EFFECT OF HEATING AND RE-CURING ON CRACKS IN HIGH-STRENGTH CONCRETE

Hokkaido University	Assistant Professor	JSCE Member	Michael Henry
Hokkaido University	Ph.D. student		Ivan Sandi Darma
Hokkaido University	Master student	JSCE Member	Yuto Haraguchi
Hokkaido University	Professor	JSCE Member	Takafumi Sugiyama

1. Introduction

Cracks caused by the dehydration of the cement paste and incompatibility in thermal expansion between the paste and coarse aggregates play a large role in the performance loss of fire-damaged concrete. Conversely, performance recovery under water supply can be partially attributed to crack healing. However, it is necessary to understand the cracking behavior under both heating and re-curing conditions.

X-ray computed tomography (CT) is a powerful tool for non-destructively examining the internal structure of an object in three dimensions. Images acquired using X-ray CT provide a visual representation of the density distribution in an object due to the variation in X-ray absorption. In the field of concrete engineering, X-ray CT has been utilized to study various properties, including three-dimensional crack geometry. However, the resolution of current microfocus X-ray CT systems is generally limited – which limits the specimen size – and most studies have focused on cement paste or mortar.

In this paper, X-ray CT was utilized to investigate the crack formation and change in crack structure in high-strength concrete in order to clarify the cracking behavior under heating and re-curing conditions.

2. Experimental program

2.1. Specimen preparation & curing

Concrete was prepared with a water-cement ratio (W/C) of 0.30 using ordinary Portland cement. After casting, cylinders (100 x 200 mm) were cured in the molds for 24 hours, then removed and placed in water curing at 20ºC for four weeks. Specimens 20 mm in diameter and 20 mm in height were then extracted from the center of the cylinder and re-submerged in water for another nine weeks for a total curing time of 13 weeks.

2.2. Heating & re-curing

Fire exposure was simulated using an electric furnace. The rate of heating increase was set at 10ºC per minute until the target temperature of 600ºC was reached, after which it was maintained for one hour. After removal from heating, specimens were cooled at room temperature for one hour, then subjected to either water or air re-curing. Water re-curing conditions were similar to the initial curing period, whereas air re-curing was conducted in atmospheric conditions at roughly 20ºC. Re-curing was carried out for up to four weeks.

2.3. Image acquisition and processing

In this research, a desktop microfocus CT system was used for image acquisition. The details of the X-ray CT specimen, slice images, and 3D image reconstruction are shown in Figure 1. Imaging was carried out after heating and after one and four weeks of re-curing.

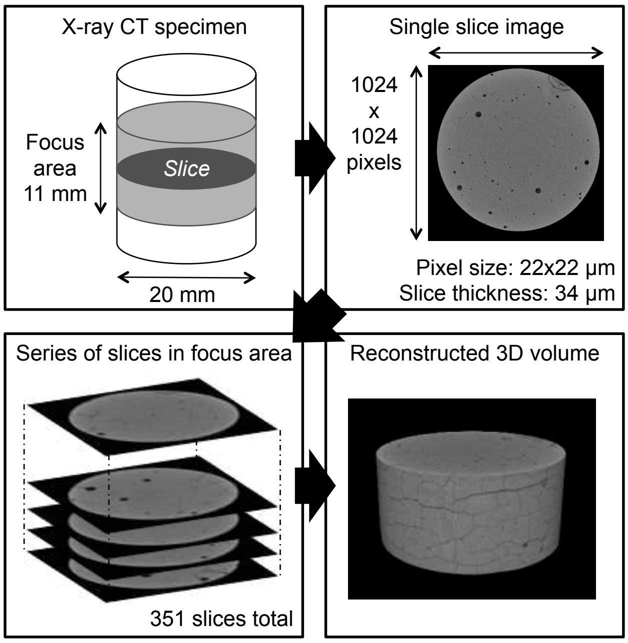

Figure 1 Image acquisition and 3D reconstruction details

In order to identify cracks in the specimen, threshold segmentation was applied. Using image processing software, void space could be extracted from the images by using a threshold value from the grey-scale value distribution to convert the grey-scale images to black (solids) and white (voids). Percolated voids (cracks) could then be extracted by carrying out a connectively analysis to remove the isolated voids.

3. Results & discussion

3.1. Segmented slice images

Representative segmented slice images from water and air re-cured specimens are shown in Figure 2. In both specimens, heating can be seen to cause cracks in the

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Address: Kita-13 Nishi-8, Kita-ku, Sapporo, Japan. TEL +81-011-706-7553

aggregate-mortar interfaces, as well as bridging between different aggregates and air voids. These cracks were likely formed due to incompatibility in thermal expansion between the aggregates and mortar.

Under water re-curing, most of the larger cracks were healed after 7 days of re-curing, with the remaining percolated void space in either the center of the specimen or within the aggregate. Conversely, while some reduction can be seen by 7 days for air re-curing, the majority of the larger cracks remain unhealed. In both cases, little change was observed between 7 and 28 days.

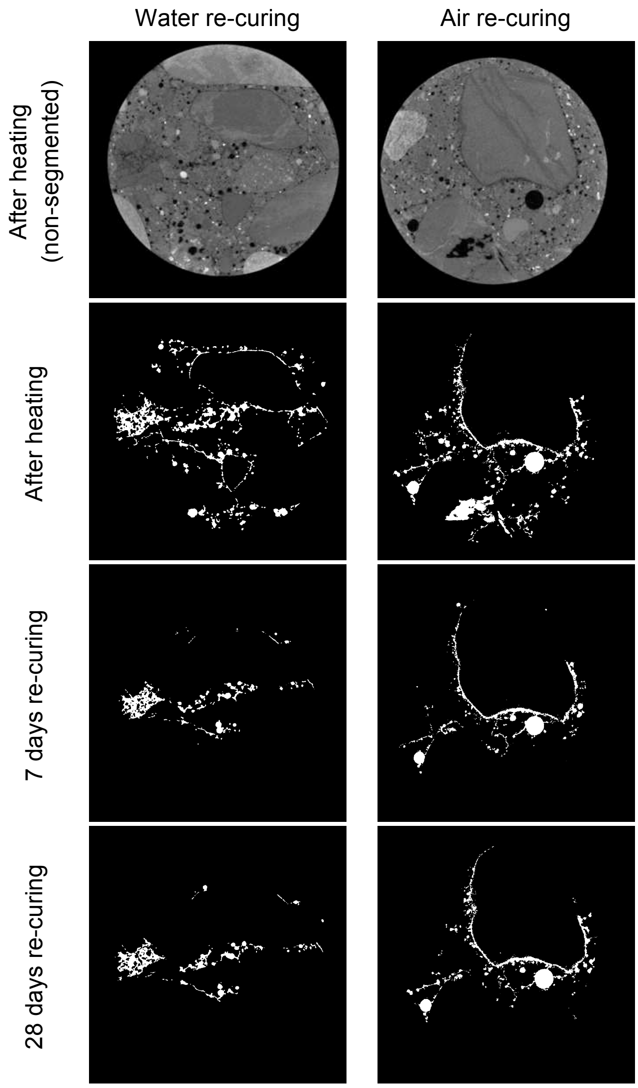

Figure 2 Cracks after heating and re-curing

3.2. Three-dimensional crack network

Three-dimensional images of the crack network are shown in Figure 3. After heating, the crack network can be seen to percolate in all three directions, with semi-solid surfaces where cracks formed in the mortar-aggregate interface. The total volume of the crack network is clearly reduced under water re-curing, with some minor cracks remaining around an aggregate; under air re-curing, it is difficult to visually observe any changes in the three-dimensional crack network.

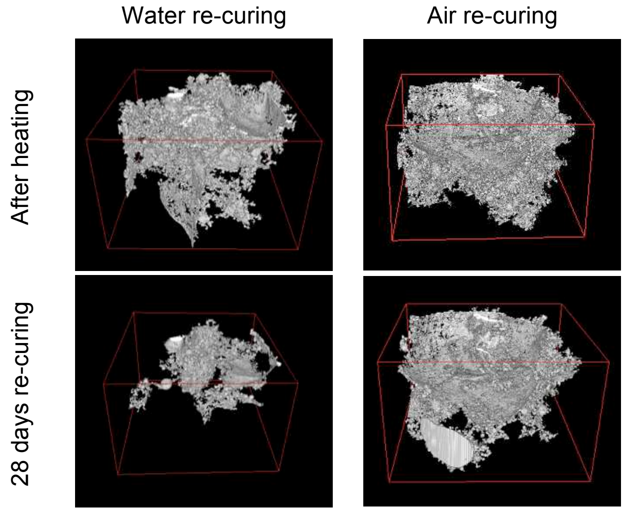

Figure 3 Three-dimensional crack networks

3.3. Crack network volume

The percentage volume of the specimen occupied by cracks is summarized in Figure 4. After heating, cracks composed 4.4% of the specimen, but water re-curing reduced the crack volume by 2.7% within 7 days, with little change up to 28 days. Air re-curing, however, only reduced crack volume by 0.9% after 7 days, with no change up to 28 days. This result quantitatively supports the results visually observed in Figure 2, which indicated that water re-curing led to a greater reduction in cracks.

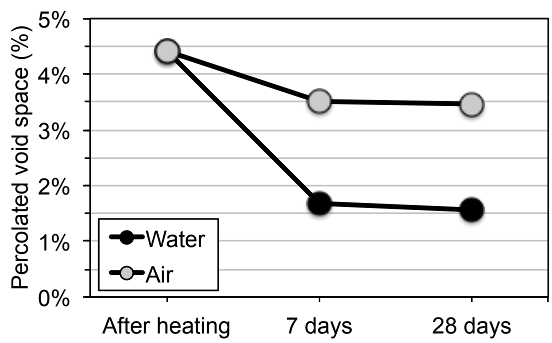

Figure 4 Change in crack volume due to re-curing

4. Conclusion

In this research, X-ray CT was applied to analyze the change in cracks in high-strength concrete after heating and re-curing. Water re-curing was both visually and quantitatively shown to reduce crack volume, whereas air re-curing had little effect. These results, however, may be affected by the size of the aggregates relative to the size of the whole specimen, and future studies will consider how to adjust for this size effect by examining specimens of various sizes or with varying aggregate size.

Acknowledgement

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