What Can Petrography Tell You About the Condition of Concrete Structures?

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According to a 2013 Report Card for America’s Infrastructure, 1 in 9 bridges in metropolitan areas are structurally deficient. The estimated investment needed to eliminate the backlog of deficient bridges by 2028 is $20.5 billion annually—that’s $8 billion more per year than currently invested. Recently, CBS addressed the topic of crumbling roads and bridges in its 60 Minutes special, “Falling Apart: America’s Neglected Infrastructure.” The report explained that the United States, which once had the best infrastructure in the world, has fallen to 16th place.

Due to the astounding costs of infrastructure replacement, it is critical to conduct a thorough material assessment to understand when repairs can save or extend the service life of the structure. A petrographic analysis provides pertinent information about the structure’s concrete and steel materials to help engineers determine the best-suited repair strategy.

Petrography is a branch of geology that is applied to concrete and concrete raw materials. This technique examines and evaluates the optical properties and microstructural characteristics of the materials. Petrographic examinations for concrete begin by accepting an aggregate for use in concrete (ASTM C295). Once the concrete is hardened, a petrographic examination that follows American Society for Testing and Materials (ASTM) C856 and ASTM C457 can be applied to verify that the product was mixed as designed and that the appropriate or specified materials were used.

Concrete petrography also helps to identify the nature of deterioration or defects, to determine the degree of damage, and to evaluate whether the damage will continue. Perhaps most critically, petrographic analyses aid repair versus replace decisions, making them an integral part of evaluation strategies.
Steps in a Petrographic Analysis

Some of the information provided during a petrographic analysis includes:

- Air content and distribution – Concrete is often entrained with small air bubbles to provide resistance to damage due to freeze thaw cycles. Petrography techniques are used to evaluate air void amount and distribution, to determine whether they are present in sufficient amounts, and to determine whether their spacing provides freeze thaw durability in their environment. Entrapped air and the locations where bleed water has left air voids are also examined and evaluated. The location, distribution, and size of air voids can uncover placement and finishing issues.
Cracking – Concrete cracking is a common issue with building owners. Cracks can be harmless, but they can also lead to water ingress-inducing chemical attack, or affect the strength of the material. Cracks are measured and patterns and sources are identified through a visual and microscopic inspection. The characteristics of the cracks are then compared with typical causes such as drying shrinkage, thermal contraction, plastic shrinkage, settlement, applied loads, chemical reactions, etc. Identification of the cause and extent of cracking can assist with repair decisions.

Steel reinforcement – Concrete often contains steel reinforcement rods. The integrity of the steel (is it corroding, properly placed, etc.) and its effect on the surrounding concrete is evaluated. Corrosion and corrosion-induced cracking, consolidation issues, and cracking typical of thermal contraction can also be identified.

Secondary deposits – Chemical reactions of the concrete components, whether with each other or with their exposure environment, can occur and may be detrimental to the integrity of the structure. These reactions result in specific formation of minerals or deposits which sometimes lead to expansion and cracking within the concrete. Internal and external sulfate attack, alkali aggregate reactions, and chloride ingress can be identified and evaluated. Detailed evaluation of these reactions are best viewed using scanning electron microscopy with energy dispersive x-ray spectroscopy (SEM/EDS).
• **Water/cement ratio and Porosity Distribution** – Correlations between the density of the concrete cement paste and the water/cement ratio can be made using fluorescent microscopy and backscattered electron microscopy. These analyses help to determine whether the material is appropriately dense for its application and specifications, and whether it was well mixed. Evaluation of the porosity distribution can also uncover finishing issues at the surface.

• **Binder Type and Paste content** – The type of binder or cementitious material used in concrete is specifically designed for the specified performance and application it was placed. Concrete is typically composed of ordinary Portland cement, and/or supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag, or silica fume. Paste content is correlated to the cement content in the mix. The area volume of cement paste is estimated or calculated and compared to the typical range for good performing concretes, and/or to the design specifications. Identification and evaluation of the binder is critical to petrographic examination.

• **Depth of carbonation** – Carbonation occurs when calcium in the material reacts with carbon dioxide from the air. By examining how deep the carbonation has penetrated, impacts to steel passivity (protection from environmental conditions) or surface durability can be determined.

The information from a petrographic analysis is most commonly used to uncover performance issues or degradation mechanisms and the extent of damage, though it can also be used to verify mix design. While understanding the material at a microscopic level is necessary for a concrete investigation, having a comprehensive picture of the material’s designed use and exposure conditions provides another layer of information necessary for making engineering decisions.

### Building a Concrete Team

Petrographic analysis is only a small piece of the puzzle when evaluating a structure for durability and performance. While petrographers analyze characteristics of concrete at the micro level, engineers or inspectors provide the visual inspection data required to have a complete understanding of the structural issues. A construction inspector or engineer with knowledge of the site, history, and exposure conditions may also identify the need for supplementary tests to evaluate the concrete mechanical properties, steel, and chemical ingress. Interpretation of the observations gathered during a petrographic examination is greatly improved with knowledge of this supplementary information about the structure and reason for the petrography testing request. When the engineer or other professional inspecting a concrete structure works directly with the petrographer to provide supporting information the collaboration leads to better decisions for repair or replacement of the structure.

### Case Study – Petrographic Examination Saves Department of Transportation $100 Million

As part of a team, RJ Lee Group was asked by a state DOT to perform a condition assessment on a 55-year old bridge. The DOT was concerned that the structure’s deterioration was so advanced that they were going to have to replace a portion of the road on an overpass. They wanted to know if anything could be done to extend the road’s service life another 25 years. Visual inspection suggested corrosion of the steel reinforcement that was beyond repair.
During the investigation, 38 cores were taken at different sampling sites. The lab testing program included compressive strength, petrographic, and chloride profiling. In this case, petrographic examination saved the bridge. The corrosion was NOT the cause of cracking. Cracks were confined to a 6-foot section near the joints where the air entrainment was not able to prevent freeze thaw damage. The freeze thaw damage in turn allowed moisture to penetrate the area, which triggered an alkali silica reaction (ASR). The ASR was confined to a small perimeter, and it was projected that the structure could be repaired for a minimum investment and the service life could be extended about 25 years through a combination of repairs and maintenance. The DOT estimated that it saved $100 million since it did not need to replace the bridge.

Conclusion

The root cause of concrete deterioration can often be attributed to quality issues seen at the microscopic level of the material. In situations where critical structures could cost millions of dollars to replace, a trained petrographer may be able to determine whether a repair solution is feasible.