CONSTRUCTION MATERIALS CONSULTANTS, INC.

Investigation Of Surface Distress of Concrete Slab-On-Grade Deck Around A Swimming Pool From Petrographic Examinations of A Concrete Core

Morio Pool
3183 Stillwater Cove NE
Solon, Iowa

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CMC 0720136

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EXECUTIVE SUMMARY

Severe surface scaling as loss of the original finished surface of concrete slab to the point of exposure of near-surface coarse aggregate particles have prompted this investigation. The slab in question is an outdoor residential swimming pool deck in Solon, Iowa that was reportedly constructed in June of 2016, and has since been exposed to multiple cycles of freezing and thawing in the moist outdoor environment. The scaling was first observed in 2019 in isolated areas, which, despite a reported resealing event of pool deck in 2019, still continued during the last winter.

As a result, a 4-in. diameter, $4^1/_2$ in. long full-depth concrete core was retrieved from the pool deck and provided for detailed petrographic examinations according to the procedures of ASTM C 856. The core showed a shiny finished exposed surface due to the reported application of a surface sealer, however, with a central about 1 in. size area where the original finished surface has been lifted-off from the main body and only loosely adhered. Such incomplete loss of the original finished surface with a loose adherence to the main body is called incipient scaling. The core, therefore, was retrieved from a location where the finished surface, though still loosely adhered, has already been lifted off as the initiate stage of complete removal, or scaling. The bottom end of the core has adhered crushed stone of subbase.

Field photos of pool deck showed several isolated areas of severe concrete surface scaling as complete loss of the finished surface to the point of exposure of underlying coarse aggregate particles, as well as 'incipient scaling,' where the finished surface is de-bonded from the main body but is still loosely adhered.

The mix design of the concrete reportedly contained 508 pounds of Portland cement, 56 pounds of fly ash, 1489 pounds of sand, 1541 pounds of $^3/_4$ in. stone, 31.5 gallons of water, an air-entraining agent for a design air content of 6.0 percent, a design water cementitious materials ratio of 0.47, and a 28-day design compressive strength of 4000 psi.

According to common industry specifications (e.g., ACI documents), an outdoor concrete slab exposed to cyclic freezing and thawing should be air-entrained and should have a minimum compressive strength of 4000 psi, preferably 4500 psi in a moist outdoor environment. The reported design strength of concrete is less than the common industry specification of 4500 psi strength for an outdoor slab exposed to freezing, salt, and snow in a moist environment.

Based on detailed petrographic examinations of the core, the concrete is found to be non-air-entrained and made using: (a) crushed limestone-dolomite coarse aggregate of nominal $^3/_4$ in. (19 mm) size where limestone is variably dense and present in major amount compared to minor relatively porous dolomite, (b) natural siliceous sand fine aggregate of nominal $^3/_8$ in. (9.5 mm) size, which contains major amount of silica sand and subordinate quartzite, feldspar and other siliceous materials, (c) a dense paste of Portland cement and fly ash having a water-cementitious materials ratio estimated to be 0.45 to 0.50, and a cementitious materials content estimated to be equivalent to 6 to $6^1/_2$ bags of Portland cement per cubic yard of which approximately 10 percent is estimated to be fly ash, and (d) an air content estimated to be 2 to 4 percent, which are all near-spherical and irregularly-shaped entrapped air voids with no evidence of intentional addition of an air-entraining agent to generate a network of fine, discrete, spherical and near-spherical less than 1 mm size entrained air. The concrete in the core is dense and well-consolidated; and aggregate particles are well-graded, well-distributed, and present in sound condition. Except for the absence of entrained air, the concrete showed no other evidence to deviate from the reported mix, or, hence, to promote surface distress.

Therefore, contrary to the reported mix design of an air-entrained concrete, the present concrete in the core is found to be non-air-entrained. Absence of air entrainment is determined to be the main reason for the surface scaling of the pool deck in the presence of moisture and cyclic freezing and thawing at critically saturated conditions. The concrete delivered at the location of the core examined here lacked an air-entraining agent hence did not stabilize a network of entrained air voids to protect the concrete from freezing-related distress.

The core showed a near-surface, surface-parallel microcrack, which has resulted in the incipient scaling of the finished surface due to cyclic freezing of the non-air-entrained concrete at the surface region at critically saturated conditions.

Due to the absence of air entrainment all throughout the depth of the core, surface scaling is judged to continue during the future winter seasons to worsen the condition with time. Therefore, the pool deck is best recommended to be replaced with an air-entrained concrete as specified for the project, or is protected with a new layer of a durable, dense, air-entrained, topping well-bonded to the existing slab.

INTRODUCTION

Reported herein are the results of detailed petrographic examinations of a hardened concrete core received from around an outdoor swimming pool deck where the concrete slab has been exposed to atmospheric elements including cyclic freezing and thawing, and has reportedly shown surface distress.

FIELD PHOTOGRAPHS

Figure 1 shows overall conditions of scaled concrete surface at the project location where the original finished surface of the concrete has been lost at isolated locations including incipient scaling where the finished surface is loosely adhered to the main body of concrete. Severe scaling of the surface to the point of exposures of near-surface coarse aggregate particles are seen in all three photos of concrete slab around the pool.

BACKGROUND INFORMATION

The swimming pool was reportedly placed on June 20, 2016. Surface of the pool is reportedly scaling after going through multiple winters and freeze thaw cycles. Problem was first surfaced in 2019 in isolated areas. The pool deck was then resealed in 2019 and the majority of the failure surfaced after the 2019-2020 winter.

The mix design of the concrete (Mix #216020304) is a 4000 psi Exterior mix, reportedly containing:

- 508 pounds of Portland cement
- 56 pounds of fly ash
- 1489 pounds of sand
- 1541 pounds of $^3/_4$ in. stone
- 31.5 gallons of water
- An air-entraining agent for an air content of 6.0%
- A design water cementitious materials ratio of 0.47.
- A 28-day design compressive strength of 4000 psi.

PURPOSES OF LABORATORY TESTING

Based on the background information provided, field photographs of concrete surface scaling, and condition of concrete core received, purposes of laboratory investigation are to determine:

(a) Composition, quality, and condition of concrete in the core including type, composition, condition, and soundness of coarse and fine aggregates in concrete;

(b) Mix proportions of concrete including cementitious materials content, water-cementitious materials ratio, and air content to investigate conformance to or deviation from the reported concrete mix and investigation of role of concrete mix proportions in the surface conditions of concrete; and,

(c) Based on laboratory testing of the core, possible reasons for the observed distress at the surface of pool deck concrete slab.

Figure 1: Field photographs showing isolated occurrences of scaling of the concrete surface around the pool deck from loss of the original finished surface of concrete.

METHODOLOGIES

PETROGRAPHIC EXAMINATIONS

The core was examined by detailed petrographic examinations by following the methods of ASTM C 856 “Standard Practice for Petrographic Examination of Hardened Concrete.” Details of petrographic examinations and sample preparation are described in Jana (1997a, b, 2001, 2004a, b, 2005a, b, 2006, 2007). Air content and air-void system of concrete were also estimated from petrography.

The steps of petrographic examinations include (Jana 2006):

i. Visual examinations of the core, as received;
ii. Low-power stereomicroscopical examinations of as-received, saw-cut and freshly fractured section, and lapped cross sections of core for evaluation of textures, and composition;
iii. Low-power stereomicroscopical examinations of air content and air-void system of concrete in the core;
iv. Examinations of oil immersion mounts in a petrographic microscope for mineralogical compositions of specific areas of interest;
v. Examinations of blue dye-mixed (to highlight open spaces, cracks, etc.) epoxy-impregnated large area (50 mm × 75 mm) thin section of concrete from the top 3 inches of core in a petrographic microscope for detailed compositional and microstructural analyses;
vi. Photographing sample, as received and at various stages of preparation with a digital camera and a flatbed scanner;
vii. Micrographs of lapped sections and thin section of sample taken with stereomicroscope and petrographic microscope, respectively, to provide detailed compositional and mineralogical information of concrete.

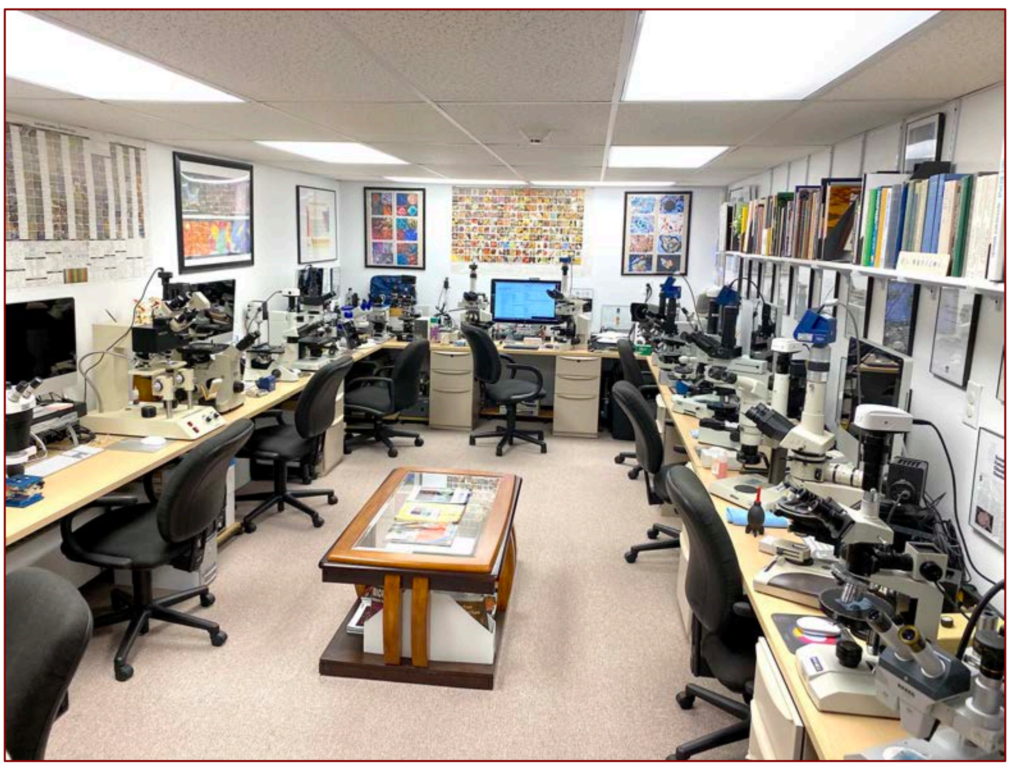

Figure 2: CMC’s petrographic laboratory that houses various optical microscopes used in this study.

SAMPLE

PHOTOGRAPHS, IDENTIFICATION, INTEGRITY, AND DIMENSIONS

Figure 3 shows the core, as received, which has a diameter of 4 in. (100 mm), and a nominal length of $4^1/_2$ in. (110 mm).

END SURFACES

The top surface is shiny-finished with an incipient lift-off of a 20 mm area at the center.

The bottom surface shows crushed stone from the subbase, indicating full depth retrieval of the core from the pool deck slab at this location.

CRACKING & OTHER VISIBLE DISTRESS, IF ANY

There are no cracks or large voids present in the core as received.

EMBEDDED ITEMS

The core contains a No. 4 reinforcing steel at a depth of $2^1/_2$ in. from the top surface, which is present in sound condition with no evidence of corrosion.

RESONANCE

The core has a ringing resonance, when hammered.

Figure 3: Shown are: (a) the top wearing surface of concrete slab at the top left photo having a central region where the original finished surface has been lifted off, but still loosely adhered to the main body; (b) crushed stone of subbase adhered to the bottom end of core (top right); and (c) side cylindrical views of the core HRM-2B showing a No. 4 reinforcing steel at a depth of $2^1/_2$ in. from the top surface, which is present in sound condition with no evidence of corrosion.

PETROGRAPHIC EXAMINATIONS

LAPPED CROSS SECTIONS

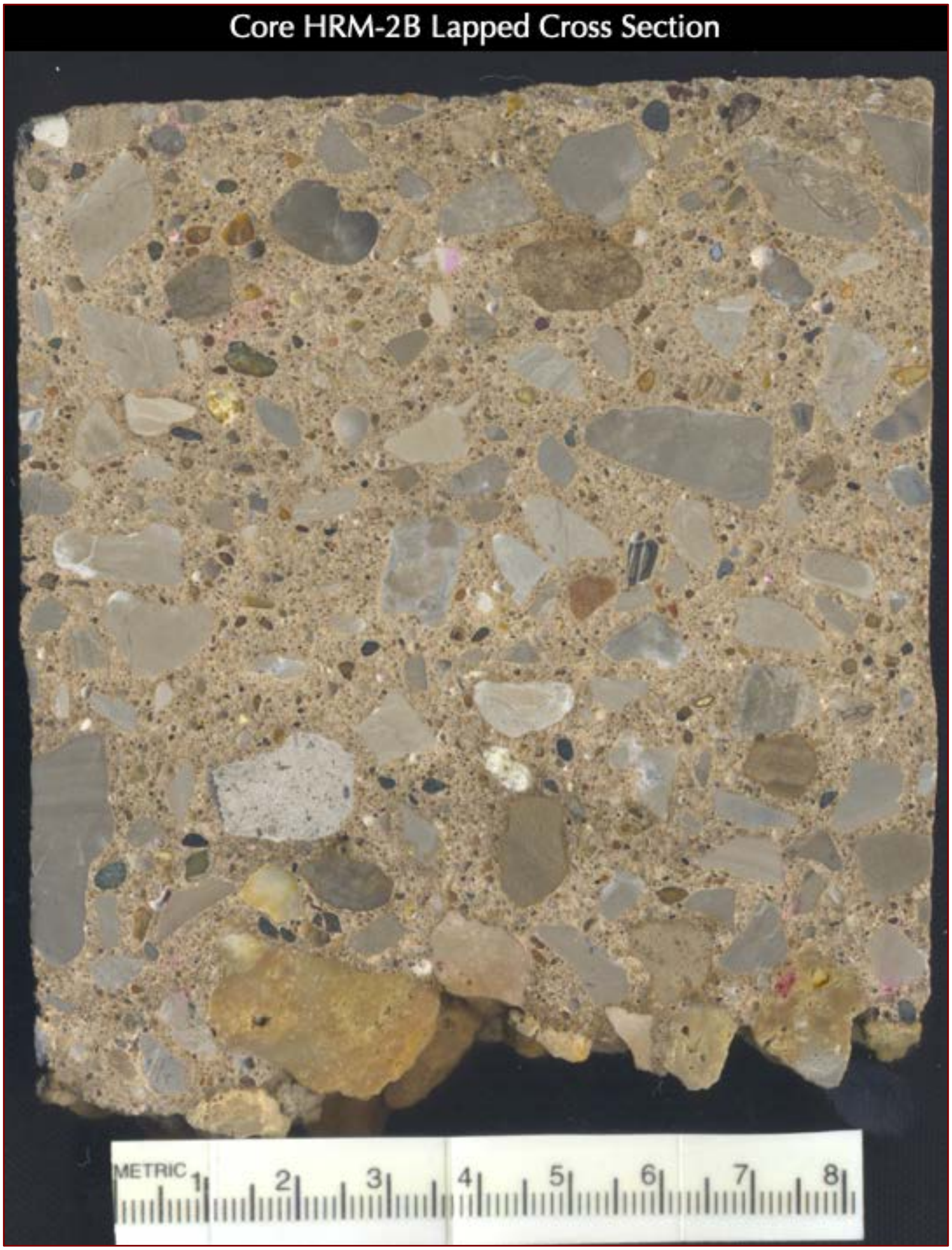

Figure 4: Lapped cross section of core showing: (a) crushed stone coarse aggregate particles that are well-graded and well-distributed; (b) overall dense and well-consolidated nature of concrete without any coarse voids; and (c) beige color tone of paste which is uniform throughout the depth. Crushed stone of subbase indicates full-depth extraction of the core.

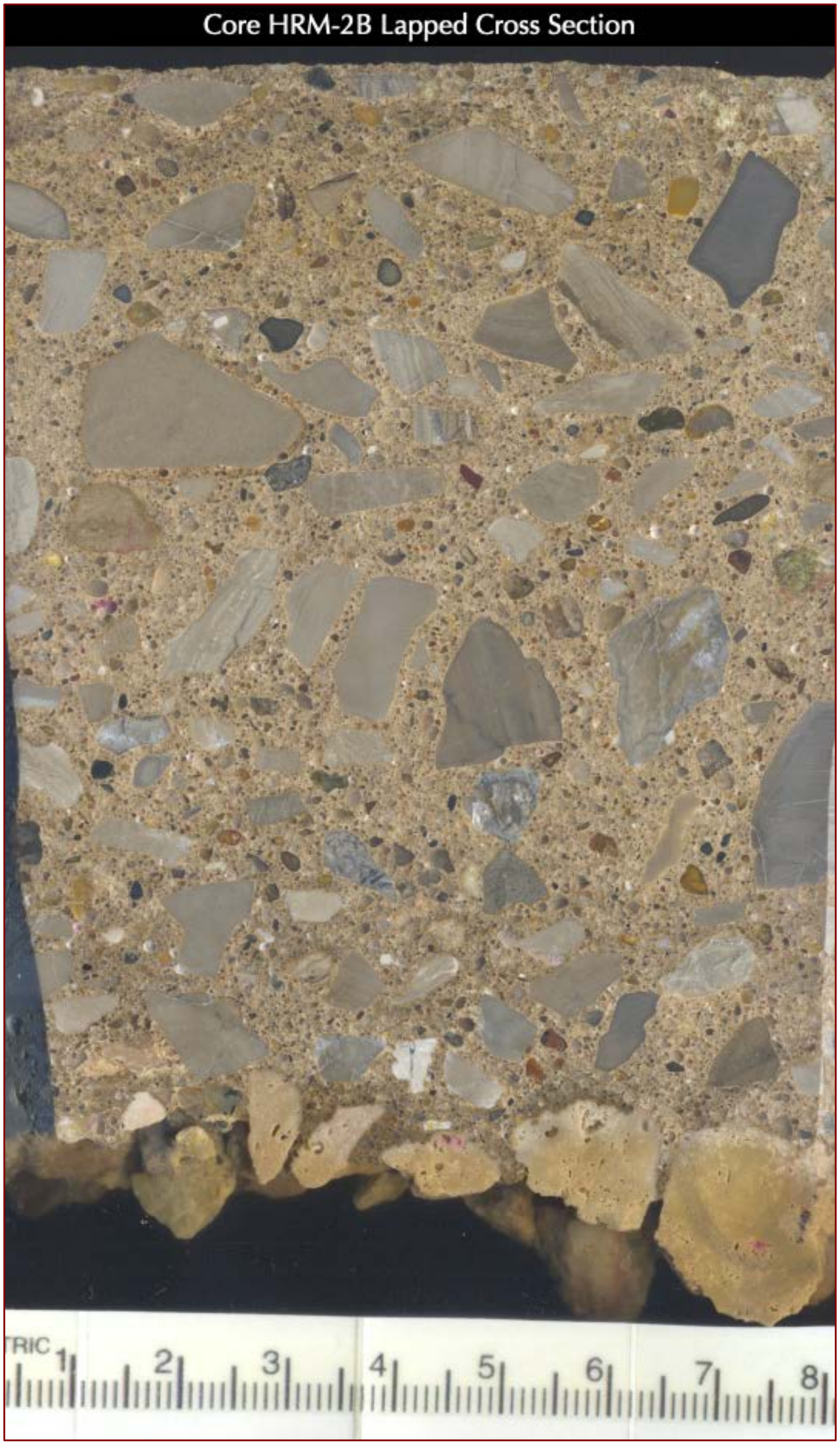

Figure 5: A second lapped cross section of core sectioned parallel to the first one shown in the previous photo showing: (a) crushed stone coarse aggregate particles that are well-graded and well-distributed; (b) overall dense and well-consolidated nature of concrete without any coarse voids; and (c) beige color tone of paste which is uniform throughout the depth. Crushed stone of subbase indicates full-depth extraction of the core.

AIR VOIDS AND CARBONATION DEPTH ON LAPPED CROSS SECTIONS

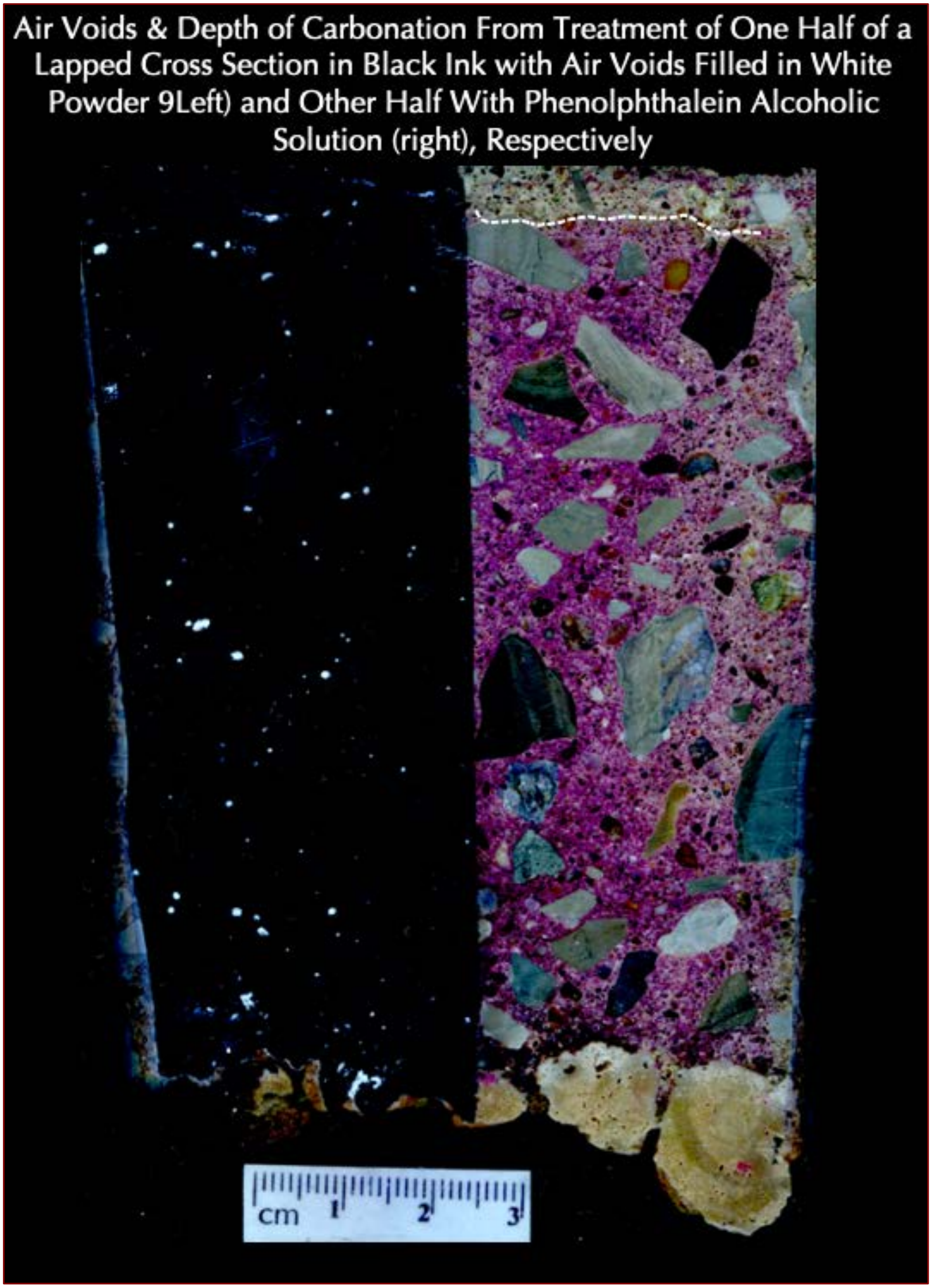

Figure 6: The second lapped cross section shown in the previous photo but after (a) treatement of one longitudinal half of the section with black ink and filing all voids with a white powder to highlight the air voids (left); and (b) with a phenolphthalein alcoholic solution to determine the depth of carbonation of concrete where the concrete remains in its normal color tone from non-carbonated interior where the concrete turns pink (right).

PHOTOMICROGRAPHS OF LAPPED CROSS SECTIONS

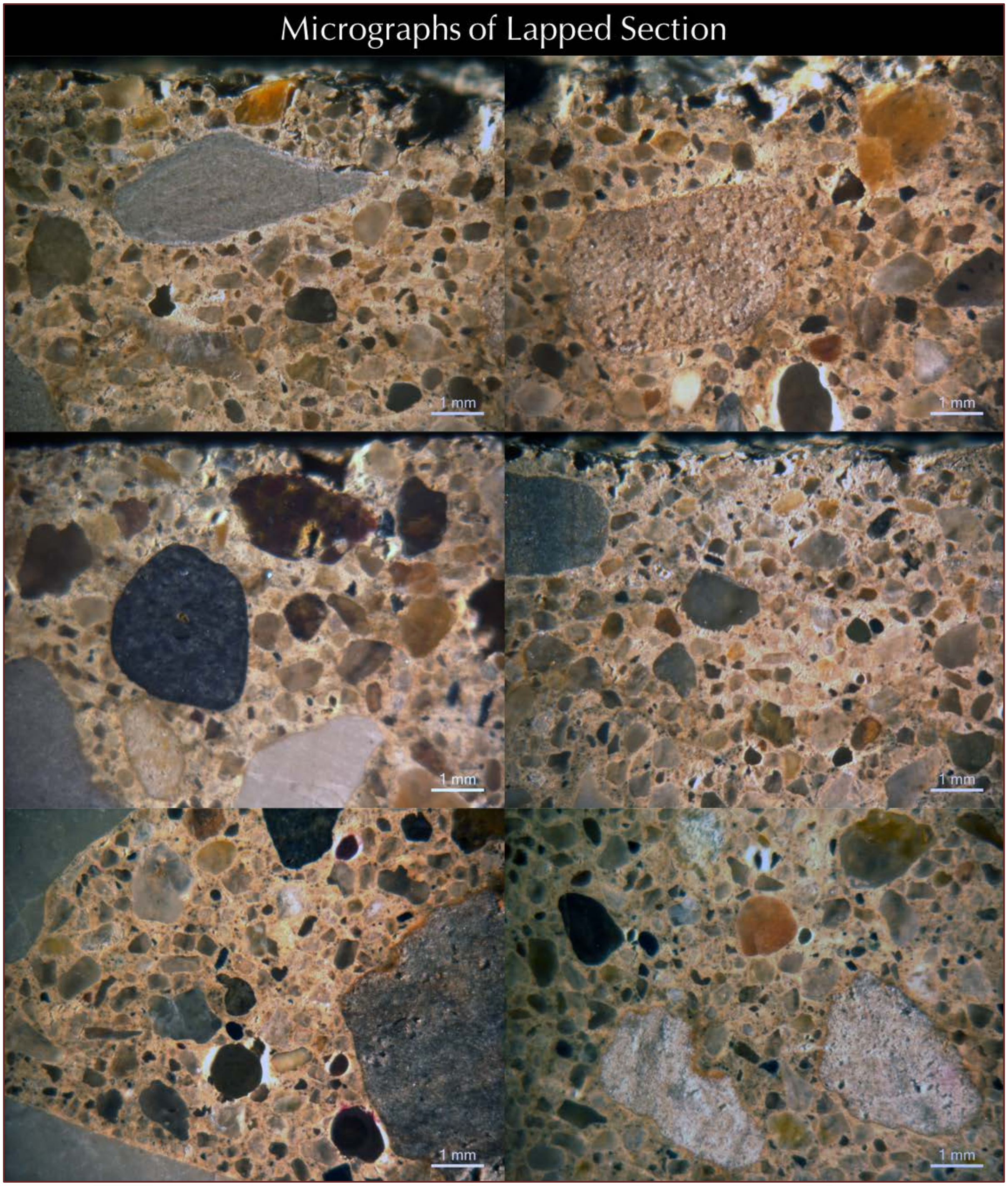

Figure 7: Micrographs of lapped cross section of core showing: (a) irregularly-shaped and elongated voids at the surface region i.e., at the top 1 to 2 mm of exposed surface formed due to finishing opreations (top two rows); (b) lack of fine, discrete, spherical and near-spherical less than 1 mm size intentionally introduced entrained air hence the non-air-entrained nature of concrete; (c) a few coarse, near-spherical accidentally formed entrapped air in the concrete; (d) overall dense and well-consolidated nature of concrete; and (e) uniform appearance and color tone of paste throughout the depth. Notice the non-air-entrained nature of concrete makes it vulnerable to surface distress as seen in the field due to exposure to moisture and cyclic freezing and thawing at critially saturated conditions.

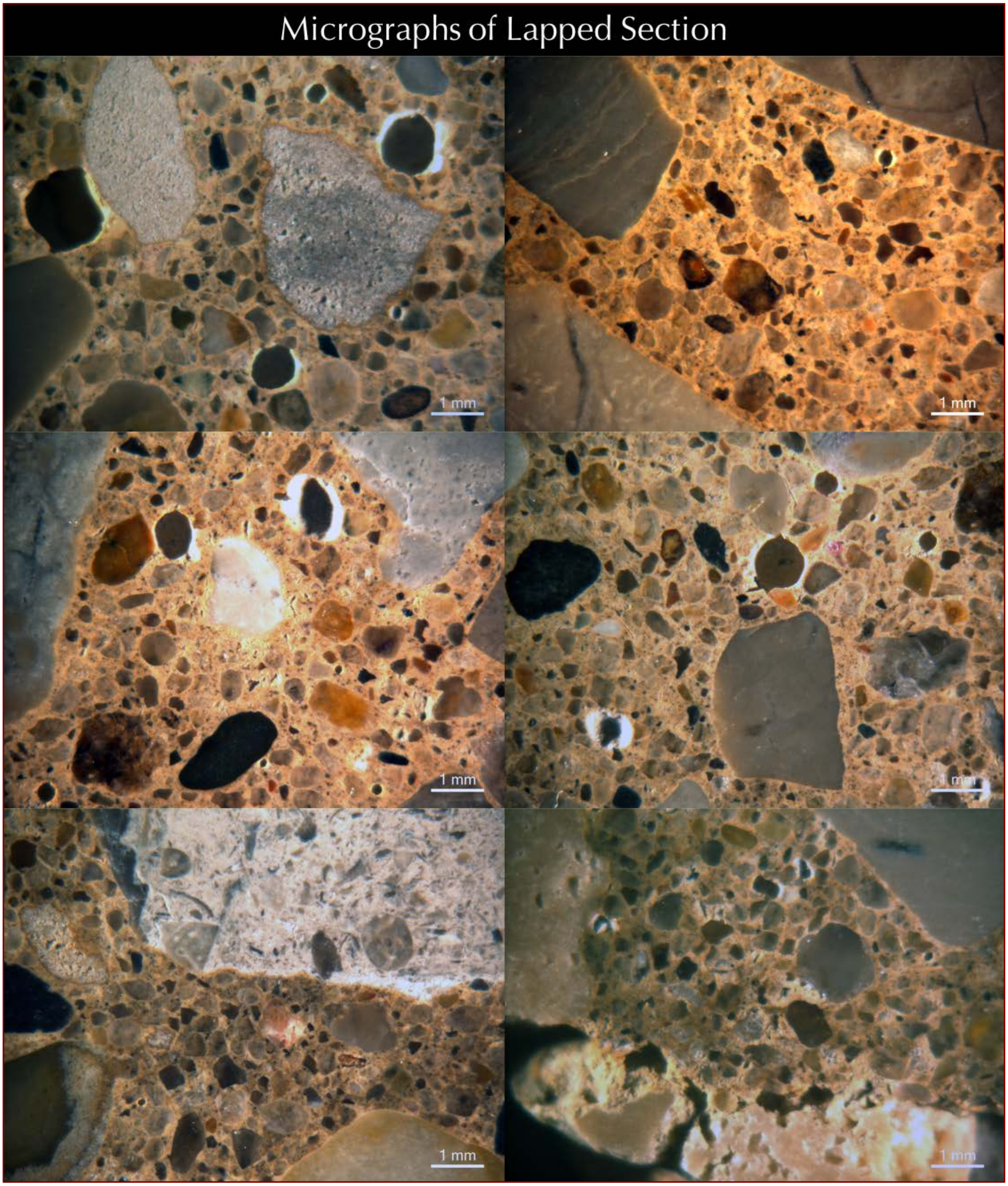

Figure 8: Micrographs of lapped cross section of core showing: (a) lack of fine, discrete, spherical and near-spherical less than 1 mm size intentionally introduced entrained air hence the non-air-entrained nature of concrete; (b) a few coarse, near-spherical accidentally formed entrapped air in the concrete; (c) overall dense and well-consolidated nature of concrete; and (d) uniform apperaance and color tone of paste throughout the depth. Notice the non-air-entrained nature of concrete makes it vulnerable to surface distress as seen in the field due to exposure to moisture and cyclic freezing and thawing at critially saturated conditions.

THIN SECTION

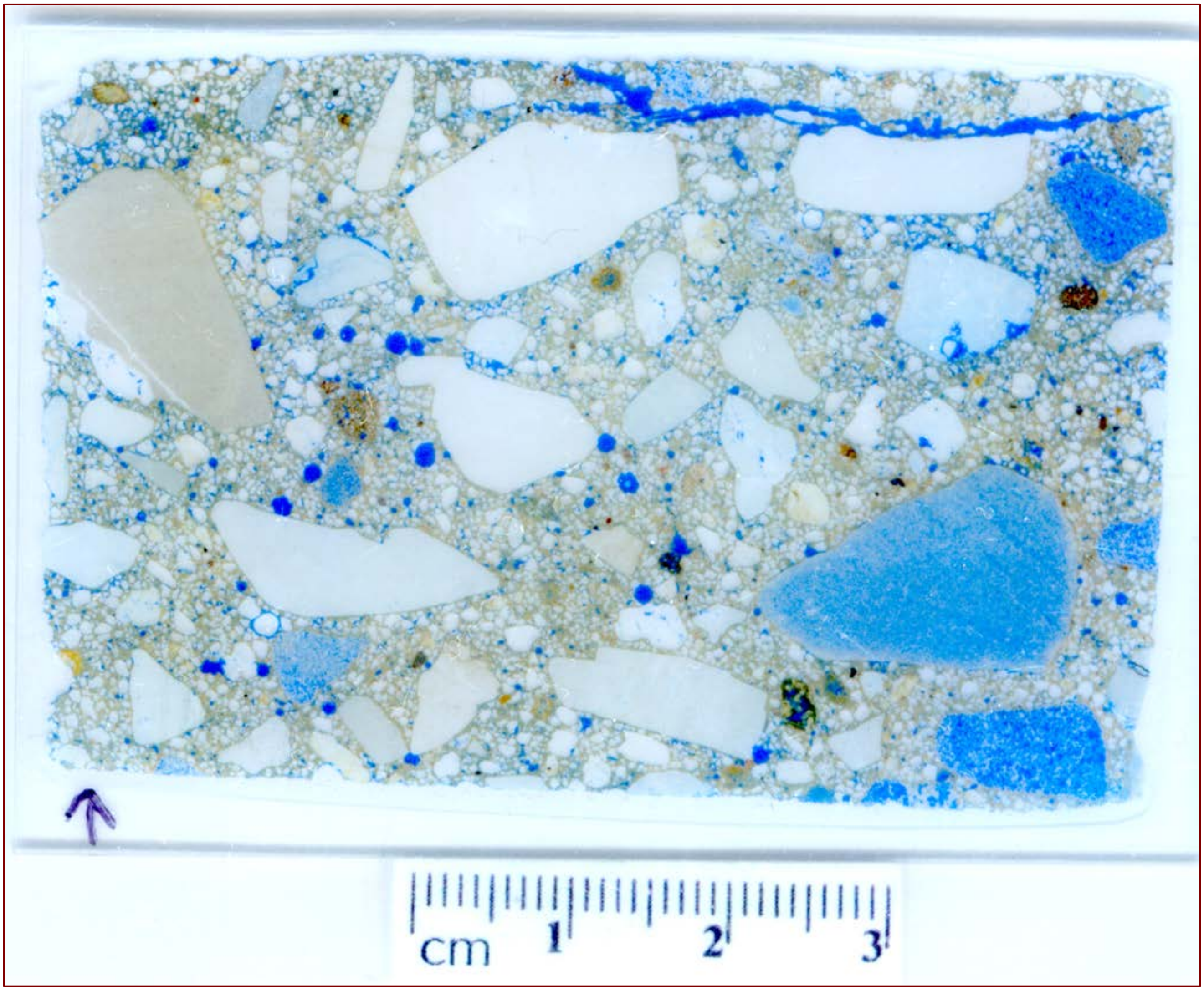

Figure 9: Blue dye-mixed epoxy-impregnated thin section of core showing the non-air-entrained nature of concrete, a surface-parallel crack, and some entrapped air voids which are all highlighted by blue epoxy. Some porous dolomite particles in crushed stone are also highlighted in blue epoxy due to greater absorption of epoxy than denser crushed limestone particles.

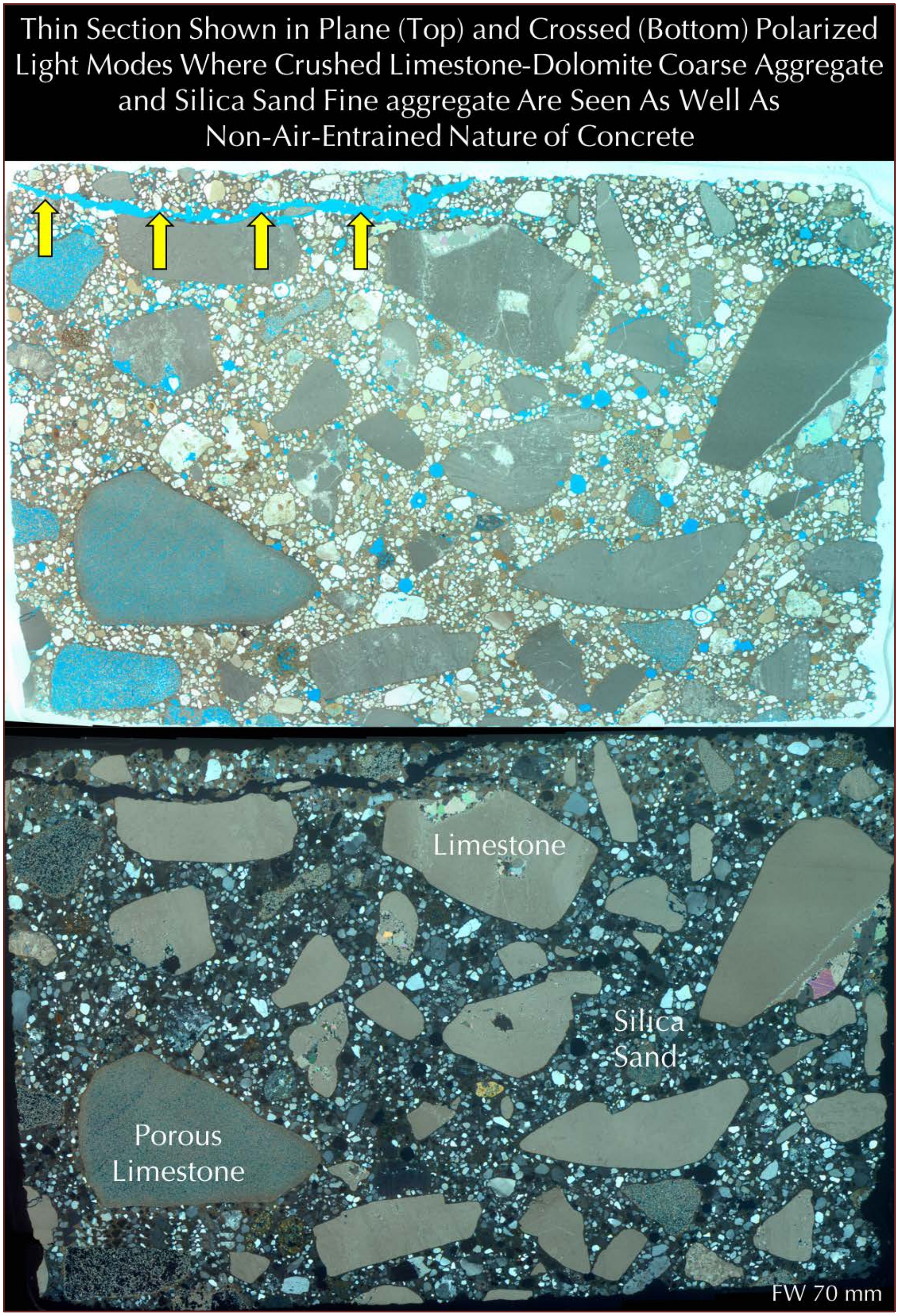

Figure 10: Scanned images of thin section of core in plane-polarized light (top) and crossed-polarized (bottom) modes in a stereo-zoom microscope taken by placing the thin section with one or two polarizing filters at perpendicular orientations. Multiple images were taken in each mode and then stitched to create the composite images. The top PPL image shows lack of entrained air, near-surface crack (arrows), and porous particles in crushed stone. The bottom XPL image shows limestone and dolomite particles in crushed stone coarse aggregate and silica sand particles in fine aggregate.

MICROGRAPHS OF THIN SECTIONS

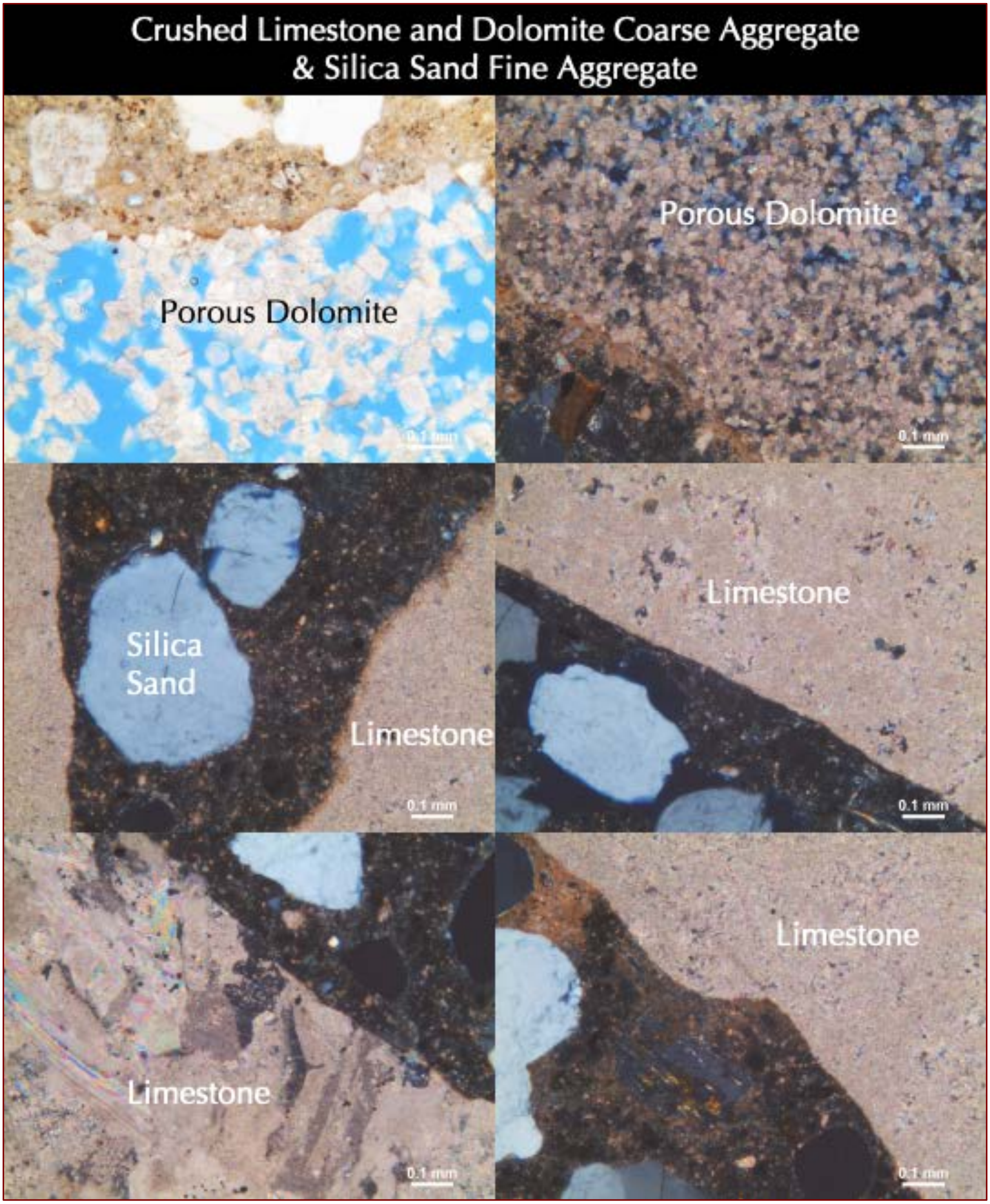

Figure 11: Micrographs of thin section of core showing: (a) crushed limestone and porous dolomite particles in crushed stone coarse aggregate and natural siliceous (quartz-quartzite-feldspar) sand fine aggregate; (b) lack of air entrainment, and (c) paste having residual Portland cement and spherical fly ash particles.

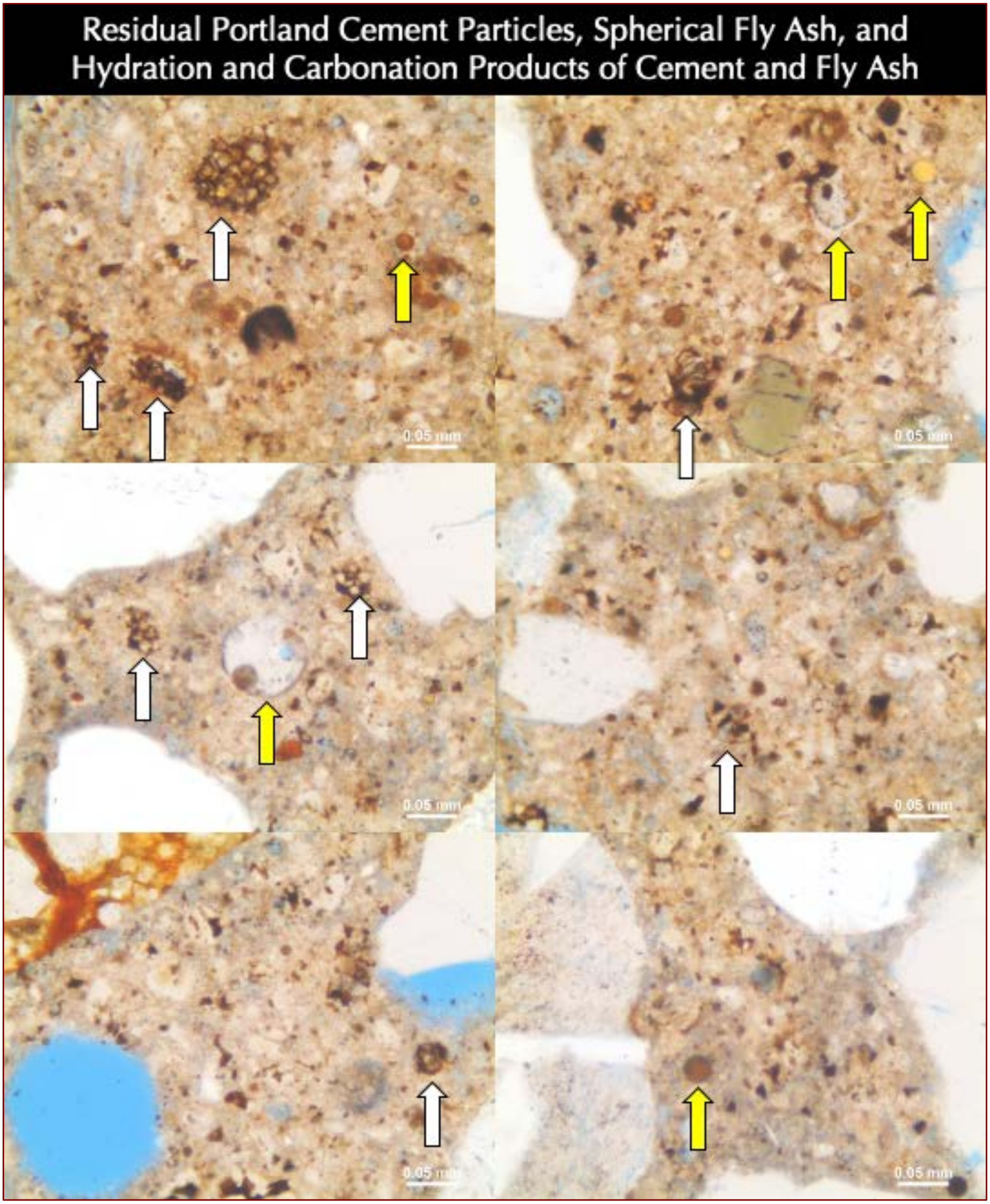

Figure 12: Micrographs of thin section of core showing the paste having residual Portland cement particles (white arrows) and spherical fly ash particles (yellow arrows).

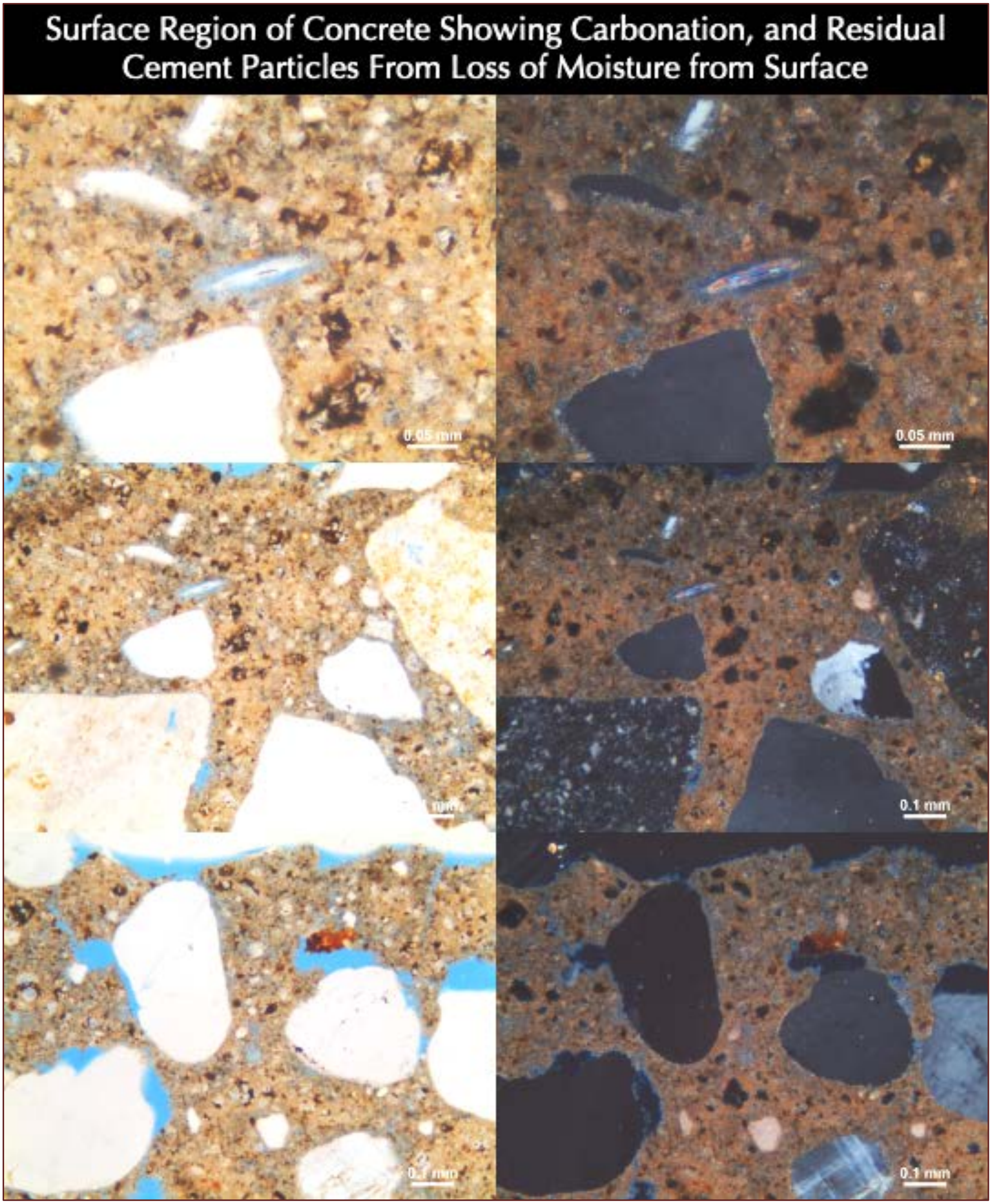

Figure 13: Micrographs of thin section of core from the exposed surface region showing carbonated nature of paste from golden yellow birefringence of paste in XPL photos at right, and abundant residual Portland cement paticles and some irregular-shaped voids at the surface region where voids are highlighted in blue epoxy.

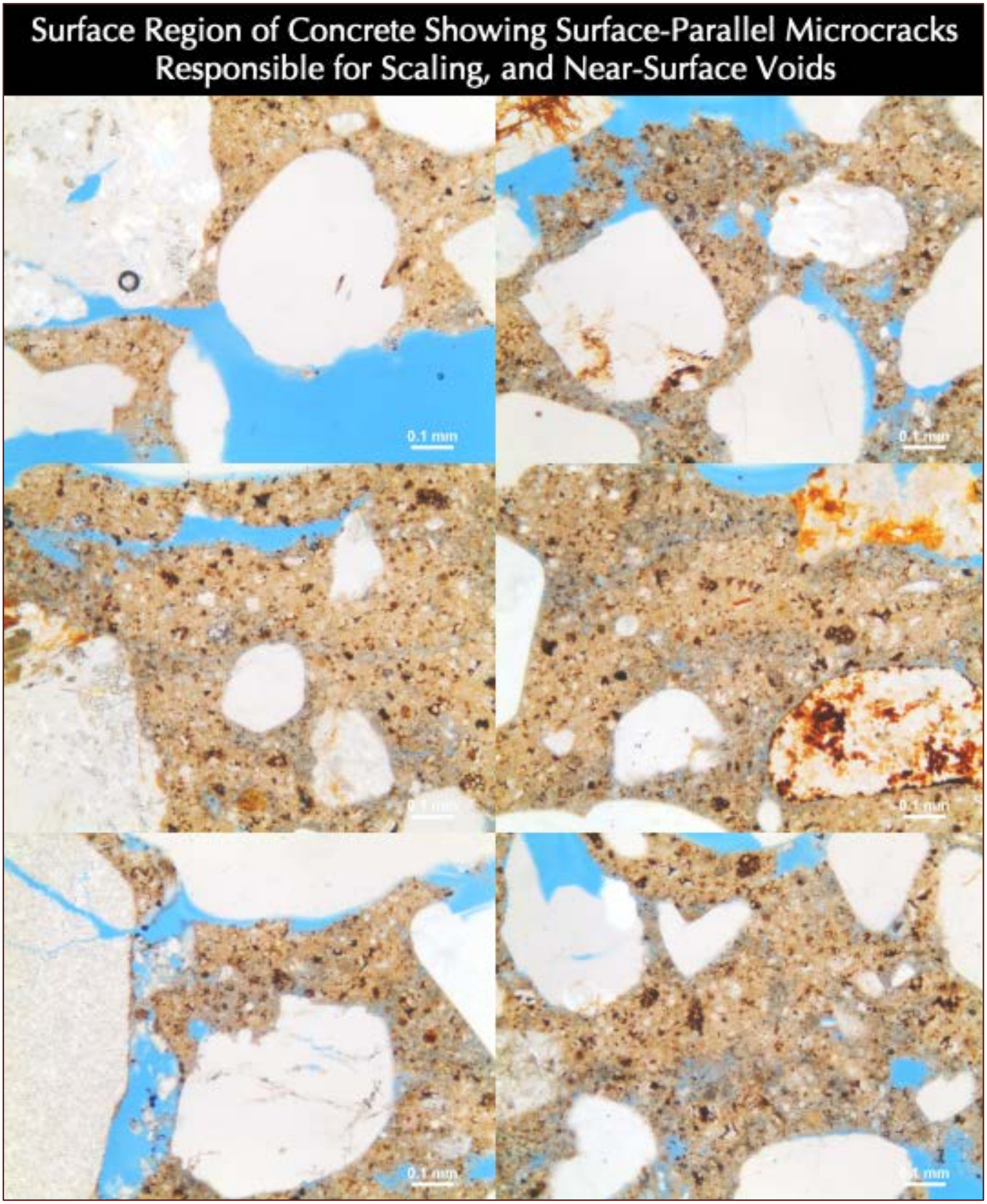

Figure 14: Micrographs of thin section of core from the exposed surface region showing abundant residual Portland cement paticles and some irregular-shaped voids at the surface region where voids are highlighted in blue epoxy.

BLACK AND WHITE CONTRAST ENHANCEMENT TO DETERMINE AIR-VOID PARAMTERS FROM A FLATBED SCANNER

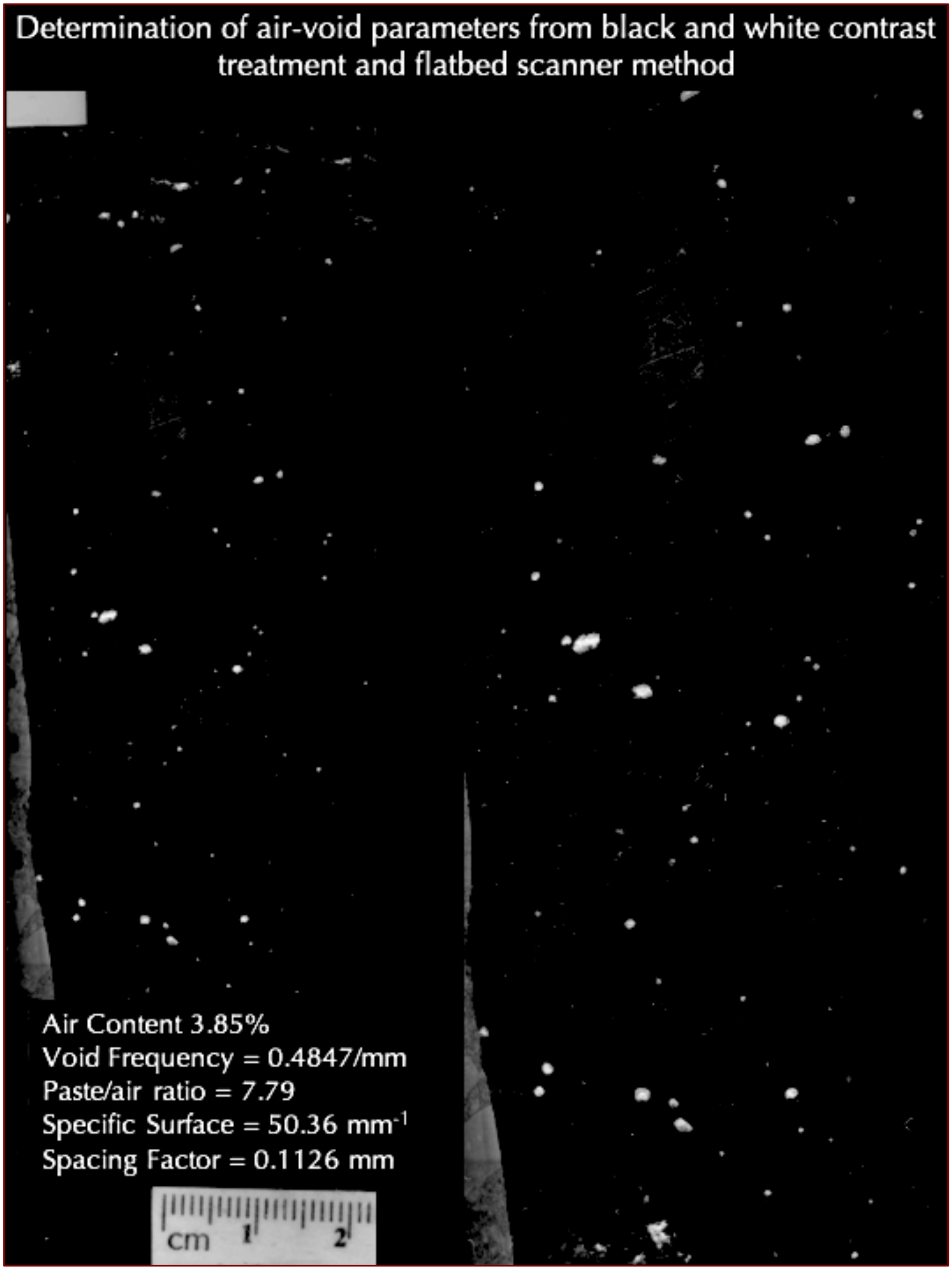

Figure 15: Lapped cross section of the core after treatment with black ink and white powders to fill all air voids against black background for scanning on a flatbed scanner according to the procedures of Peterson et al. (2016). The flatbed scanner method is used to determine air content and air-void parameters which showed non-air-entrained nature of concrete and a total air content of less than 4 percent.

COARSE AGGREGATE

Coarse aggregate is crushed stone consisting of major amount of limestone and subordinate amount of dolomite, where unlike limestone many dolomite particles are highly porous in having interstitial void spaces between dolomite rhombs, which makes those particles susceptible to distress due to freezing at critically saturated conditions (especially if they are present in near-surface regions and exposed to moisture and freezing). Particles have nominal maximum sizes of $^{3}/_{4}$ in. (19 mm). Particles are angular, variably dense to porous, variably hard, beige to gray, massive textured typical of limestone and dolomite, equidimensional to elongated, unaltered, uncoated, and uncracked. Coarse aggregate particles are well-graded, well-distributed, have been sound (except potential unsoundness of some porous dolomite particles as mentioned) during their service in the concrete with no evidence of any potentially deleterious alkali-aggregate reactions, and are judged not to have contributed to the observed surface distress of the concrete.

FINE AGGREGATE

Fine aggregate is natural siliceous sand having nominal a maximum size of 4 mm. Particles contain major amounts of quartz, and subordinate amounts of quartzite and feldspar, and other siliceous rocks. Particles are light gray to clear, angular to subangular, dense, hard, equidimensional to elongated, unaltered, uncoated, and uncracked. Fine aggregate particles are well-graded and well-distributed. There is no evidence of alkali-aggregate reaction of fine aggregate particles. Fine aggregate particles have been sound during their service in the concrete.

The following Table summarizes properties of coarse and fine aggregates determined from the core.

Properties and Compositions of Aggregates	Morio Pool Core
Coarse Aggregate	
Types	Crushed Limestone and Dolomite
Nominal maximum size	$^{3}/_{4}$ in. (19 mm)
Rock Type	Major amount of limestone and subordinate amount of dolomite
Angularity, Density, Hardness, Color, Texture, Sphericity	Angular, variably dense to porous, variably hard, beige to gray, massive textured typical of limestone and dolomite, equidimensional to elongated
Cracking, Alteration, Coating	Unaltered, Uncoated, and Uncracked
Grading & Distribution	Well-graded and Well-distributed
Soundness	Sound
Alkali-Aggregate Reactivity	None
Fine Aggregates	
Types	Natural siliceous sand
Nominal maximum size	4 mm
Rock Types	Major amounts of quartz, and subordinate amounts of quartzite and feldspar, and other siliceous rocks

Properties and Compositions of Aggregates	Morio Pool Core
Cracking, Alteration, Coating	Light gray to clear, subangular to subrounded, dense, hard, equidimensional to elongated
Grading & Distribution	Well-graded and Well-distributed
Soundness	Sound
Alkali-Aggregate Reactivity	None

Table 1: Properties of coarse and fine aggregates of concrete in the core.

PASTE

Properties and composition of hardened cement paste are summarized in Table 2. Paste is dense, and uniform in appearance throughout the depth. Freshly fractured surfaces have subvitreous lusters and subconchoidal textures. Residual and relict Portland cement particles are present and estimated to constitute 8 to 10 percent of the paste volume in the bodies of the cores. Besides Portland cement, fine, spherical, clear, light to dark brown and black glassy particles of fly ash are present having the fineness of cement. Hydration of Portland cement is normal.

Properties and Compositions of Paste	Morio Pool Core
Color, Hardness, Porosity, Luster	Dense, and uniform in appearance throughout the depth
Residual Portland Cement Particles	Normal, 8 to 10 percent by paste volume in the bodies
Calcium hydroxide from cement hydration	Normal, 10 to 14 percent by paste volume in the bodies
Pozzolans, Slag, etc.	Fly ash
Water-cementitious materials ratio (*w/c*), estimated	0.45 to 0.50
Cement contents, estimated (bags of Portland cement per cubic yard)	6 to $6^1/_2$
Secondary Deposits	None
Depth of Carbonation, mm	2 to 5 mm from the finished surface
Microcracking	Near-surface, surface-parallel freezing-related microcrack
Aggregate-paste Bond	Tight
Bleeding, Tempering	None
Chemical deterioration	None

Table 2: Proportions and composition of hardened cement paste in the core.

The textural and compositional features of the paste are indicative of cementitious materials contents estimated to be equivalent to 6 to $6^1/_2$ bags of Portland cement per cubic yard of which about 10 percent is estimated to be fly ash, and, a water-cementitious materials ratio estimated to be 0.45 to 0.50. There is no evidence of any deleterious secondary deposits found in the core. Carbonation was restricted to the top 5 mm from the exposed surface. Bonds between the coarse and fine aggregate particles and paste are tight.

AIR

Air occurs as a few coarse, near-spherical and irregularly shaped voids of sizes coarser than 1 mm. The voids are characteristic of entrapped air. There is no evidence of intentional addition of fine, discrete, spherical and near-spherical less than 1 mm size entrained air voids in concrete.

Air-void system of concrete is suggestive of no addition of an air-entraining agent in the mix. Therefore, concrete is determined to be non-air-entrained having an estimated air content of 2 to 3 percent.

DISCUSSIONS

Mix Design of Concrete

The mix design of the concrete reportedly contained 508 pounds of Portland cement, 56 pounds of fly ash, 1489 pounds of sand, 1541 pounds of $^3/_4$ in. stone, 31.5 gallons of water, an air-entraining agent for a design air content of 6.0 percent, a design water cementitious materials ratio of 0.47, and a 28-day design compressive strength of 4000 psi.

According to common industry specifications (e.g., ACI documents), an outdoor concrete slab exposed to cyclic freezing and thawing should be air-entrained and should have a minimum compressive strength of 4000 psi, preferably 4500 psi in a moist outdoor environment. The reported design strength of concrete is less than the common industry specification of 4500 psi strength for an outdoor slab exposed to freezing, salt, and snow in a moist environment.

Air Contents and Air-Void Systems

Contrary to the reported mix design of an air-entrained concrete, the present concrete in the core is found to be non-air-entrained. Absence of air entrainment is determined to be the main reason for the surface scaling of the pool deck in the presence of moisture and cyclic freezing and thawing at critically saturated conditions. The concrete delivered at the location of the core examined here lacked an air-entraining agent hence did not stabilize a network of entrained air voids to protect the concrete from freezing-related distress.

Aggregates

The crushed limestone-dolomite coarse aggregate and siliceous sand fine aggregate particles are present in sound conditions and did not contribute to the observed surface distress. Some near-surface porous dolomite particles in coarse aggregate, however, can cause pop out-type distress if exposed to freezing at saturated conditions.

Placement, Finishing, and Curing

The interior concrete is dense and well-consolidated without any coarse voids or honeycombing, indicating adequate consolidation of concrete during placement. There is also no evidence of any segregation of aggregates during placement. There is, therefore, no evidence of any improper consolidation practices of at the location of the received core.

There is no evidence of any finishing-induced improprieties found in the core at the time of examination.

Curing is essential for adequate cement hydration at the surface, and, thereby, development of the necessary strength of concrete at the surface by providing enough moisture and optimum temperature for cement hydration. Exposed surface of the core shows no evidence of inadequate curing of concrete, e.g., no evidence of restricted cement hydration at the scaled surface at least to cause the reported surface scaling.

Mortar Lift-Off

Mortar lift-off as loss of thin sheet of the original finished surface of concrete from over the flat topside of near-surface aggregate particles is seen in field photos, which could also contribute to the surface distress. Mortar lift-off is not due to the exposed aggregate, which is sound and did not fracture (as would have been in the case of aggregate popout). Instead, the thin sheet of surface mortar was lost due to inadequate bond to the near-surface coarse aggregate. Mortar lift-off could have been avoided by deep embedding of aggregates along with a better bond of finished surface to the coarse aggregate from proper finishing operations and curing. Improper finishing can lead to mortar lift-off where flat topsides of aggregates situated very near the exposed surface do not form a good bond with the finished surface either due to repeated finishing passes and/or from excess water or other reasons.

Compressive Strengths

For adequate resistance to freezing-related stresses, the common industry (e.g., ACI Committee 201)-recommended compressive strength of concrete exposed to an outdoor environment of moisture and freezing is at least 4000 psi. A concrete having a compressive strength of at least 4500 psi is usually recommended for an outdoor concrete slab exposed to moisture, salts, and snow, where the good strength of concrete provides the necessary resistance against freezing-related tensile stresses in concrete.

Reported design compressive strength of concrete is 4000 psi, which is less than the common industry specifications of 4500 psi for an outdoor concrete exposed to freezing, moisture, salt, and snow.

Concrete Maturity

The maturity of concrete is defined as: (i) a period of air drying and (ii) a compressive strength of at least 4000 psi – both prior to the first exposure of salts and snow so that the concrete does not contain any 'freezable' water in its capillary pores to freeze, expand, and thus cause distress (hence the importance of at least a period of air drying), and is strong enough to resist freezing-related stresses (hence the importance of adequate strength of at least 4500 psi) both prior to the first exposure of snow and salt (Jana 2004, Jana 2007). A concrete, therefore, needs to be 'matured' prior to the first exposure of freezing, especially during the winter weather constructions. Reported June 2016 placement of slab should have provided the necessary maturity prior to the first winter weather exposures.

Deicing Salts

Deicing salts, usually, do not cause surface scaling in a properly air-entrained concrete having a good air-void system that is made using sound aggregates, and has been placed, finished, cured, and was matured properly (Jana 2004, 2007), *unless*: (i) salt is applied prior to the attainment of maturity of concrete, and/or (ii) a chemically aggressive (e.g., magnesium or ammonium sulphate or urea-based) salt is applied that can chemically decompose the paste (calcium-silicate-hydrate, the heart of concrete). A well-designed concrete placed, finished, and cured properly should resist the deleterious action of salt unless salt was brought in too early and/or a chemically corrosive salt (magnesium sulfate or ammonium-based) was present that has caused chemical erosion of paste.

Beneficial Aspect of a Surface Sealer

Exposed surface of core showed evidence of application of a surface sealer (from the shiny appearance). It is the concrete itself, i.e. an adequately air-entrained concrete made using optimum air content and good air-void system, sound aggregates, good paste, placed, finished, and cured properly, and has been matured prior to the first exposure to freezing, salts, and snow, which should provide the necessary durability in an outdoor environment of freezing, salt, and snow. When all these basic factors are fulfilled from concrete materials to construction practices, having an additional surface sealer is not needed for protection. A surface sealer, however, does provide an additional protection, particularly when the inherent concrete quality and/or construction practices is/are questionable such as in this present case, where concrete is non-air-entrained. There are, however, many incidences of surface scaling in many outdoor slabs that did receive surface sealers, simply because sealer did not provide a long-term protection, and needed repeated applications. On the other hand, there are many incidences of perfectly sound outdoor slabs without any sealer that were exposed to freezing, salts, and snow but no distress at all simply because the concretes were made using sound durable materials and were well-constructed (consolidated, finished, cured), and matured properly. Therefore, having or not having a sealer is not the paramount factor for providing the first-hand protection against the environment. Sealer becomes more important when the inherent quality of concrete is questionable as here for having no air entrainment at all.

CONCLUSIONS

Based on detailed laboratory investigations, surface distress of concrete is determined to be due to lack of air entrainment in concrete exposed to cyclic freezing and thawing at critically saturated conditions. Beneath the distressed surface the interior concrete is non-air-entrained and hence would continue to deteriorate through depth. The concrete did not follow the reported specification of use of an air-entrained mix.

REFERENCES

ACI Committee Report 201.2R, Guide to Durable Concrete, ACI Manual of Concrete Practice, Vol. 1, American Concrete Institute, 2008.

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END OF REPORT[1]

[1] The CMC logo is made using a lapped polished section of a 1930's concrete from an underground tunnel in the U.S. Capitol.