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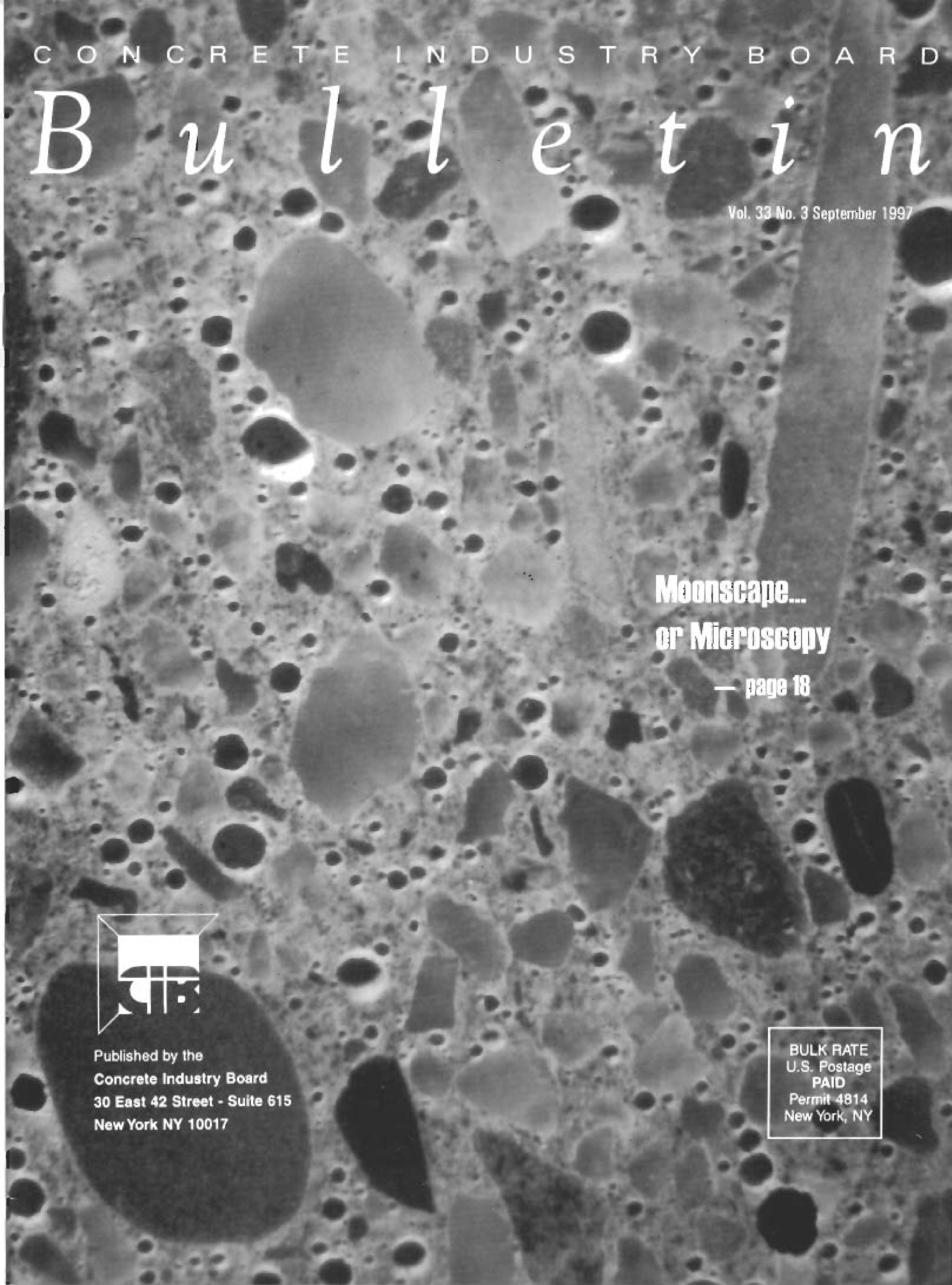

Moonscape...
or Microscopy

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Microscopy: A Practical Solution to Concrete Problems

By Dipayan Jana and Akin A. Cole

Since the early 1930's, petrography, the science of macroscopic and microscopic examination of natural rocks, has been a powerful tool in determining the quality of cement, concrete and concrete aggregates. Microscopical examination of freshly fractured concrete specimen, or polished concrete slabs or thin sections (≤0.0006 inch thick, transparent to light where all concrete constituents preserve the original composition and distribution) can provide a quick, accurate and cost-effective method for the detection of many commonly encountered problems in concrete structures.

The ability of various optical and electron microscopes to magnify objects by more than 100,000 times allows for the thorough examination of the texture and microstructure of concrete (**Photo 1**). The information obtained from representative concrete slabs or cores from a structure has tremendous potential in troubleshooting various concrete problems.

A few examples of typical information possible to collect from a routine test include :

- **Aggregate quality** (type, shape, gradation, distribution, freshness, potential alkali-reactivity, freeze-thaw resistance, chemical weathering resistance, identification of deleterious constituents like clay lumps, fine particles, organic matter, etc.
- **Paste quality** (hardness, porosity, permeability, degree of carbonation, water/cement ratio, degree of cement hydration, compositional homogeneity, etc.).
- **Tightness of bonding** between aggregates and paste.
- **Types and effects of dosage of admixtures.**
- **Identification, location, and amonnt of secondary deposits.**
- **Air void characteristics** (amount, distribution, spacing).
- **Nature and extent of cracking.**
- **Mix** (aggregates-paste-air voids) **proportions.**
- **The severity and extent of damage of a concrete** structure by various physical and chemical deteriorations.

Following are some common construction problems which can be determined by microscopic examination :

Mix design problems: Any variation between the project specified and the observed mix design can be readily identified from microscopical determination of proportions of coarse and fine aggregates, paste and air voids

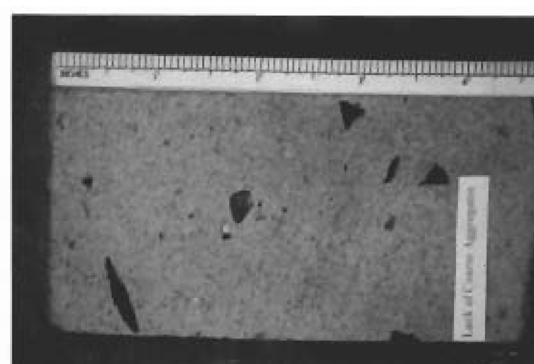
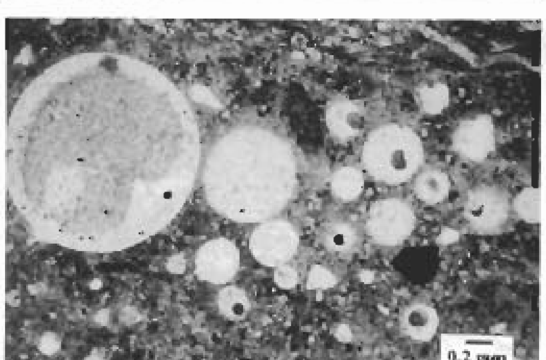


Photo 1, left: Reflected (left) and transmitted (right) light microscopes: two indispensable tools for solving common concrete problems.

Photo 2, right: Improper mix design: too little coarse aggregates



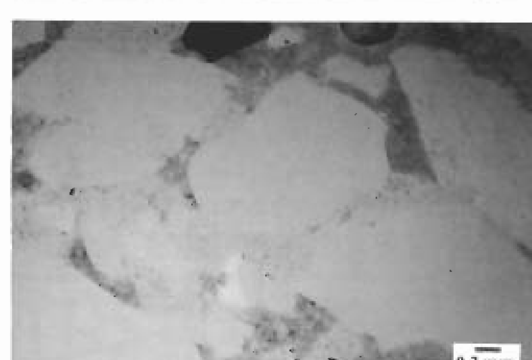
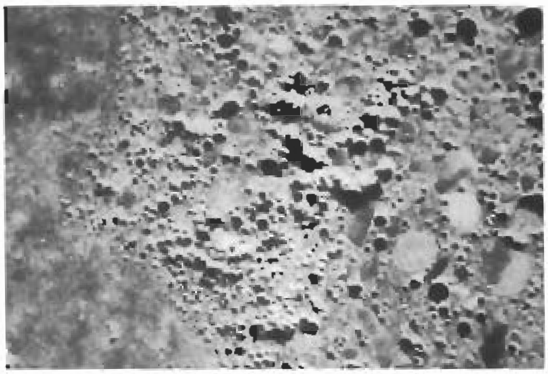


Photo 3, left: Improper mix design: too much air voids.

Photo 4, right: Improper mix design: too little paste.



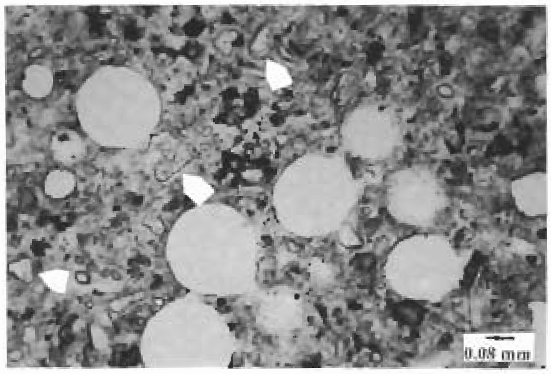
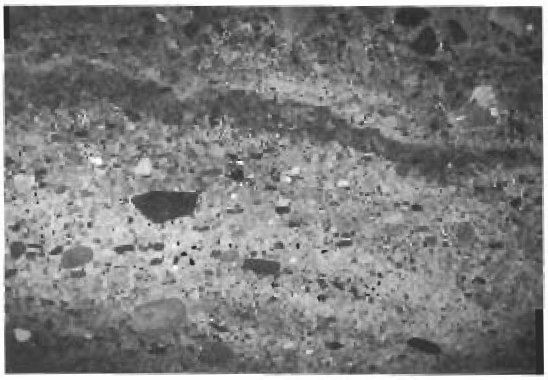


Photo 5, left: Inadequate mixing: air void clustering

Photo 6, right: Clustering of air voids and unhydrated cement particles.



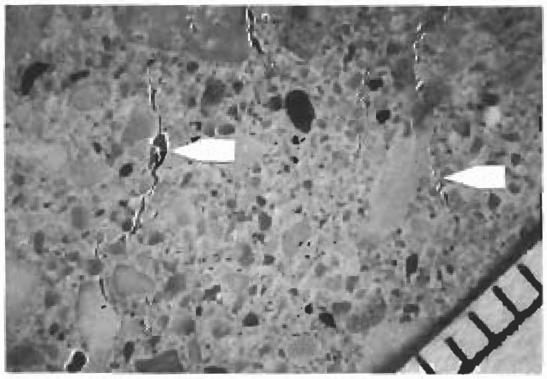
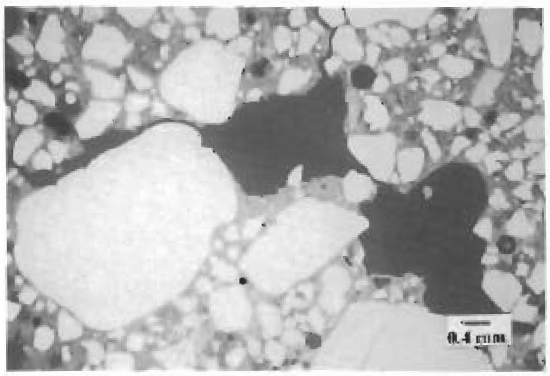


Photo 7, left: Inadequate mixing: sand streaks.

Photo 8, right: Bleeding channels.



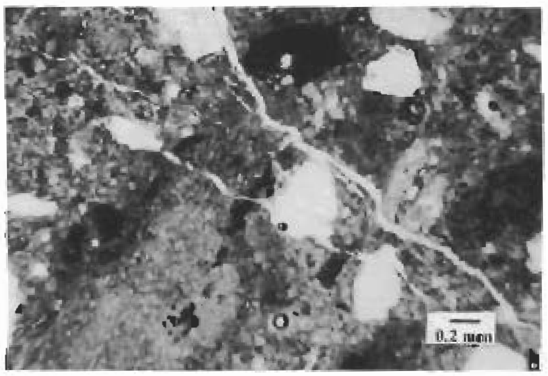


Photo 9, left: Inadequate compaction: honeycombing.

Photo 10, right: Rapid drying: plastic shrinkage cracks in paste.

in hardened concrete (**Photos 2-4**).

Mixing problems: Inadequate mixing can be suspected from clustering of aggregates or air voids (**Photo 5**) or unhydrated cement particles (**Photo 6,** marked with arrows), variation in mortar density, or from the presence of sand streaks (**Photo 7**).

Placement & finishing problems: Bleeding and overvibration can be detected from a gradual increase in the size of coarse aggregates towards the bottom, from the segregation of large voids towards the top, and from narrow bleeding channels around aggregates (**Photo 8**). Retempering, or addition of excess water during placement to increase the workability in hot weather can be detected from dark gray patches of concrete or mortar of low water/cement ratio (W/C) in a light gray matrix of high W/C, coatings of dark gray paste around aggregates, air void clustering, or small-scale compositional and physical heterogeneity in paste. Improper compaction can be detected from the presence of large irregularly shaped entrapped air voids adjacent to coarse aggregates (honeycomb, **Photo 9**). Presence of elongated or poorly graded or dirty aggregates question proper

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consolidation because of increased water demand and reduced concrete strength.

Curing problems: Inadequate curing can be suspected from soft chalky-textured highly carbonated paste, plastic shrinkage cracks due to rapid evaporation of surface water before complete hardening (**Photo 10**). Inadequate curing or finishing while there is bleed water on the surface, sprinkling cement on the surface to dry up the bleed water are some of the possible causes of surface dusting, scaling, crazing, cracking which a petrographer usually suspects before detailed investigation of a newly damaged concrete structure.

***Alkali-Aggregate Reaction* (AAR)**: Identification of reactive aggregates, cracking in aggregates extending towards paste (**Photo 11**), reaction rims around aggregates, alkali-silica gel extrusion to fractures and open spaces, and the presence of large rhombic crystals of dolomite in fine grained matrix of calcite, dolomite, clay (in alkali-carbonate reaction, **Photo 12**).

Sulfate attack: Abundant needle-like calcium sulfoaluminate hydrate crystals (ettringite) and platy gypsum crystals in paste, fractures and air voids (**Photo 13**). Also, thaumasite needles in concrete affected by both carbonation and sulfate attack.

Staining and discoloration of concrete walls can be ascribed to the presence of soluble iron oxide, hydroxide or sulfide minerals in aggregates.

Paste carbonation : Readily evident from the presence of abundant calcium carbonate crystals in soft chalky-textured paste, or change in the color of the paste from light pink (noncarbonated) to colorless (carbonated) when treated with phenolphthalein solution (**Photo 14**).

Corrosion of reinforcing steel : Cracking and spalling of concrete from the reinforcement and presence of iron oxide or hydroxide expansive reaction products in concrete (**Photo 15**).

Low strength can be suspected from the petrographically estimated high W/C (**Photo 14**, paste with severe carbonation), improper aggregate-paste-void proportioning, or high amount of air voids (**Photo 3**), etc.

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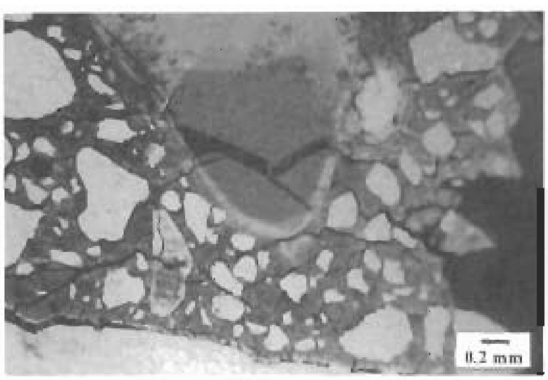


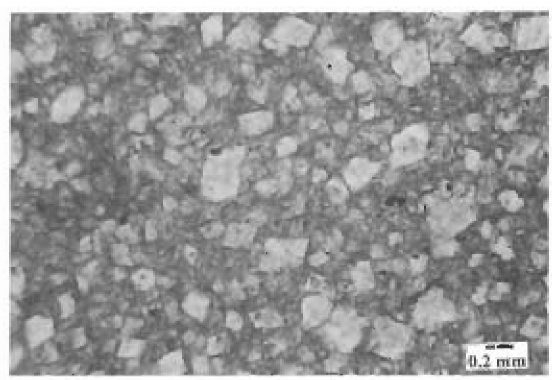
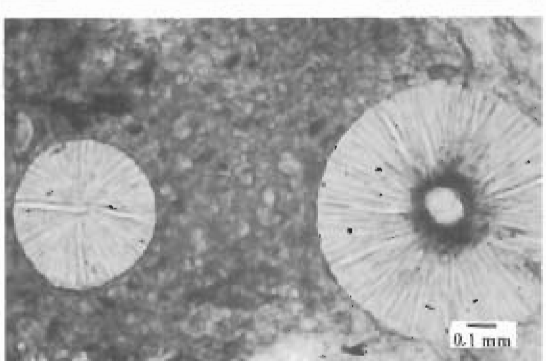


Photo 11, left: Alkali-silica reaction: cracking in aggregates and paste.

Photo 12, right: Alkali-carbonate reaction: large dolomite crystals in fine-grained matrix.



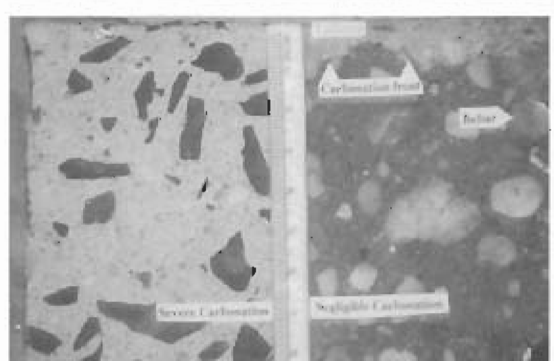
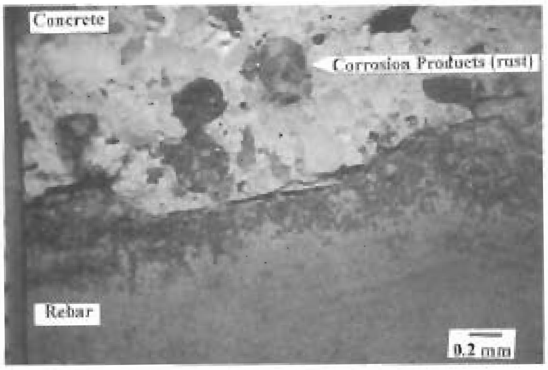


Photo 13, left: Sulfate attack: ettringite needles in air voids.

Photo 14, right: Paste carbonation.



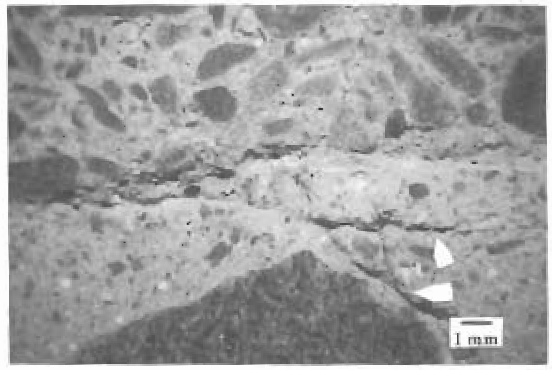
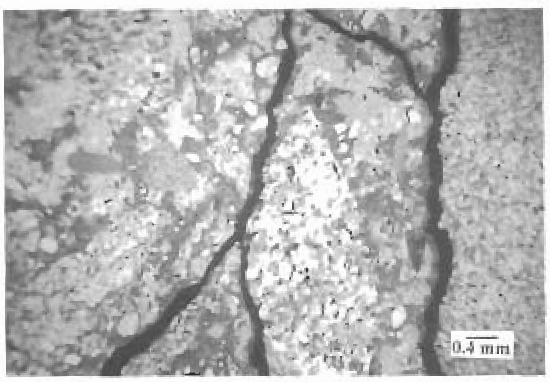


Photo 15, left: Corrosion of reinforcing steel.

Photo 16, right: Top concrete: air entrained (no cracking). Bottom concrete: non-air entrained (cracking).



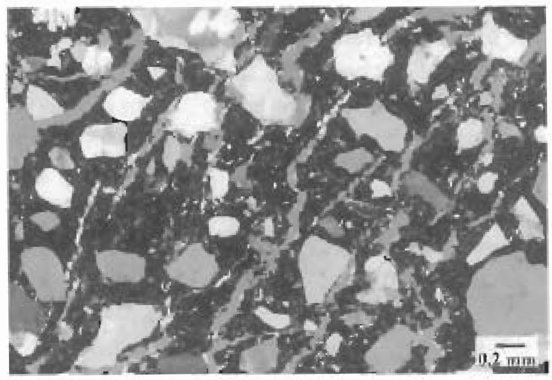


Photo 17, left: Freeze-thaw cracking.

Photo 18, right: Ice crystal impressions – freezing of plastic concrete.

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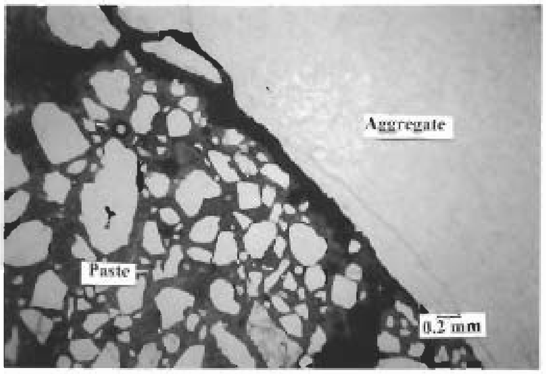

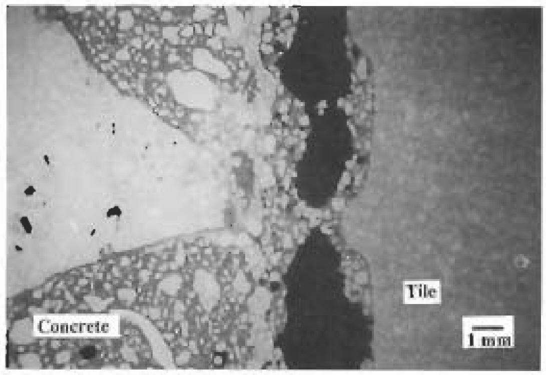

Photo 19, left: Weak aggregate – paste bonding.

Photo 20, right: Weak bonding between concrete and tile.

Low freeze-thaw resistance (e.g., scaling, spalling, cracking, aggregate popouts, etc.) can be suspected from the lack of proper air entrainment **(Photos 16, 17)**, large spacing among air voids, subparallel cracking in the paste **(Photo 17)**, the presence of water absorptive minerals in aggregates, the presence of ice crystal impressions in the paste (**Photo 18**), or the presence of chloroaluminate crystals (from deicing salts) in the paste.

Leaching of paste in aggressive water (acidic water, rain water, seawater) can be determined from the soft, porous nature of the paste and the presence of efflorescent salt deposits in the paste.

Bonding problems : Weak paste-aggregate bonding (**Photo 19**) can be ascribed to water void concentration at the interfaces indicating high w/c ratio or internal bleeding in the paste, or due to presence of expansive chemical reactions, or due to dirty aggregates with a thin layer of water absorptive clay minerals preventing tight contact. Weak concrete-to-component bonding can be due to the presence of soft, porous mortar at the interfaces **(Photo 20)**.

On a modern construction technology team, an experienced petrographer can expand his/her role from a designer to an active forensic investigator to a doctor by investigating the quality control of fresh concrete, searching for the causes of structural failures, and providing constructive recommendations for better future performances. This good, old science of geology is becoming an important testing tool for the modern construction industry. ■

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About the Authors:

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