Petrography as an essential complementary method in forensic assessment of concrete deterioration: Two case studies

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ABSTRACT

Concrete damage is most often first assessed using traditional methods, e.g., strength testing (compressive, tensile), total porosity from water uptake, water infiltration depth, cement/aggregate ratio and chloride content. While traditional methods may produce useful results bearing clues to resolve the problem, in some cases they do not, and can even be harmful to the parties involved. This paper describes two such cases where traditional methods provided false or inadequate results, putting liability with the wrong party. Both cases illustrate that petrography is an indispensable tool in the forensic assessment of concrete.

In the first case, a building and construction contractor was held liable for the damage to a newly built sedimentation basin, according to the results of an initial assessment "of poor quality concrete". A second assessment using impregnation–fluorescence petrography combined with detailed geochemical analysis revealed that instead the concrete was of normal constitution and compliant with specification, and that the damage was due to the application of urea, releasing the contractor from his conviction.

The second case deals with pre-fabricated foundation piles that cracked upon pile-driving. The pile-driving contractor was blamed for the damage, allegedly from too much driving energy in combination with a worn-out wooden baffle. While the compressive strength of the concrete was normal, the tensile strength was found to be less than half of the expected value. Thin section petrography revealed poor adhesion of aggregate to the surrounding paste, confirming field observations. This could be attributed to "liquefaction and water expulsion" at an early stage of production when the piles still were under the care of the manufacturer.

1. Introduction

Many damage problems with concrete structures are first assessed using traditional methods, including among others strength testing (compressive, tensile), total porosity from water uptake, infiltration depth, cement/aggregate ratio, and chloride content. While in many cases such traditional methods may produce useful clues to finally resolve the problem, in other cases they may not, and false or inadequate results can be harmful to any of the parties involved. Such damage cases require a different approach to determine the actual problem and to distinguish cause from consequence, using methods from applied mineralogy and geochemistry rather than traditional property testing techniques [1]. This paper describes two unrelated cases of concrete damage where traditional methods initially provided false or inadequate results, putting liability with the wrong party.

The first case involves the assessment of a circular sedimentation basin in a newly constructed municipal wastewater treatment facility. Its top surface was finished with

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water-tight epoxy grit, and urea was applied as a pre-icing agent to prevent the wheel driving the bottom scraper from slippage. After just over 1 year of service, the basin wall extending ~0.7 m over ground level had become completely stripped of its initially smooth formworks surface. The engineering consultancy that had designed the entire facility prescribed urea as "the smart chloride-free alternative to salt". The consultancy also supervised the building and construction process and held the contractor liable for the 'inadequate concrete quality'. An initial investigation by visual assessment of extracted cores suggested that the concrete was of poor quality and non-compliant with specifications. Furthermore, determination of cement content suggested that some parts of the basin wall concrete contained an excessive 540 $kg{\cdot}m^{-3}$, compared to 300–350 $kg{\cdot}m^{-3}$ as specified. The contractor admitted that the concrete might not be 'state-of-the-art', but it did comply with the specifications as given. Thus, the contractor appealed the initial 'conviction', which held them responsible for the cost of a complete rehabilitation of the sedimentation basin. Instead of going to court, both parties agreed that a second opinion was needed to settle the disagreement.

The second case involved prefabricated foundation piles that cracked upon pile driving. The cracks split the piles from the top downward, even after the wooden baffle plates had been replaced with newer and softer ones and energy was adjusted down until the piles were no longer driven at a sensible rate. The pile manufacturer blamed the piling contractor for using too much energy when driving the piles, crushing the pile heads. In return, the piling contractor blamed the manufacturer for having produced concrete of poor quality. Whereas initial testing confirmed compressive strength to be as expected, tensile strength appeared significantly lower than the ~20% of the compressive strength that a general 'rule-of-thumb' predicts. No further explanation was given for the observed low tensile strength; nevertheless, the project supervisor blamed the pile driving contractor for incompetence and demanded replacement of the piles. The contractor appealed this "conviction".

In both cases, results obtained from traditional assessment methods had implicated one party in a dispute with seemingly valid and solid arguments against them. However, second assessments using impregnation–fluorescence petrography (combined with complete geochemistry for the sedimentation basin concrete) provided quite different arguments to the original ones. Results from these second assessments are elaborated below.

2. Materials and Methods

2.1. *Sample Extraction and Handling*

For the sedimentation basin, four cores Ø100×250 mm were drilled across the basin wall for petrography. Separate cores were extracted at the same height above ground level for geochemical assessment (see below). From the foundation piles, three cores Ø100×450 mm were extracted across three different pile heads, including the original hand-trowelled top surface and formworks bottom surface. All cores were extracted using a stand firmly affixed to the structure, and the diamond crown was cooled sparingly with water. Directly after extraction, cores were quickly rinsed in fresh water to remove adherent slurry, wrapped in a clean white cotton cloth and then cling-foil, before packaging in rigid PVC tubing for transport.

During core extraction from the sedimentation basin wall, a marked ammonia smell was noticed. This odour was prominent when the diamond crown cut into the concrete surface, but not when the drill had reached greater depths.

2.2. *Thin Section Preparation and Petrography*

The Ø100 mm cores were cut in half lengthwise with a closed-rim diamond blade, again with limited water cooling. Locations for thin sections were selected from both the original structure surface and the concrete interior, after visual inspection of both core halves using a stereo microscope. Impregnated thin sections for fluorescence petrography were prepared in conformance with Danish Standard 423.40 [2], and finished with a 0.17 mm cover glass for protection and preservation. For the sedimentation basin concrete only, four additional non-impregnated standard petrographic thin sections were prepared, without cover slip [3]. Two of the uncovered sections were stained with Alizarin-Red essentially using the procedure from Friedman [4], to reveal calcite present in aggregate material. This method also stains the porous and basic cement paste.

The modal content of coarse aggregate in sedimentation basin concrete was assessed by grid counting on core halves using a 10×10 mm grid. The modal contents of fine aggregate and cement paste were determined by point counting in thin sections, with a minimum of 1000 points/section. Results reported here always represent averages from three separate counts. Modal composition of the concrete from the foundation piles was not assessed in further detail.

Thin sections were studied in a petrographic microscope using transmitted illumination in plane polarized light (PPL), cross-polarized light (XPL), and incident fluorescent illumination (FL).

2.3. *Geochemical Assessment*

Using the second core-set from the sedimentation basin, a single 15 mm thin disc weighing ~350 g and containing the outer surface was cut using minimum water and very low cutting speed to avoid heating. Again, a marked ammonia smell was noticed, as had been generated during core extraction from the structure. Similar ~15 mm thick sections were cut from the center of the core in the middle between the two wall surfaces. Here, however, no ammonia smell was observed. The disc sub-samples were comminuted in a jaw crusher and subsequently pulverized in an agate-lined vibratory disc-mill. Sample size and representativeness of (Dutch) aggregate material are discussed in [5].

Bulk concrete was analyzed by XRF for Na_2O, K_2O, MgO, CaO, MnO, Al_2O_3, Fe_2O_3-total, TiO_2, SiO_2, and P_2O_5 after HT-digestion in excess Li-tetraborate ($Li_2B_4O_7$). Operating conditions of the XRF instrument were set at 50 kV and 50 mA. Bulk-LOI was determined gravimetrically by weighing powdered