Concrete, Construction, or Salt— Which Causes Scaling?

Part 2: Importance of finishing practices

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Scaling of concrete surfaces is a common problem in many outdoor slabs exposed to deicing salts and cyclic freezing and thawing. Despite occurrences of adjacent panels—one perfectly sound while the other severely scaled—exposed to the same deicing conditions, salt is, allegedly, the most common culprit of scaling. The first part of this two-part article described how a poor air-void system can cause surface scaling in concrete. In all case studies described, concrete scaling was *initiated* due to the poor air-void system and was *aggravated* by the presence of deicing salts. Concrete with a good air-void system showed much better resistance to freezing and salt than that with a poor air-void system.

This second part describes three additional case studies where, despite having good air-void systems, the concrete scaled due to improper finishing practices such as: a) initiation of finishing prior to the cessation of bleeding (entrapping bleed water under the finished surface); b) finishing in the presence of excess water at the surface, which reduces the scaling and abrasion resistance of the surface; and c) prolonged finishing, which severely reduces the air content at the surface and increases the concrete's potential to scale.

IMPORTANCE OF FINISHING

Case study I: Premature finishing

This particular case study is of a concrete sidewalk that developed severe scaling in some panels within 2 years of placement. The scaled panels, however, were adjacent to sound, broom-finished panels. Within the scaled panels, isolated areas lay where the original broom-finished surface was found loosely adhered to the main body of the slab with a distinct gap (Fig. 1). This gap between the loosely attached, finished surface (having a nominal thickness of 1/8 in. [3.2 mm]) and the main slab is usually less than 1/8 in. (3.2 mm) in width.

The sheet-like masses of loosely adhered finished surfaces are incipient scales, ready to be scaled off by cyclic freezing and thawing and/or by traffic loading. Unlike the lenticular configuration of scales formed by cyclic freezing and thawing of poorly air-entrained concrete, these sheet-like scales have an almost uniform thickness. Areas surrounding the incipient scales are severely scaled where the finished surface is missing, and coarse and fine aggregate particles are exposed; therefore, it is unlikely that this difference in surface conditions of adjacent panels is due to the application of deicing salts.

Detailed petrographic examinations of core samples taken from the sound and scaled panels showed textural and microstructural evidence indicative of premature finishing (that is, finishing prior to the cessation of bleeding, which entraps bleed water underneath the finished surface and causes scaling and incipient scales). Some of this textural and microstructural evidence includes bleed water channels, soft paste at the surface, and coarse aggregate sockets on the scaled surface and on the undersides of scales (Table 1 and Fig. 1).

The optimum time to finish a concrete surface has proven to be between the initial and final sets. Conditions that slow and/or prolong bleeding and/or increase the rate of evaporation of water at the surface alter the optimum finishing time and increase the potential for premature finishing. In the petrographic analysis, the air-void systems of both scaled and sound cores were similarly good in the slab and at the surface, thus they were not responsible for scaling. Because deicing salts increase the degree of saturation of concrete, the gap underneath the incipient scales saturates more easily in the presence of salts, which increases the aggressiveness of scaling.

Case study II: Excess surface water

Figure 2 shows a core taken from a contraction joint in a sidewalk having adjacent sound and scaled panels.

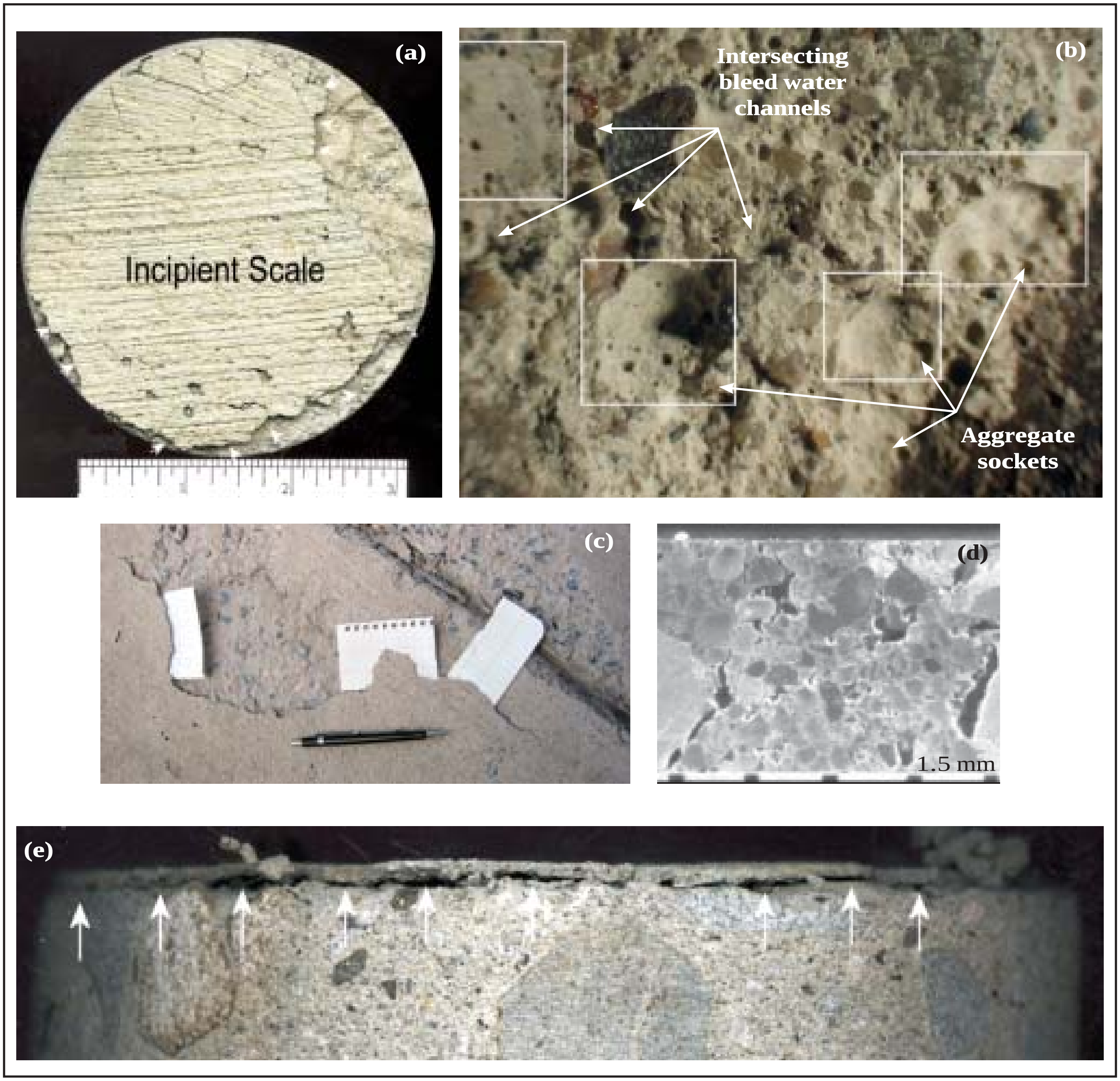

Fig. 1: Case study I (Scaling due to premature finishing)—Shown are: (a) a core from an incipient scale showing a broom-finished surface loosely adhered to the body of the core; (b) abundant coarse aggregate sockets, intersecting bleed water channels, and voids on the scaled surface; (c) insertion of paper into the "gaps" between the finished surface and the body; (d) bleed water channels underneath the finished surface; and (e) the incipient scaling of the finished surface in the side view of the core shown in (a)

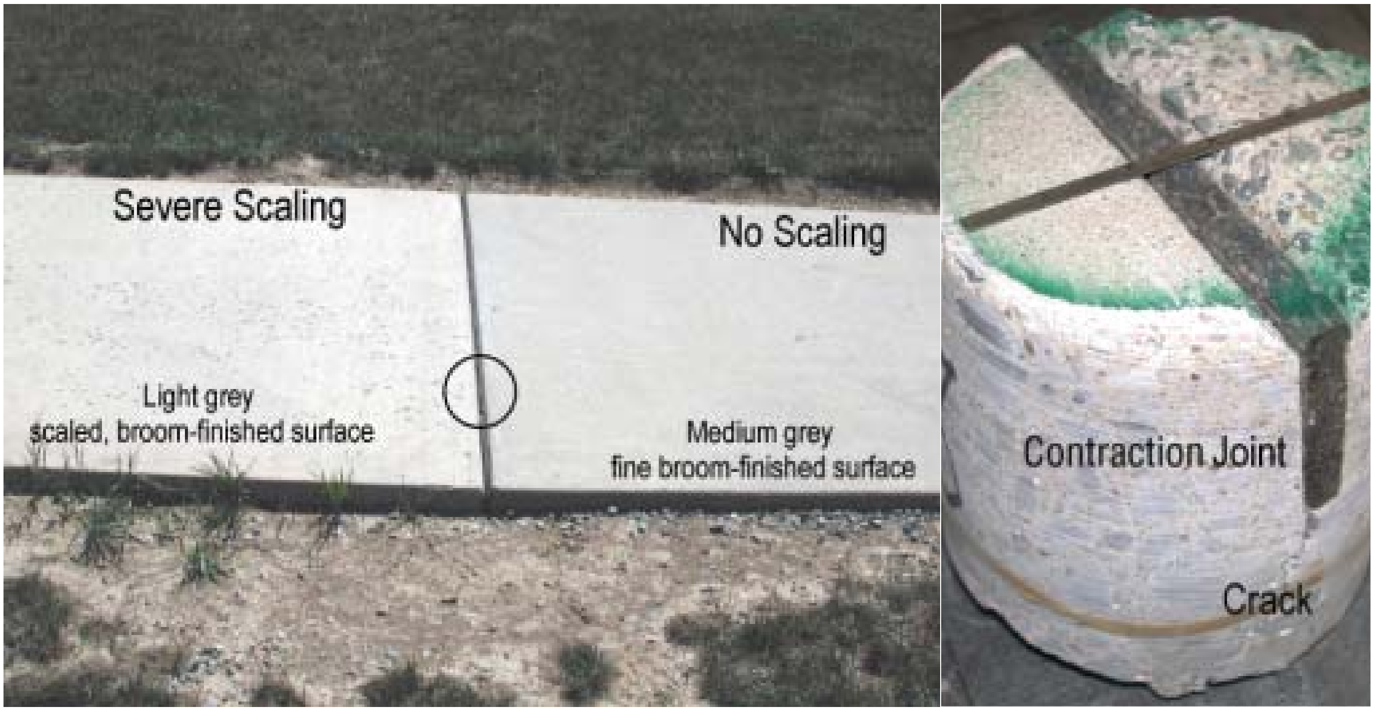

Fig. 2: Case study II (Scaling due to finishing in the presence of excess water at the surface)—Concrete core from a contraction joint showing adjacent sound and scaled surfaces

TABLE 1: Some petrographic observations in the three case studies of scaling described in this article

Case studies of scaling	Petrographic observations
I: Scaling due to cyclic freezing and thawing of concrete that has been finished prematurely prior to the cessation of bleeding	1) A distinct, narrow separation (not a crack) between the loosely adhered finished surface (the incipient scale) and the body of the concrete. 2) Uniform thickness of loose scales. 3) Texture of the underside of the incipient scale shows irregularly shaped water voids that are indicative of bleed water entrapment. 4) Narrow, vertical, stringy voids or bleed water channels in the body, some of which may be intersected by the scaled surface. 5) Evidence of excessive bleeding in the concrete such as progressively increasing *w/cm* toward the top and laitance. 6) Texture of the freshly scaled surface under the loosely adhered, incipient scale shows soft, high *w/cm* paste relative to the *w/cm* in the main slab. 7) The scaled surface (and the underside of incipient scale) contains abundant coarse aggregate sockets that are indicative of a weak aggregate-paste bond due to the presence of excess water during finishing.
II: Scaling (abrasion) due to finishing in the presence of excess water at the surface	1) Soft, porous, fragile, high *w/cm*, light gray paste on the scaled surface and to a depth of 1/8 to 1/2 in. (3 to 13 mm). 2) Distinct variations of these surface properties from the paste in the interior of the slab. 3) High depth of carbonation. 4) The abundance of residual portland cement particles is significantly less at the surface than in the interior; the degree of hydration of cement particles is adequate at the surface.
III: Scaling (delamination) due to prolonged finishing and lack of air voids at the surface	1) Severe loss of air at the surface and in the near-surface region of air-entrained concrete (usually to a depth of 1 in. [25 mm]). 2) A dense, hard, dark gray, low (or no) air-near-surface zone rich in the mortar fraction of the concrete.

Both panels were made using the same concrete and were sealed after finishing with a cure-seal compound. Cores taken from both panels have good air-void systems and similar chloride contents (Table 2); but the top 1/2 to 3/4 in. (13 to 19 mm) in the scaled panel was found to have soft, porous, fragile paste compared to the interior of the slab or to the concrete in the sound panel.

The soft paste of the scaled surface was due to a higher water-cementitious materials ratio (*w/cm*) in the surface paste relative to that in the rest of the slab or in the sound panel. As a result, there were fewer residual portland cement particles at the panel surface and a greater depth of carbonation compared with the sound panel (Table 1). Soft, high *w/cm* paste at the scaled surface typically occurs when finishing is performed in the presence of excess water at the surface (from bleed water and/or from water added during finishing). This soft paste not only reduces the abrasion resistance of the surface, but also increases its vulnerability to scaling due to cyclic freezing at critically saturated

TABLE 2:
Air-void parameter, *w/cm*, and chloride content of sound and scaled concrete cores in the three case studies described

Three case studies of scaling	Surface conditions of samples	Locations where various parameters were measured	Total air content, %	Entrained air content, %	Specific surface, in^2/in^3	Void-spacing factor, in.	Estimated *w/cm*	Chloride content, % by mass of concrete
Industry recommended parameters[*]	—	—	6 to 7[†] 1.5[‡]	—	≥600	≤0.008	≤0.45	—
Scaling due to improper finishing practices								
I: Scaling due to premature finishing prior to the cessation of bleeding	Sound	Top 1/8 to 1/4 in.	4.6	3.0	660	0.007	0.50	0.178
		Interior	5.2	4.2	610	0.007	0.45	0.012
	Scaled	Top 1/8 to 1/4 in.	4.4	3.0	675	0.008	0.45	0.156
		Interior	5.5	4.4	640	0.008	0.40	0.008
II: Scaling due to finishing in the presence of water at the surface	Sound	Top 1/8 to 1/4 in.	3.5	3.0	670	0.007	0.45	0.255
		Interior	4.6	3.8	650	0.007	0.40	0.023
	Scaled	Top 1/8 to 1/4 in.	3.4	3.0	620	0.012	0.60	0.252
		Interior	4.4	3.6	600	0.008	0.44	0.020
III: Scaling (delamination) due to prolonged finishing and lack of entrained air at the surface	Sound[†]	Top 1/8 to 1/4 in.	4.6	3.6	720	0.007	0.40	0.008
		Interior	5.2	4.0	645	0.008	0.45	0.008
	Scaled[†]	Top 1/8 to 1/4 in.	0.0	0.0	—	—	0.30	0.006
		Interior	4.5	4.0	620	0.008	0.45	0.004

Note: The most important parameter responsible for scaling is highlighted in orange. In all cases, the scaled and sound cores came from adjacent panels or sidewalks and were exposed to similar environmental and deicing conditions (except the last case).
1 in. = 25.4 mm; 1 mm^2/mm^3 = 25.4 $in.^2/in.^3$

[*]ACI 201.2R-01, "Guide to Durable Concrete;" ACI 212.3R-91, "Chemical Admixtures for Concrete;" ACI 318-02/318R02, "Building Code Requirements for Structural Concrete and Commentary;" ASTM C 457.

[†]The scaled core is from a trowel-finished surface inside a warehouse floor and the sound core is from a broom-finished surface on the loading dock of the warehouse—both cores are air-entrained and made using the same concrete.

[‡]The industry recommended air content is for concrete containing 1/2 to 1 in. (13 to 25 mm) size aggregates and exposed to severe weather conditions.

conditions, especially in the presence of deicing salts. Due to the absence of scaling in the adjacent sound panel, salt was not the primary cause of scaling.

Case study III: Finishing-induced loss of air

In the first part of this article, it was mentioned that finishing practices can reduce the air content at the surface relative to that in the body of the slab. As long as finishing-induced air loss is due to a reduction of large voids (where large voids are replaced with many fine, close-space entrained air voids) and the surface still contains the industry recommended specific surface and void spacing factor (and has been placed, cured, and matured properly—see Part I), the surface will still resist scaling. If finishing is prolonged and extended beyond the final set of concrete, however, or if the finishing pressure is high due to excessive steel troweling or machine troweling, the air content at the surface can be reduced significantly. When exposed to the outdoors, such severe loss of air by prolonged finishing increases the potential for scaling at saturated conditions, especially in the presence of salt. Even good, air-entrained concrete can lose most of its air at the surface by prolonged finishing.

Usually such finishing-induced loss of air occurs in the top 1/4 to 1 in. (6 to 25 mm) of the slab, depending on the duration and the pressure applied during finishing. Cases have been observed where a severe air loss has caused scaling in outdoor slabs and delamination in machine-troweled indoor slabs. Figure 3 shows an example of finishing-induced loss of air at the surface of a warehouse slab where delamination developed due to finishing prior to the cessation of bleeding, accumulation of bleed water and air underneath the dense machine-troweled surface, and development of a "plane" of delamination. Air entrainment was included due to the anticipated exposure of the concrete to freezing during construction, but the slab was subsequently delaminated due to the machine troweling of the air-entrained slab.

LESSONS LEARNED

1. A good, air-entrained concrete that is finished prematurely (prior to the cessation of bleeding) can scale because bleed water is entrapped beneath the finished surface;
2. Air-entrained concrete can lose air near its surface by prolonged finishing. Unless the surface is adequately dense and impermeable to moisture or has adequate fine, closely spaced voids, it can have a high risk of scaling (due to low or no air) and delamination (if machine troweled);
3. Trowel-finishing an air-entrained concrete increases its potential for delamination;
4. Concrete's scaling and abrasion resistance decreases if water is added during finishing or if it is finished in the presence of bleed water. In the latter case, concrete may scale even in the presence of adequate air;

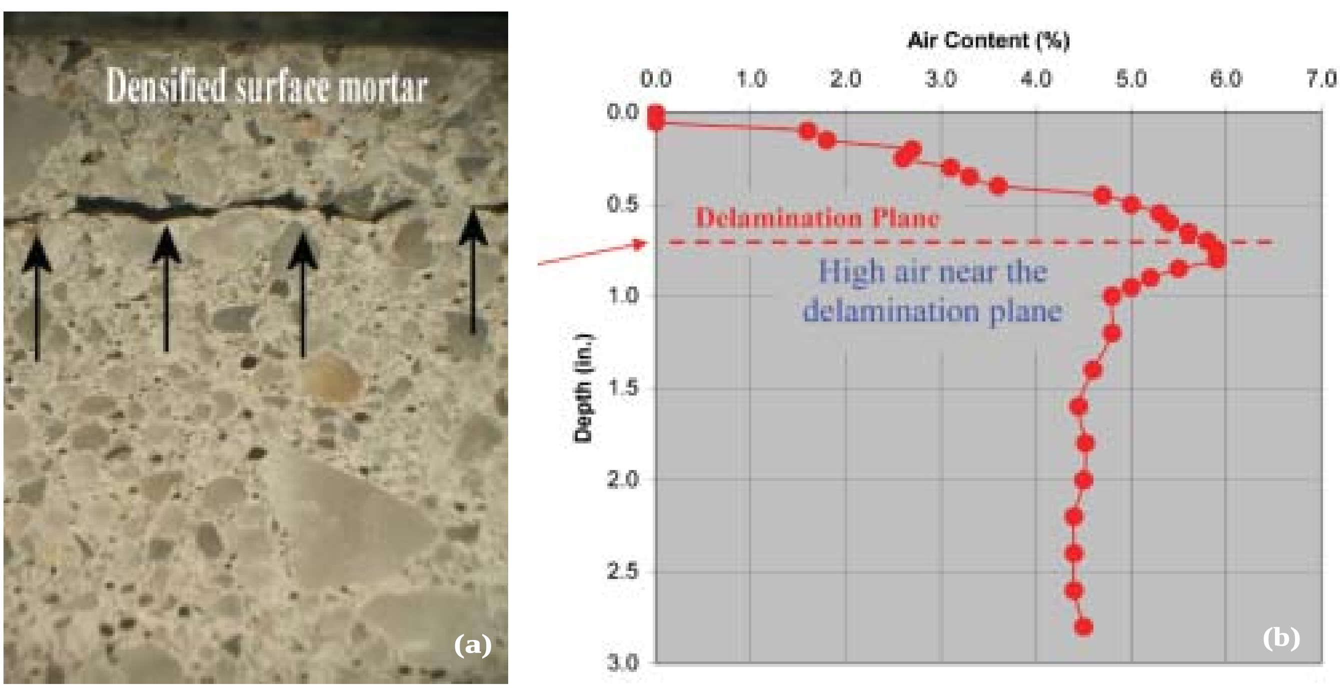

Fig. 3: Case study III (Delamination due to prolonged finishing and entrapment of bleed water and air beneath the finished surface)—(a) cross section of a concrete core, and (b) air profile showing the dense, air-free, near-surface mortar, the plane of delamination, and the air-entrained concrete in the slab. Note: 1 in. = 25.4 mm

5. Inadequately air-entrained or nonair-entrained concrete is very susceptible to scaling when saturated with water (especially in the presence of deicing salts) even if the concrete is placed, finished, cured, and matured properly. Horizontal structural elements (slabs and beams) are more susceptible to scaling than vertical elements (columns and walls);

6. An improperly air-entrained concrete having adequate total air but a coarse air-void system, has a marginal chance of avoiding scaling or delamination, especially in the presence of deicing salts; and

7. Meeting industry recommendations for strength, *w/cm*, and "total air" content will not necessarily guarantee a scale-resistant slab. The concrete must also have a good air-void system and have been placed, finished, cured, and matured properly.

ACHIEVING GOOD QUALITY CONCRETE

Other factors to remember

- Because the surface of concrete is exposed to freezing-and-thawing cycles and deicing salts, it's essential that the surface is adequately cured to have a dense, near-impermeable paste and a good air-void system;
- Aggregates should be well graded and frost resistant;
- Aggregates with a low modulus of elasticity (argillaceous rocks such as shale, slate, greywacke), porous limestone, dolomite, and alkali-silica reactive particles (chert, chalcedony, volcanic rocks) can cause expansion and aggregate popouts at the surface. Lift-off of a thin layer of surface mortar above flat, near-surface coarse aggregates can occur due to finishing improprieties and/or inadequate curing;
- Factors that slow or prolong bleeding (air, fine particles, thickness of the slab, or set-retarding chemicals) can increase the potential for scaling because finishing may begin prior to the cessation of bleeding;
- Crusting of the surface due to rapid evaporation of surface water on a hot, sunny, windy, or dry day can also trap bleed water and cause scaling;
- Working excess bleed water at the surface during finishing or sprinkling dry cement to remove excess bleed water are bad practices, which can cause dusting, softening of the surface mortar, and scaling;
- Inadequate curing creates a soft, friable paste with a low degree of cement hydration. This soft paste will be susceptible to abrasion by freezing and thawing and/or traffic loading;
- Slabs placed during late fall or winter may not attain maturity prior to freezing—in that case, it may be beneficial to avoid salting during the first season, and preferably protect the concrete by a film-forming or penetrating type surface sealer; and
- Inadequate drainage and water ponding will keep concrete saturated during freezing and increase its potential for scaling, especially if the concrete is poorly air-entrained.

MORE THAN AIR, W/CM, AND STRENGTH

Occurrences of concrete surface scaling are increasing at an alarming rate. Common industry recommendations for freezing-and-thawing resistance of concrete are: a) a total air content of 6 to 7% (±1½%) (for concrete containing 1/2 to 1 in. [13 to 25 mm] nominal maximum size aggregate and exposed to severe weather conditions); b) a minimum compressive strength of 4500 psi (32 MPa); and c) a maximum *w/cm* of 0.45. Fulfilling these three parameters is certainly not sufficient for scaling-resistance unless the concrete has a good air-void system and has been placed, consolidated, finished, cured, and matured properly.

Many mixture proportions requiring "total air" do not account for the amount of the entrained air, or the size, distribution, and spacing of the bubbles, which are more important for scaling-resistance than the mere volume of the total air. Attention to the concrete quality, construction procedures, and design details are all needed to improve concrete's salt and scaling resistance. Concrete, construction, and salt all cause scaling, but the first two are commonly more responsible than the last. The presence of salt surely makes good concrete and proper construction practices even more critical.

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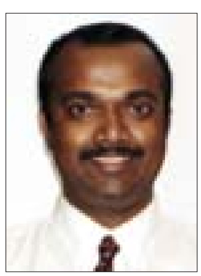

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