IN-SITU CT OBSERVATION OF WATER MIGRATION IN HEATED CONCRETE

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Summary: In order to study damage in concrete exposed to fire, a series of continuous X-ray computed tomography (CT) measurements were performed on a concrete sample heated, in-situ, on one side. The water migration relative to time and 3D space and, in particular, the dynamic condensation and vaporization of water droplets in the pores was quantified. This approach shows significant potential for further investigation of fire-related concrete damage.

INTRODUCTION

Concrete is the most widely used building material on earth [1]. In particular, high-performance concrete is a material utilized in structures like tunnels and high-rise buildings, which can be exposed to the risk of damage caused by fire. The thermally driven water migration in heated concrete is recognized as one process directly responsible for spalling of the material [2,3]. In this context, there is an urgent need to develop techniques for measuring the interacting hydrodynamic and thermodynamic processes during concrete heating. In recent years, some methods to measure moisture condensation were developed [4-6]. Nevertheless, 3D approaches are still lacking.

For decades, X-ray computed tomography (CT) has been an essential tool for non-destructive examination of concrete microstructure [7]. In this work, a concrete specimen was exposed to heating to mimic the conditions of a fire. Simultaneously, in-situ CT measurements of the specimen were collected in order to observe water migration due to heating. Subsequently, a method was developed to visualize and quantify the migration of water.

2. METHODOLOGY

2.1 Experiment

For the experiment, a nearly cylindrical sample (40 mm in diameter and 100 mm in length) was cast from a high-performance concrete (strength class C90/105) [8]. The specimen was cast in a ceramic tube (with an outer diameter of 50 mm). After 7 days storage in water the specimen was pre-conditioned under standard climate conditions (20 C/65 % rel. humidity). During the experiment the ceramic shell is used to generate almost one-dimensional moisture flux within the specimen and to prevent the thermal expansion of the concrete . To simulate a nearly one-dimensional heat flux within the specimen, the ceramic tube was additionally encased in a 10 mm thick layer of thermal insulation made of mineral wool.

The specimen's upper surface was heated at a rate of approximately 10K/min for 28 minutes by a heating device. Subsequently, the heating device was used to hold the temperature constant at 300 °C. A General Electric v|tome|x L300 X-ray device with a 2048x2048 pixel Perkin Elmer detector (200 µm pixel size) was used to collect 7 subsequent tomographic images. 1300 projections were acquired each for 1 sec exposure at 250 kV accelerating voltage.

2.2 Evaluation of CT reconstructions

The standard Feldkamp, Davis, Kress (FDK) algorithm was used to reconstruct all of the CT images. The CT reconstructions were analyzed using the program ZIB-Amira [9] in combination with a series of custom image processing algorithms in-house developed at BAM.

For each CT reconstruction, both the outer boundary of the sample and the outer boundaries of individual air pores were identified using a masking procedure. For each slice of the CT image along the depth of the sample, the gray values of pixels were averaged for two cases, one for all pixels within the sample boundary and one for pixels located only within the boundaries of air pores. The differences of subsequent profiles to the profile

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corresponding to the first measurement were then calculated in order to visualize the density changes inside the sample (e.g., the localized moistening and drying as a function of time). Although drying within the material matrix was easily identifiable, the presence of matrix moistening was more unable to detect until now. Water agglomeration was found to be most evident in the form of positive density changes within the masked pores (Fig. 1). Such pore-based water agglomeration is observable in the form of water droplets that appear and disappear within the concrete pores and can be inferred by the density change on CT images collected at different times during the heating process. It is further planned to correct the measured data for uncontrolled (thermal and hygroscopic) voxel movement by means of digital volume correlation.

3. CONCLUSIONS

For the first time, to the best of our knowledge, a 3-dimensional *in-situ* observation of the heat-inducted migration of water in concrete was performed. This experiment successfully showed that the time-dependent saturation of the pores with water can be clearly visualized by means of image analysis of CT reconstructions. Indirectly, it was possible to quantify the waterfront position using the measurement of water accumulation inside of the pores. This approach can be systematically used to advance the development of a more robust understanding of concrete performance during fire exposure.

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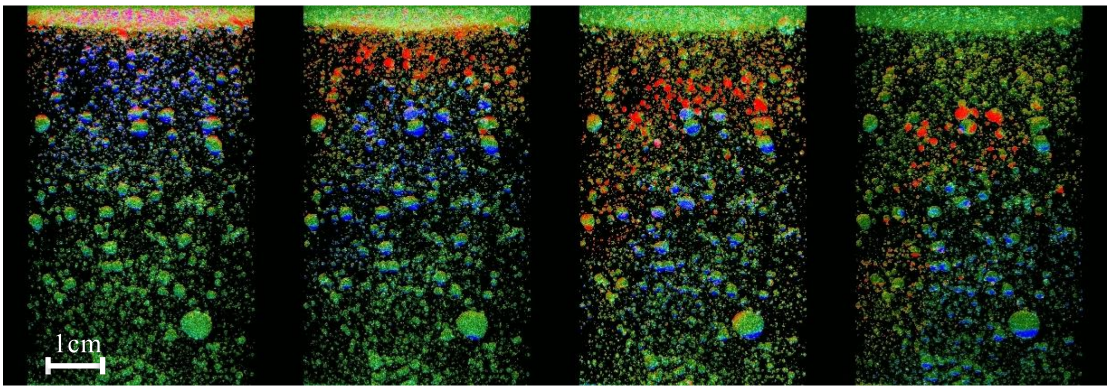

Figure 1: Density changes within the pores taking the reference state after 15 min heating, and computing incremental differences at 28, 42, 60 and 84 minutes. Red = decrease, green = no change, blue = increase.