Type IL Cement and Concrete Scaling

by Dipayan Jana

ASTM C595/C595M Type IL cement, or portland-limestone cement (PLC), is portland cement clinker interground with 5 to 15% of limestone by mass.[1] In a series of durability tests to verify resistance to alkali-silica reaction (ASR), sulfate attack, freezing-and-thawing cycles, deicing salt scaling, and carbonation, Thomas et al.[2] found equivalent performance of both PLC and Type I/II portland cement (PC) mixtures when PLC was ground finer to produce equivalent 28-day (mortar) strength as PC. PLC + supplementary cementitious materials (SCMs) mixtures produced similar performance in ASR and sulfate attack as PC + SCMs. They stated, "PLC concrete, with or without SCMs, is no less robust than PC concrete in terms of resistance to freezing and thawing, deicer salt scaling, and carbonation, even when subjected to poor practices such as the addition of water, improper finishing, and inadequate curing."[2] In a separate durability study,[3] PLC concrete with Class F fly ash provided better performance related to chloride ingress than Type I/II PC concrete with Class F fly ash. Numerous other studies on durability mentioned in Reference 2 showed comparable results between concrete mixtures with Type IL and Type I cements of similar strengths (and water-cementitious materials ratio [*w/cm*]), regardless of the presence of SCMs. Type IL densifies paste microstructure through effective particle packing of finer-ground, softer limestone than ground clinker, providing nucleation sites for cement hydrates to grow on, and carboalumination formation from reaction with tricalcium aluminate—all of which provide durability benefits.[1]

However, construction issues attributed to PLC have included reduced bleeding and extended setting time,[4-6] which can lead to surface scaling from:

- Finishing prior to the cessation of bleeding, causing bleed water to accumulate beneath the finished surface, leading to "sheet-type" scaling;
- Finishing with the bleed water sheen on the surface, which can increase the *w/cm* at the surface and thus create a soft, porous layer with decreased scaling resistance; or
- Placement on a hot, dry, or windy day without adequate curing to cause evaporation of water from the dried/stiffened finished surface, leaving a scale-prone surface of soft, porous, and weak paste.

These issues are not necessarily due to the use of Type IL cement. Commonly used SCMs, slag cement, excessive entrained air, or finely ground Type I/II cement can also reduce bleeding and lead to scaling. Other issues attributed to PLC have included popouts, low abrasion resistance, and poor resistance to cyclic freezing and thawing. However, these effects can arise due to factors related to improper concrete quality; improper placement, finishing, and curing practices; and lack of protection of wearing surface from deleterious effects of salts.[7-12] Popouts can be caused by unsound aggregates; poor resistance to abrasion can be the result of inadequate consolidation during placement, premature finishing, inadequate curing, or exposure to freezing prior to the attainment of maturity; and poor resistance to cyclic freezing can be caused by excessive *w/cm*, inadequate air content and/or air-void system, or inadequate compressive strength. This article focuses on how petrographic examination can help determine the probable causes of scaling in exterior flatwork.

Diagnosing Scaling

In common investigations of scaling, petrographic examination of a drilled core from a scaled area is performed according to ASTM C856/C856M. Optical microscopy (using a stereomicroscope and a petrographic microscope), digital image analyses of micrographs, often extending to scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS) (ASTM C1723) studies, are done on: 1) fresh fractured surface; 2) lapped cross section; and 3) polarized light-transparent 30 μm (0.03 mm) thin section of concrete (all sectioned perpendicular to the wearing surface) to observe the properties and composition of paste at the wearing surface and their potential differences from the paste in the interior body. Some of the observed properties will include:

- Color, hardness, capillary porosity, abundance of unhydrated binders at the wearing surface, as well as their variations from the interior body;

- Depth of carbonation and carbonation-induced changes in paste compositions and porosities at the wearing surface;
- Change in *w/cm* of paste and associated microstructure at the wearing surface from finishing operations;
- Occurrences of drying or plastic shrinkage-related microcracking at the wearing surface region and their potential correlation with the abundance of unhydrated cement and SCM particles at the surface region;
- Change in air content and air-void system of concrete at the wearing surface region relative to the interior body;
- Evidence of bleed water channels, water voids, bleed water entrapment beneath the finished surface, or change in properties of paste (color, *w/cm*, increased fines, or laitance at the surface) from bleeding;
- Evidence of inadequate embedding of potentially unsound near-surface aggregate particles by the mortar fraction of the finished surface to cause aggregate popout;
- Evidence of a weak bond between the thin sheet of finished surface and underlying flat topside of otherwise sound near-surface aggregate to cause mortar liftoff due to the poor bond from inadequate curing, prolonged finishing, or finishing of a softened high *w/cm* paste at the surface;
- Effects of various SCMs, PLC, and various environmental factors on the degree of hydration of cementitious particles at the wearing surface region; and
- Change in capillary porosity, abundance of calcium hydroxide component of cement hydration, and the presence of potentially expansive chloride salts at the wearing surface region from exposure to deicing chemicals.

Examinations of polished thin sections and polished solid sections in optical and electron microscopes are considered best practices for in-depth microstructural and microchemical investigation of the mentioned properties of wearing surface regions to evaluate: 1) the relative effects of concrete quality, construction practices, and harmful effects of exposures; and 2) potential freezing-and-thawing durability and future serviceability of the wearing surface in an exterior flatwork. Many of these properties can provide clues to reduced bleeding, whether due to PLC or other factors. Proper sample preparation and investigation are paramount to correctly interpreting microstructures and assessing the reasons for surface scaling.

Case Studies

As a petrographer, the author's experience investigating the scaling of exterior flatwork involving Type IL mixtures has shown no direct role of PLC in causing scaling, at least to be unequivocally differentiated from other common factors such as inadequate air entrainment, finishing improprieties, or deleterious effects of salts.[8-12] Four case studies are presented herein. Case 1 was a sidewalk constructed using Type IL cement containing 20% Class F fly ash replacement. Cases 2, 3, and 4 were outdoor concrete slabs constructed using Type IL cement with 25 to 40% slag cement replacement. In all cases, distress was confined mostly to the top few millimeters of the slabs, while the interior zones were mostly sound and serviceable.

Figure 1(a) and (b) summarize the process followed for these scaling investigations. In all cases, relevant factors included: 1) materials and mixture proportions; 2) background information (timing of placement and distress, extent, and severity of scaling); 3) fresh concrete properties, design *w/cm*, and design strength; 4) compressive strength of laboratory-cured cylinders; 5) results of hardened air analysis by modified point-count method of ASTM C457/C457M; 6) results of water-soluble chloride analyses (ASTM C1218/C1218M) at the surface region, middepth, and bottom ends of the cores from the scaled and sound areas; 7) information obtained from petrography (ASTM C856/C856M), including the depth of distressed surface to replace, condition and future serviceability of the interior concrete, and conformance to materials and mixture design; and 8) the author's interpretations of factors responsible for surface distress.

An air-entraining agent was used in all mixtures (at various dosages). All mixtures comprised crushed limestone coarse aggregates. Proportions of interground limestone in the PLC were estimated using petrographic examinations of the paste. This limestone was separable from the dust associated with crushed limestone aggregate based on grain size as well as textural and mineralogical differences. All cases showed exposure to chloride-based deicing salts in cores collected from both scaled and sound areas. All cases were placed during the summer through fall seasons of 2021 to 2024, with sufficient time for the concrete to attain the necessary maturity, including a compressive strength of at least 4000 psi (28 MPa), prior to the first freezing exposure. All four cases showed that only the top ~5 to 10 mm (0.2 to 0.4 in.) of the slabs were affected by a distressed zone, mostly from the quality of the air-void system and/or subsequent finishing practices.

Case Study 1

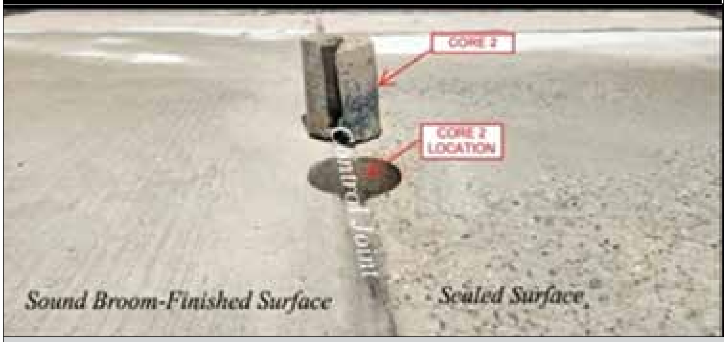
An air-entrained, 4000 psi sidewalk slab-on-ground in Louisville, KY, USA, placed in the summer of 2023, showed severe scaling within the first winter of 2024. Spectacular near-surface, surface-parallel microcracks were seen within the top 10 mm of the scaled surface (Fig. 2), while the interior concrete was relatively sound. Despite meeting the "design air" requirement for in-place concrete, air-void parameters in the hardened air showed a low frequency of entrained bubbles, resulting in nonconformance to specific surface and void-spacing factors from common industry-recommended limits. Additionally, the surface region showed finishing-induced loss of air from the interior (Fig. 2), which had degraded the scaling resistance, especially when the surface was exposed to deicing salts at severe concentrations to cause preferential scaling at locations of repeated salt exposures. The author deduced that low dosage of the air-entraining chemical along with finishing-induced air loss failed to stabilize the optimal entrained air bubbles, especially at the surface, to achieve the required durability.

<table>
<tr><th colspan="2">Case 1: Scaling in Type IL + SCM (20% Class F fly ash), <i>w/cm</i> 0.45, 6% air, 4000 psi mixture Slab-on-ground sidewalk, Louisville, KY, USA</th><th colspan="3">Case 2: Scaling in Type IL + SCM (25% slag cement), <i>w/cm</i> 0.45, 6% air, 4500 psi mixture Slab-on-ground ramp, Towson, MD, USA</th></tr>
<tr><td colspan="2"></td><td colspan="3"> </td></tr>
<tr><td colspan="5">Materials, ASTM specifications, and 1 yd^3 weight</td></tr>
<tr><td>Type IL cement, ASTM C595/C595M</td><td>451</td><td colspan="2">Type IL cement, ASTM C595/C595M</td><td>476</td></tr>
<tr><td>Class F fly ash, ASTM C618</td><td>113</td><td colspan="2">Slag cement, ASTM C989/C989M</td><td>159</td></tr>
<tr><td>Natural sand, ASTM C33/C33M</td><td>1205</td><td colspan="2">Natural sand, ASTM C33/C33M</td><td>1090</td></tr>
<tr><td>Mixed No. 8 and No. 11 crushed limestone, ASTM C33/C33M</td><td>1785</td><td colspan="2">No. 57 crushed limestone, ASTM C33/C33M</td><td>1900</td></tr>
<tr><td>Water, ASTM C1602/C1602M</td><td>257.3</td><td colspan="2">Water, ASTM C1602/C1602M</td><td>280</td></tr>
<tr><td>Air-entraining agent, ASTM C260/C260M</td><td>1.1 oz/cwt</td><td colspan="2">Air-entraining agent, ASTM C260/C260M</td><td>0.25 to 4 oz/cwt</td></tr>
<tr><td>Water reducer, ASTM C494/C494M</td><td>5 oz/cwt</td><td colspan="2">Water reducer, ASTM C494/C494M</td><td>3 to 7 oz/cwt</td></tr>
<tr><td colspan="5">Background information</td></tr>
<tr><td>Concrete placement</td><td colspan="2">April to May 2023, maturity was attained</td><td colspan="2">July to August 2021, maturity was attained</td></tr>
<tr><td>Distress reported</td><td colspan="2">Winter 2024</td><td colspan="2">Spring 2022</td></tr>
<tr><td>Exposure</td><td colspan="2">Severe weather, exposed to salts</td><td colspan="2">Severe weather, exposed to acetate/chloride salts</td></tr>
<tr><td colspan="5">Plastic concrete properties</td></tr>
<tr><td>Slump (in.), design air content (%), unit weight (lb/ft^3), design <i>w/cm</i></td><td colspan="2">4 in., 6 (±1.5)%, 140, 0.45</td><td colspan="2">2 to 5 in., 6.5 (±1.5)%, 146, 0.42</td></tr>
<tr><td colspan="5">Compressive strengths of lab-cured cylinders</td></tr>
<tr><td>Design strength and lab-cured cylinder strengths (psi) at 7 and 28 days</td><td colspan="2">4000, 2950, 4780</td><td colspan="2">4500, 4240, 5850</td></tr>
<tr><td colspan="5">Hardened air (ASTM C457/C457M) of cores from sound and scaled areas; all cores are air-entrained
Total air (%), void frequency (%), specific surface (in.^{2}/in.^{3}), void-spacing factor (in.)</td></tr>
<tr><td>Air-void parameters of sound core</td><td colspan="2">—</td><td colspan="2">6.8%, 14.4%, 850 in.^{2}/in.^{3}, 0.0062 in.</td></tr>
<tr><td>Air-void parameters of scaled core</td><td colspan="2">6.08%, 5.38%, 354 in.^{2}/in.^{3}, 0.0137 in.</td><td colspan="2">7.9%, 13.7%, 690 in.^{2}/in.^{3}, 0.0066 in.</td></tr>
<tr><td>Finishing-induced air loss at the surface</td><td colspan="2">Yes</td><td colspan="2">Slight air loss at the top 5 mm with coarse, irregular voids from finishing a high-air mixture</td></tr>
<tr><td colspan="5">Water-soluble chloride (ASTM C1218/C1218M) from exposed surface—to middepth—to bottom end of cores, in ppm</td></tr>
<tr><td>Sound core</td><td colspan="2">—</td><td colspan="2">671-70-135 (chloride salt exposure)</td></tr>
<tr><td>Scaled core</td><td colspan="2">3153-89-116 (severe chloride salt exposure)</td><td colspan="2">565-125-146 (chloride salt exposure)</td></tr>
</table>

Petrographic observations (ASTM C856/C856M)		
Type of surface distress in the cores	Severe scaling, incipient scales from near-surface microcracks at top 3 to 4 mm	Severe scaling in scaled core
Coarse aggregate, WG is well graded, WD is well distributed, UA is unaltered, UC = uncracked, S is sound aggregate	9.5 mm maximum size crushed limestone dolomite, WG, WD, UA, UC, S	19 mm maximum size crushed limestone (limestone, many with argillaceous bands), limestone with detrital quartz inclusions, sparite WG, WD, UA, UC, S
Fine aggregate	6.5 mm maximum size natural siliceous-argillaceous-calcareous sand, WG, WD, UA, UC, S	9.5 mm maximum size size natural siliceous sand, WG, WD, UA, UC, S
Finishing-induced high *w/cm* soft, porous paste at the surface, mm	None, *w/cm* is slightly lower at the surface than the interior	None in the sound core but very thin high *w/cm* paste at the top of the scaled core
Finishing-induced densified low *w/cm* zone at the surface with lower air, mm	0.40 to 0.45 at top 3 to 4 mm, air loss at 3 to 4 mm	Dense carbonated zone beneath the porous carbonated top in the scaled core, but dense carbonated zone above relatively less dense non-carbonated paste in the body of the sound core
w/cm, estimated in the body	0.45 to 0.50	0.40 to 0.45
Excessive bleeding, laitance, bleed water accumulation beneath the finished surface, finishing with bleed water on the surface	Despite sheet like scaling from freezing-related near-surface cracking, no evidence of premature finishing or bleed water trapping beneath finished surface	None
Tempered water addition	None	Evidence of tempered water addition during placement
Depth of carbonation, mm	Shallow (<5 mm) in both sound and scaled cores	Shallow (<5 mm) in both sound and scaled cores
Depth of distressed zone, maximum, mm	10	<5 mm
Microcracking at the surface region, mm	Near-surface, surface-parallel extensive microcracks, a few vertical microcracks, all within <10 mm	None
Inadequate curing/restricted hydration and hence soft, porous, crumbled paste?	Not in any cores	None found in the cores
Interior concrete	Dense, well-consolidated, sound, but with questionable durability for poor air-void system	Dense, well-consolidated, sound, durable, and serviceable
Conformance to materials and mixture proportions	Yes	Yes
Interpretation of surface distress		
Concrete materials and mixture proportions	Sound materials, proportions as per design mixture, but lack of adequate entrained air from low dosage of AEA resulting in a poor air-void system	Sound materials, proportions as per design mixture
Workmanship	Finishing-induced loss of air at the top 10 mm	Finishing-induced air loss at the top 10 mm, higher *w/cm* at the top <5 mm of scaled surface due to finishing a “sticky” high-air (8%) concrete
Future durability and serviceability	Questionable durability and serviceability for low air	Once distressed surface is repaired with a well-bonded, durable coating, interior concrete is serviceable

Fig. 1(a): Summary of parameters investigated in Cases 1 and 2

Note: 1 in. = 25 mm; 100 psi = 0.7 MPa

Case 3: Scaling in Type IL + SCM (35% slag), *w/cm* 0.45, 7% air, 3500 psi mixture Slab-on-ground, Michigan, USA		Case 4: Scaling in Type IL + SCM (40% slag), *w/cm* 0.42, 6% air, 4500 psi mixture Airport apron pavement slab, Washington, DC, USA	
			
Materials, ASTM specifications, and 1 yd^3 weight			
Type IL cement, ASTM C595/C595M	367	Type IL cement, ASTM C595/C595M	382
Slag cement, ASTM C989/C989M	197	Slag cement, ASTM C989/C989M	254
Sand, ASTM C33/C33M	1323	Sand, manufactured, ASTM C33/C33M	334
No. 57 crushed limestone, ASTM C33/C33M	1635	Sand, natural, ASTM C33/C33M	930
Water, ASTM C1602/C1602M	254	No. 57 crushed limestone, ASTM C33/C33M	1800
Air-entraining agent, ASTM C260/C260M	8.5 oz	Water, ASTM C1602/C1602M	267
Water reducer, ASTM C494/C494M	50.8 oz	Air-entraining agent, ASTM C260/C260M	0.1 to 6 oz
—		Water reducer, ASTM C494/C494M	2 to 8 oz

Background information		
Concrete placement	April to May 2023, maturity was attained	May to November 2024, summer placements were matured
Distress reported	Winter 2024	January 2025
Exposure	Severe weather, exposed to salts	Severe weather, exposed to acetate/chloride salts
Plastic concrete properties		
Slump (in.), design air content (%), unit weight (lb/ft^3), design *w/cm*	6 in., 7 (±1.5)%, 140, 0.45	3 in., 6%, 147, 0.42
Compressive strengths of lab-cured cylinders		
Design strength and lab-cured cylinder strengths (psi) at 7 and 28 days	3500, 2250, 4150	4500, 4250, 5850
Hardened air (ASTM C457/C457M) of cores from sound and scaled areas; all cores are air-entrained Total air (%), void frequency (%), specific surface (in.^{2}/in.^{3}.), void-spacing factor (in.)		
Air-void parameters of sound core	6.5%, 13.5%, 833 in.^{2}/in.^{3}, 0.0057 in.	5.1%, 12.5%, 991 in.^{2}/in.^{3}, 0.0052 in.
Air-void parameters of scaled core	7.2%, 14.2%, 791 in.^{2}/in.^{3}., 0.0059 in.	8.5%, 15.0%, 707 in.^{2}/in.^{3}, 0.0057 in.
Finishing-induced air loss at the surface	Yes, at the top 2 mm in all cores	No
Water-soluble chloride (ASTM C1218/C1218M) from exposed surface—to middepth—to bottom end of cores, in ppm		
Sound core	203-71-83 (chloride salt exposure)	284-63-55 (chloride salt exposure)
Scaled core	271-73-37 (chloride salt exposure)	237-65-59 (chloride salt exposure)

Petrographic observations (ASTM C856/C856M)		
Type of surface distress in the cores	Severe scaling, incipient scales from near-surface microcracks at top 3 to 4 mm, mortar liftoffs	Severe scaling
Coarse aggregate, WG is well graded, WD is well distributed, UA is unaltered, UC is uncracked, S is sound aggregate	19 mm maximum size crushed limestone (biosparite, biomicrite) WG, WD, UA, UC, S	19 mm maximum size crushed limestone (limestone, dolomitic, dolomitic, marble) WG, WD, UA, UC, S
Fine aggregate	9.5 mm maximum size natural siliceous-calcareous sand, WG, WD, UA, UC, S	9.5 mm maximum size natural siliceous sand WG, WD, UA, UC, S
Finishing-induced high *w/cm* soft, porous paste at the surface, mm	None	Slightly higher (0.45 to 0.50) in lighter gray paste at the top 3 to 4 mm
Finishing-induced densified low *w/cm* zone at the surface with lower air, mm	0.40 to 0.45 at top 3 to 4 mm, air loss at 3 to 4 mm	None
w/cm, estimated in the body	0.45 to 0.50	0.40 to 0.45
Excessive bleeding, laitance, bleed water accumulation beneath the finished surface, finishing with bleed water on the surface	None	None
Tempered water addition	None	Evidence of tempered water addition during placement
Depth of carbonation, mm	7 mm in both sound and scaled cores	<5 mm in both sound and scaled cores
Depth of distressed zone, maximum, mm	<5 mm	<5 mm
Microcracking at the surface region, mm	Vertical shrinkage microcracks at the top 5 mm of all cores	—
Inadequate curing/restricted hydration and hence soft, porous, crumbled paste?	Not in any cores	Not in any cores
Interior concrete	Dense, well-consolidated, sound, durable, and serviceable	Dense, well-consolidated, sound, durable, and serviceable
Conformance to materials and mixture proportions	Yes	Yes
Interpretation of surface distress		
Concrete materials and mixture proportions	Sound materials, proportions as per design mixture	Sound materials, proportions as per design mixture
Workmanship	Finishing-induced air loss, prolonged finishing of densified surface to cause mortar liftoff and freezing-related near-surface cracking	Potential water addition during finishing a high-air “sticky” concrete creating a higher *w/cm* zone at surface, inadequate mixing of tempered water
Future durability and serviceability	Once distressed surface is repaired with a well-bonded, durable coating, interior concrete is serviceable	Once distressed surface is repaired with a well-bonded, durable coating, interior concrete is serviceable

Fig. 1(b): Summary of parameters investigated in Cases 3 and 4

Note: 1 in. = 25 mm; 100 psi = 0.7 MPa

Case Study 2

Figure 3 is from an outdoor slab-on-ground ramp in Towson, MD, USA, placed in July-August of 2021. The ramp showed preferential scaling along the edge by spring of 2022, when the center portion of the ramp was still sound. Air content and other air-void parameters were all excellent in the cores from scaled and sound areas. However, an air content of up to 8% was found in the scaled core. Carbonation of the paste occurred across the top porous layer to the underlying densified zones, with a difference in paste capillary porosity between the two zones diagnosed from differential dye absorption in thin sections. Lapped cross

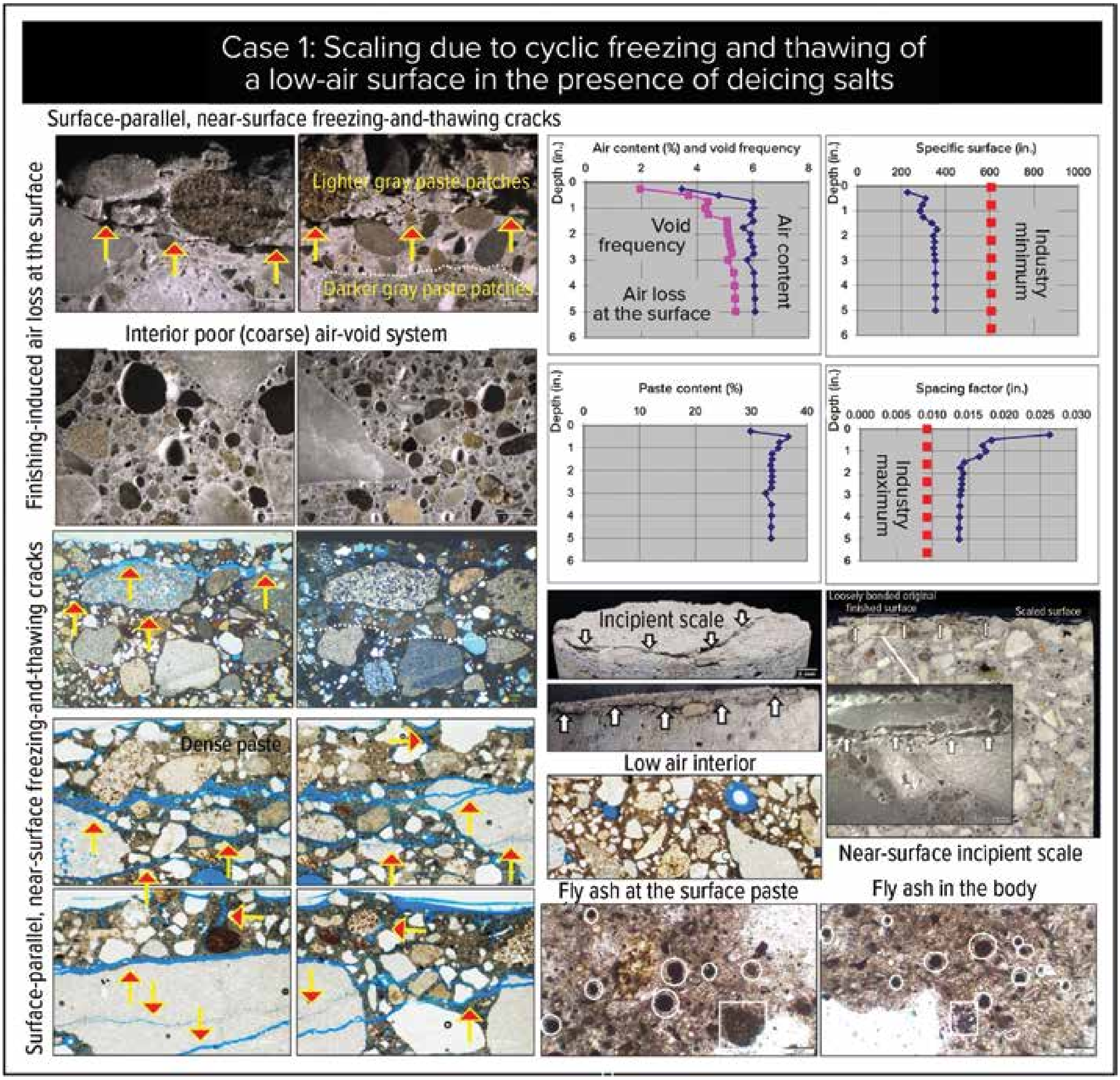


Fig. 2: Images and data from Case 1. Finishing-induced air loss at the top 1 in. (25 mm) as seen in the micrographs and air content profile reduced the scaling resistance of wearing surface and caused extensive near-surface, surface-parallel microcracks from freezing. Incipient scales from loosely adhered finished surface to the body of the core is the result of these microcracks (instead of bleed water entrapment beneath a finished surface, which was not seen here). Low void frequency reduced the specific surface and increased the void-spacing factor from respective industry-recommended limits. There is no evidence of increased residual fly ash particles at the surface region compared to the interior

sections of the cores showed local patches of lighter gray (higher *w*/*cm*) paste than the surrounding from incomplete mixing of tempered water added during the placement, which may have been required to increase the stiffness of the concrete during placement, and may also have contributed to the undesirable softness of the paste along the scaled areas. The author deduced that the high air content reduced the bleeding rate and made the concrete slightly "sticky," thus increasing the difficulty of obtaining a desirable finish. This resulted in a longer-than-optimal finishing duration, creating coarse, irregularly shaped voids in the surface region. It also created the potential for adding water to enhance finishability, resulting in a thin zone of a high *w*/*cm* less scale-resistance paste at the exposed surface of the scaled core.

Case Study 3

A sidewalk in Michigan was constructed using a 3500 psi (24 MPa) air-entrained mixture. Examination revealed an excellent air-void system below the finished surface. While there was no evidence of premature finishing or finishing with bleed water sheen on the surface to raise the surface *w*/*cm*, there was evidence of mortar liftoff over near-surface aggregates, as well as extensive surface-parallel microcracking (Fig. 4). The author deduced that prolonged finishing operations reduced the surface air content to cause the liftoffs and near-surface cracking. It is of interest, however, that the Michigan Concrete Association (MCA) is finding more scaling issues with Type IL 3500 psi mixtures than with 4000 or 4500 psi (31 MPa) mixtures; hence, it recommends at least a 4000 psi mixture for Type IL applications in driveways and sidewalks.[13]

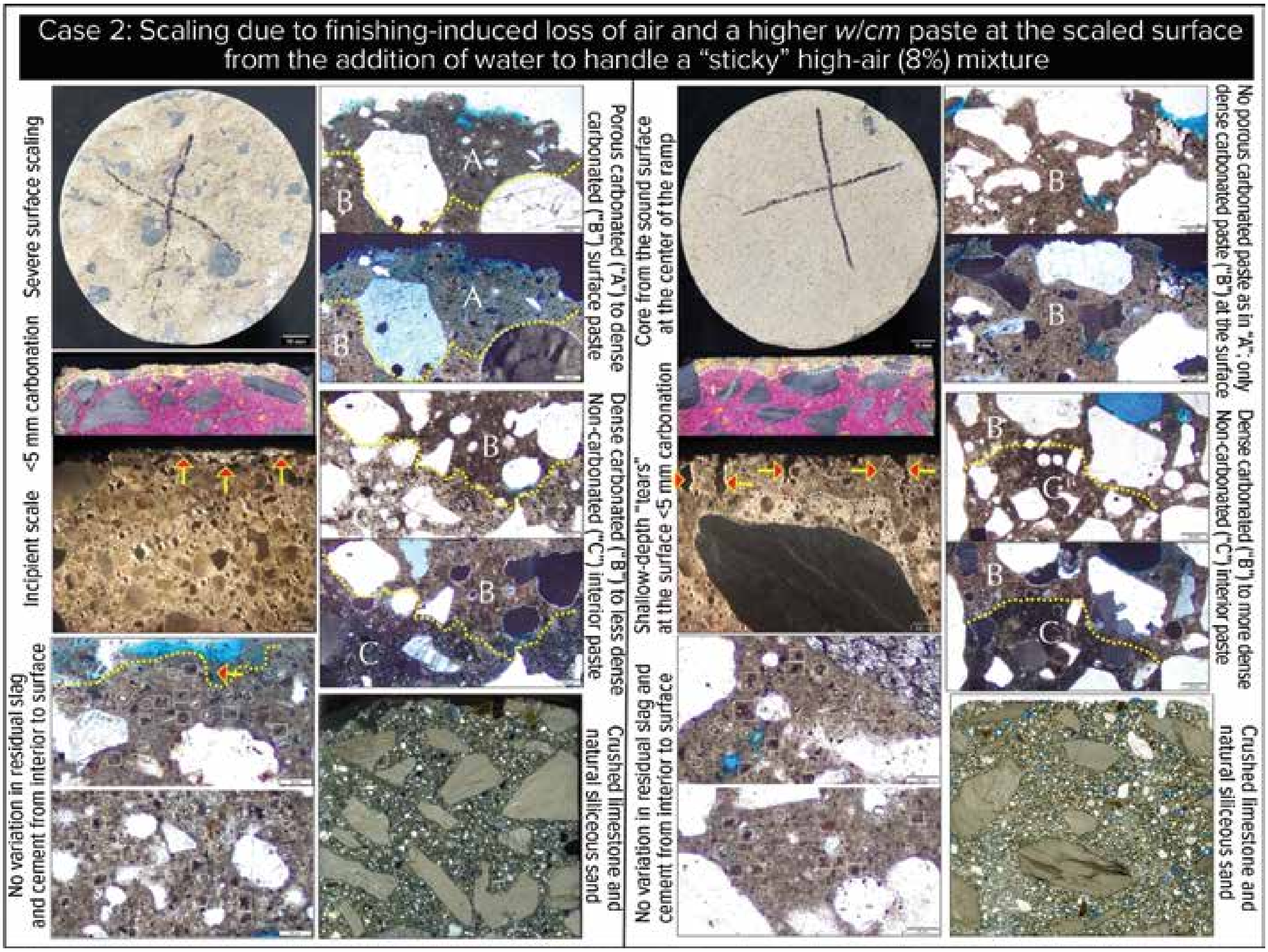


Fig. 3: Images from Case 2. High (8%) air in the scaled concrete reduced the bleeding rate; made concrete "sticky" which increased the difficulty of achieving a desirable finish; and prolonged finishing to create coarse, irregular-shaped voids at the surface region. Potential water addition to enhance the finishability resulted in a zone of a thin, high *w/cm*, less scale-resistance paste at the top of the scaled core (marked as "A"), situated above the densified finished surface ("B"). Adjustment of dosage of air-entraining chemical was needed to control the formation of excessive fine air bubbles, which can reduce bleeding and increase the duration of finishing. Notice some shallow (1 mm depth) vertical "tears" (third column from left, as opposed to typical fine hairline shrinkage microcracks) on the sound finished surface within the finishing-induced densified surface region of the sound core

Case Study 4

This case is from apron pavement slabs of the Baltimore/Washington International Airport, where as much as 25% of the pavement area placed during May through November of 2024 exhibited surface scaling (Fig. 5). Petrographic examinations revealed large variations in air contents (from 5 to 8.5%). The author deduced that placements containing 8% or more air, along with slag cement replacement levels of up to 40%, had slowed the bleeding to promote premature finishing and/or addition of water on stiffened surfaces. These factors resulted in local increases in *w/cm* and reduced the concrete's scaling resistance.

Conclusions

Petrographic investigations of distressed flatwork show the deleterious physical and chemical effects of deicing salts. The studies also show that scaling can be the result of reduced bleeding, largely associated with excessive entrained air. In some cases, this results in premature finishing and entrapment of bleed water beneath the finished surface, causing sheet-type scaling and development of incipient scaling. Other cases show that reduced bleeding may result in the addition of water during finishing of a stiffened surface, especially in a "sticky" concrete with a high air content. Further, such sticky mortars may also result in prolonged finishing, damaging the bond between the mortar and the topside of near-surface aggregate. Other observed factors have included inadequate dosages of air-entraining agent, jobsite water additions, and premature exposure to deicers. The effects of these factors are the same whether the concrete is produced using Type IL cement or Type I/II cement of comparable fineness. Traditional practices followed in creating a scale-resistant flatwork from a carefully crafted mixture to adjustments in placement, finishing, and curing practices of Type IL mixture,[14] especially during hot or cold weather placements, and protections against deleterious effects of deicers continue to be paramount during paradigm shifts with new binders to control the carbon footprint.

References

1. Tennis, P.D.; Thomas, M.D.A.; Weiss, W.J.; Farny, J.A.; and Giannini, E.R., "State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%," SN3148, American Cement Association, Washington, DC, 2024, 101 pp.

2. Thomas, M.D.A.; Delagrave, A.; Blair, B.; and Barcelo, L., "Equivalent Durability Performance of Portland Limestone Cement," *Concrete International*, V. 35, No. 12, Dec. 2013, pp. 39-45.

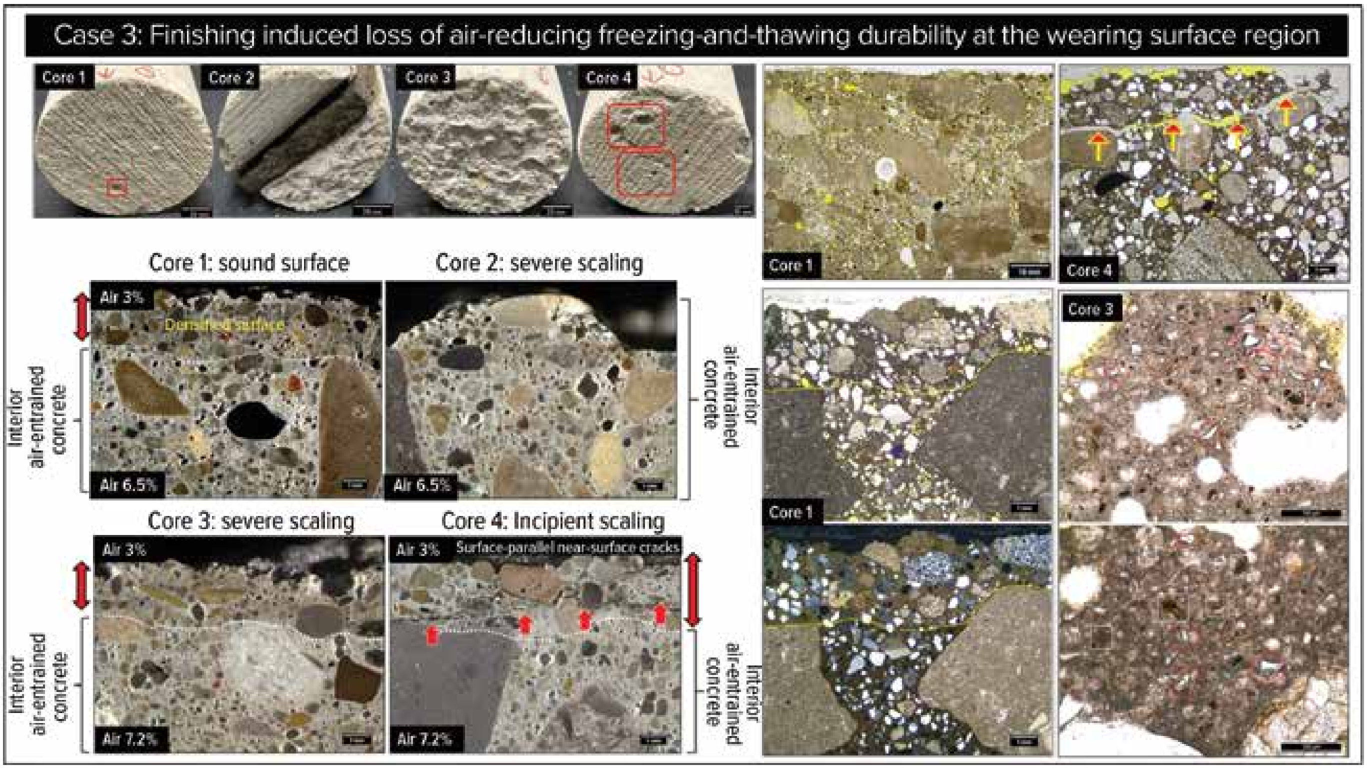
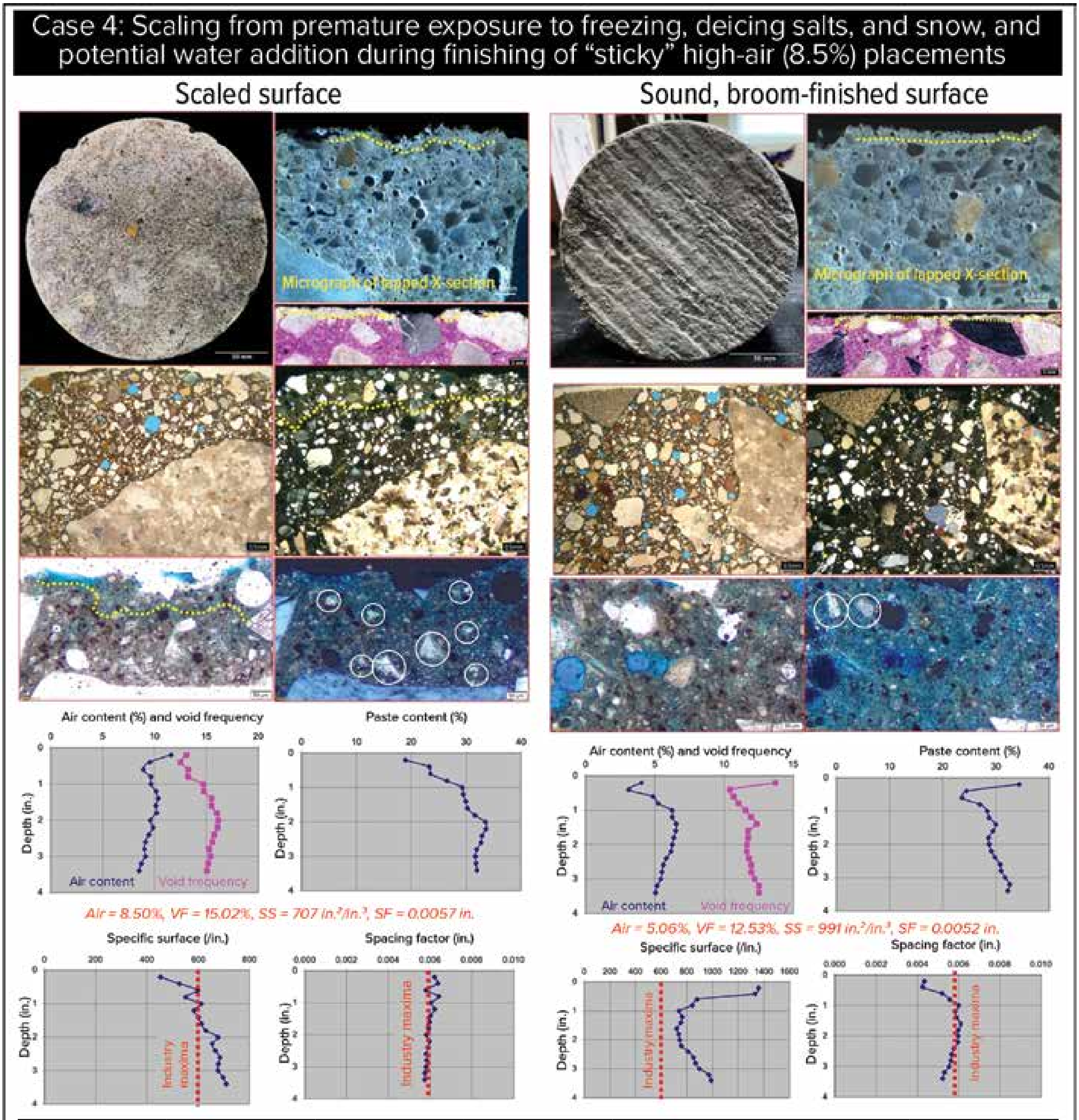


Fig. 4: Images from Case 3. Despite delivery of a concrete mixture with excellent air-void system, subsequent prolonged finishing has ruined the surface air content down to lower than half of the interior air, causing not only mortar liftoff over near-surface aggregates, but more so extensive near-surface surface-parallel microcracks seen on lapped cross section of Core 4. Proportion of residual slag particles is relatively higher at the surface region than the interior (best seen in the thin section micrographs in the plane polarized-light mode of a petrographic microscope as shown in the two rightmost images). Higher residual slag particles at the surface are not due to reduced bleeding, or evaporation of water or inadequate curing of the surface, but from removal of some mixture water from the surface during finishing to reduce the overall *w/cm* of paste at the finishing-induced densified surface region



Core ID	Scaled surface			Sound, broom finished surface		
Depth (mm)	10	90	190	10	90	190
Cl, ppm in concrete	284 (salt exposure)	63	55	237 (salt exposure)	65	59

Fig. 5: Images from Case 4. Cores from a scaled and a sound broom-finished area are compared where both showed a shallow (<5 mm depth) soft, porous, higher *w/cm*, and lighter-gray-toned carbonated skin (marked by yellow dotted lines) that are more obvious in the micrographs of thin sections and less obvious in the sound core than the scaled one. There is no enrichment of ground limestone, or residual slag or residual portland cement particles found at these porous surficial zones compared to the denser interiors, indicating the absence of evaporative loss of water after finishing, or inadequate curing. Air contents, other air-void parameters, and profiles of air parameters are given in the respective plots. Both scaled and sound cores are from areas that have received chloride-based salts, but preferential occurrence of scaling was related to the thickness of the porous zone along with the severity of salt exposures to increase the degree of saturation of the porous zones with water (from the hygroscopic nature of salts) prior to freezing

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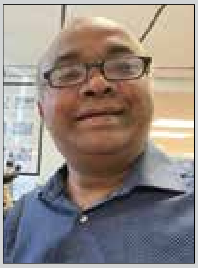
Note: Additional information on the ASTM International standards discussed in this article can be found at www.astm.org.

Selected for reader interest by the editors.



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