IN-SITU ANALYSIS OF WATER TRANSPORT IN CONCRETE COMPLETED USING X-RAY COMPUTED TOMOGRAPHY

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Summary: The water-transport characteristics of concrete have a major impact on its resistance to damaging chemical processes such as Alkali-Silica-Reaction (ASR). Water transport in samples of damaged and undamaged concrete was measured using in-situ CT. The resulting measurements of water-front movement relative to time and the change in 3D-moisture distribution within the samples, are needed for calibration and validation of water-transport numerical models.

1. INTRODUCTION

Concrete infrastructure is highly vulnerable to chemical degradation processes such as Alkali-Silica-Reaction (ASR) [1]. ASR is intensified by the presence of internal water, which serves as a transport mechanism for the chemical reaction [1,2]. For this reason, the Deutsche Forschungsgemeinschaft (German Research Foundation (DFG)) has provided funding to the Bundesanstalt für Materialforschung und –prüfung (Federal Institute for Materials Research and Testing (BAM)) and a series of other project partners to investigate ASR behavior and to develop numerical tools for accurately simulating its long-term effects.

One aspect of this research program involves assessing the effect of mechanical damage on water absorption in concrete. To investigate this phenomenon, a concrete-beam with dimensions of 27 x 50 x 200 cm was subjected to five million cycles of four-point bending load. During each load cycle, the maximum bending stress within the beam oscillated between approximately 1.3 and 2.3 N/mm². After the loading was completed, 5 cm diameter cores were extracted from both the center of the beam, where damage was most severe, and from the ends of the beam, where there was little or no damage. Following sample extraction, X-ray computed tomography (CT) was used for evaluating water transport behavior in the different samples. The goal of these experiments was to determine changes in both the average moisture profile along the length of the samples and the 3D distribution of moisture throughout the cores. This experimental data was needed in order to serve as the basis for more advanced simulations of water transport and ASR damage mechanisms in concrete.

2. EXPERIMENTAL METHOD

During the water-transport testing, the core samples were placed within an in-situ water exposure apparatus developed specially for this purpose and scanned within a laboratory CT machine. The water exposure apparatus contained a small pump, which ensured that the bottom surface of the sample was constantly in contact with water throughout the testing period (Figure 1a). The cylindrical surface of the sample was coated with a polymer layer to ensure a one-dimensional moisture transport in the concrete specimen. This layer prevented water seepage and evaporation from the sides of the sample during testing. CT scans were conducted at increments of one hour, three hours, six hours, one day, two days and three days. During the measurement time the water contact was eliminated.

As one of the first experimental programs evaluating water transport in concrete through the use of CT, new experimental and analysis methods had to be developed and many challenges were encountered. The movement of

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water within the sample was visualized and quantified using subtraction-based image processing techniques. It became clear from the resulting images that X-ray scattering effects due to water had a major impact on the pixel-grayscale distribution within the images. To reduce this effect, the water exposure apparatus was temporarily drained during CT scanning for later experiments.

3. RESULTS

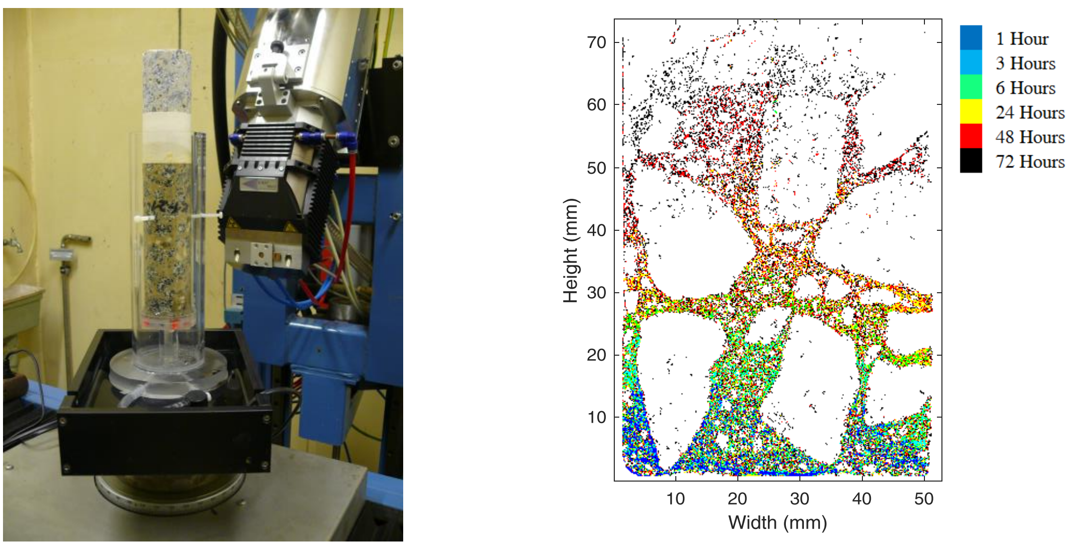
Traditional binarization techniques for CT image processing were successfully used to visualize the 1D propagation of the water front (Figure 1b). They could not, however, be used to measure the temporal variation in the 3D distribution of moisture percentage (i.e. the moisture percentage change at each voxel), which is essential for calibrating simulations of the phenomenon. In order to successfully measure this 3D moisture percentage change, grayscale depth within the subtraction images had to be directly correlated with moisture percentage and quantified. This required a much higher level of grayscale precision than is typical for most CT research and the images proved to be highly sensitive both to the variation in performance of laboratory CT equipment over time and to the variation in scattering characteristics over time due to changes in water distribution within the samples. To reduce the impact of these effects, image processing techniques were developed which calibrated the images using material markers within the scan images which were considered to possess constant X-ray attenuation properties throughout the experiments. The resulting measurements of water-front movement and moisture content change could also be compared with the results of Nuclear Magnetic Resonance (NMR) measurements conducted on the samples both prior to and after water exposure for further calibration and validation.

Further research is recommended which compares the results of the CT testing program with water-transport measurements from other non-destructive evaluation methods, such as neutron CT and 3D-NMR techniques. By conducting such a comparison, the scope and accuracy of current X-ray CT measurement and analysis techniques could be significantly improved through a process of further calibration and validation.

References

[1 M.D.A. Thomas, B. Fournier and K.J. Folliard. Alkali-Aggregate Reactivity (AAR) Facts Book. Report No. FHWA-HIF-13-019. Federal Highway Administration (FHA), 2013.

[2] C.F. Ferraris. Alkali-Silica Reaction and High Performance Concrete. Report No. NISTIR 5742. National Institute of Standards and Technology (NIST), 1995.



(a) (b)

Figure 1: (a) Photograph of in-situ water-exposure apparatus and (b) depiction of time-based water transport measured using CT.