mass of concrete) | |
|---|---|---|---|---|---|
| **Cores** | **Air content (%)** | **Specific surface ($in^2/in^3$)** | **Void spacing factor (in.)** | **Depth (in.)** | **(%)** |
| Scaled | 5.8 | 465 | 0.0091 | 0–½<br>2½–3 | 0.07<br>0.02 |
| Unscaled | 6.7 | 685 | 0.0063 | 0–½<br>3½–4 | 0.06<br>0.02 |
| Industry Standard | 6 ± 1½ | >600 | <0.008 | - | - |

concrete are too big, and the distance between air voids is too large; the concrete has a coarse air-void system. Possible causes for the different air-void systems include:

(**a**) variations of air within the concrete batch, such as due to a delay in discharge after some of the batch was placed

(**b**) the addition of water to a partially discharged batch, and

(**c**) continuation of concrete placement using a new concrete batch.

The cause of the scaling is an air-void system that is ineffective at protecting concrete from cyclic freezing, especially when exposed to the aggravating effects of chloride de-icing chemicals.

### Case study 3

Some concrete driveways in a residential subdivision in the Midwest scaled while others did not. The concrete came from a single supplier, and several contractors were involved in the driveway construction. There was no pattern to the distress, although there were claims that de-icing chemicals caused the scaling. Concrete samples from randomly selected scaled and unscaled driveways were examined in the laboratory using standard petrographic methods; air-void analyses were done using a standard modified-point count method.

To summarize the results:

(**a**) coarse and fine aggregates were similar in all of the concrete samples examined

(**b**) the samples contained similar cementitious material contents in amounts estimated to be equivalent to six bags per cubic yard, of which 20 percent was estimated to be fly ash

(**c**) water-cementitious material ratios were similar and estimated to be 0.40 to 0.45, and

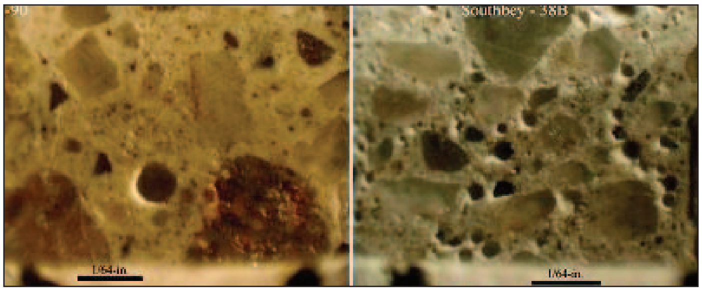

**Figure 3. Cross sections of the non-air- and air-entrained concretes.**

(**d**) there was no evidence that the concrete was improperly finished.

The difference, however, is in the air-void systems of the scaled and unscaled driveways. Based upon the petrographic examinations, the scaled concretes are poorly air-entrained, with air contents ranging from 1½ to 3 percent; the unscaled concretes are properly air-entrained and have estimated air contents of 5 to 5½ percent.

Figure 3 shows cross sections of the non-air-entrained scaled concrete and the air entrained unscaled concrete. There is a direct relationship between scaling and the nature of the air-void system in the concrete. Whether or not de-icing chemicals were used is irrelevant. The absence of air entrainment led to the distress. De-icing salts may have aggravated scaling of the non air-entrained concrete, but scaling would have occurred with or without the salt.

Although it may be surprising to find this much variation in air content within a single project and for concrete supplied by a single company, we find that it is not unusual. This example indicates the need for frequent concrete air measurements, which can be done using one of several ASTM methods:

## Cold weather concreting tips

For successful cold weather concrete placement, consider these tips:

**General:**

- Schedule/plan a preconstruction meeting.
- The recommended minimum concrete temperature at the time of placement is a function of the minimum dimension of section size and ambient temperature. See Table 3.1 of ACI 306R-88 for guidance.
- Make sure that the concrete has been proportioned for cold weather placements including the appropriate accelerating admixtures.
- Accelerators are not antifreeze agents, they just shorten the set time and accelerate strength-gain of protected concrete.

**Batching & mixing:**

- Aggregate temperature will affect the concrete temperature more than any other constituent since aggregate occupies the most volume in a concrete mix. Hot water can also be used to heat the mix.
- Sequence batches to avoid contact between hot water and cement.

**Placing & curing:**

- Plan ahead—make sure you have all the equipment necessary for placement, including plenty of blankets and heaters if necessary. Consider having backup equipment for critical items like vibrators and heaters.
- Do not place concrete on frozen ground. Remove all snow, ice, and frost from areas to be concreted.
- The temperature of embedded items (including reinforcement) should be above freezing when coming in contact with concrete.
- Cure concrete after placement and protect it from freezing. Edges and corners of placements are more susceptible to freezing, so give them extra protection. Do not allow concrete to dry out during the curing and protection period.
- If combustion heaters are used, make sure the exhaust is vented properly to reduce risk of carbonation that can lead to dusting of concrete surfaces.
- Maintain in-place temperature at 50° F, or greater, until required strength has been attained. Consider nondestructive methods of determining in-place strength such as the maturity method.
- At the end of the protection period, concrete should be cooled gradually to reduce the potential of cracking due to thermal stresses.

These are general tips for cold weather concreting. For specific recommendations refer to ACI 306R-88.

— Jeffrey Groom, PE, Vice President/ Principal Engineer of CTL|Thompson Materials Engineers

- ASTM C231, “Air Content of Freshly Mixed Concrete by the Pressure Method”
- ASTM C173, “Air Content of Freshly Mixed Concrete by the Volumetric Method”, or
- ASTM C138, “Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.”

For the C138 method, a relatively small container holding two tenths (0.2) of a cubic foot can be used for up to 1-inch aggregates. The container is filled with concrete and weighed, and that weight is compared to the design weight. A small hand-held device for more general field use is the Chase Air Indicator.

**Comments**

When scaling due to cyclic freezing occurs, often the cause is judged to be de-icing chemicals, particularly calcium chloride. It’s the easy one to blame because it is so commonly used, and it has, through the years, become the scapegoat of scaling distress.

In our experience, though, concrete that has attained maturity (or near maturity), that has an air-void system that meets industry standards, and that is properly made, cured, and finished, will be resistant to the damaging effects of cyclic freezing and de-icing chemicals. The need for concrete “maturity” is emphasized in the ACI Committee 201.2R report (Guide to Durable Concrete) that states, “Before being exposed to extended freezing while critically saturated ... concrete should attain a compressive strength of about 4000 psi. A period of air drying following curing is advisable.” We recommend that the concrete achieve a compressive strength of about 3000 psi for moderate exposure.

Our experience, based upon detailed laboratory studies of thousands of samples, attests to the durability of concrete sidewalks and driveways that are:

- made with good-quality air-entrained concrete
- constructed using sound construction practices
- allowed to “mature” before exposure to cyclic freezing and de-icing chemicals.

Owners are typically cautioned to not apply de-icing chemicals during the first winter, or for one year after construction. That may be sound advice to ensure that concrete has reached maturity before being exposed to cyclic freezing and de-icing chemicals, and thus is strong enough to resist their potential damaging effects. Waiting until the attainment of maturity is essential, but prolonged waiting is irrelevant once concrete has matured.

But how does one know when the concrete is mature? Because ambient conditions usually are not accurately known, there is no simple gage that can be used. Certainly maturity meters can be used and provide good information. But when there is a problem, the best approach to understanding why concrete has or has not been durable is to analyze it using petrographic methods. ■

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