Investigation of self-healing in cementitious materials with sulfoaluminate cement microcapsules using X-ray computed tomography

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ABSTRACT

This paper presents work toward the studying of a new family of self-healing cementitious material. This innovative system features the design of microcapsules with calcium sulfoaluminate cement (CSA) as healing agent. The aim of this study is to comprehensively monitor the whole crack-healing process of microcapsules based self-healing system by means of X-ray computed tomography (X-ray CT). In order to study the crack-healing process, the micro cracks were created with the help of pre-loading test. The crack-healing process at different healing time were non-destructively monitored and analyzed by using X-ray CT and image analysis technique. The inner micro-topography of specimen with microcapsules was successfully reconstructed and analyzed. Experimental results show that the microcapsules based self-healing cementitious material has a remarkable crack-healing effect.

1. INTRODUCTION

Cracks in cementitious material is an important issue because it has a negative impact on durability of cementitious material based structures; however, the repair cost is large and sometimes repair is difficult to achieve due to the technological limit. Self-healing strategy is regarded as a promising solution to reduce the high maintenance and repair cost of cementitious composite [1, 2]. In this project, we attempt to study a new family of microcapsules based self-healing cementitious materials. What more, in order to un-destructively study the whole healing process and healing effect of this self-healing system, X-ray computed tomography and image analysis technique were applied in this research [3]. Hence, the whole healing process and healing effect can be comprehensively studied.

2. MATERIALS AND METHODS

A novel kind of microcapsule was designed and synthesized for the research, in which calcium sulfoaluminate cement was chosen as curing agent. Mortar specimens with microcapsules were prepared as follow parameters: the water-cement ratio is

0.4, the weight ratio of cement and fine aggregate is 1:1 and the weight ratio of microcapsules and binder is 0.05. The fresh mortar was cast into mould with 10×10×10 mm. Once mortar was produced in the mould, samples were placed for one day in humidity chamber (95% RH), to ensure sufficient humidity and minimize risk of shrinkage and consequent cracking. Next, the specimens were demoulded and subjected to additional curing in humidity chamber (95% RH, 20℃) for 28 days.

The microscopic compression testing instrument was equipped in the XCT test system to achieve real-time compressive loading. Sample 1 and Sample 2 were put in the built-in loading device and pre-loaded with 1100 Newton (N) and 900 N, respectively. And the samples with initial cracks were then cured in different curing conditions, in which sample 1 was put in submerged condition and sample 2 was cured in a standard curing condition (95% RH, ±20℃). X-ray CT was applied to monitor the variation of inner microstructures at different healing time. Based on the raw data measured by X-ray CT, the reconstruction of inner microstructure was carried out by means of image analysis technique. The crack-healing process and healing effect were evaluated with the help of the reconstruction of inner microstructures (including 2D slices, 3D digital image) and quantitative analysis.

3. RESULTS AND DISCUSSION

Fig. 1 shows an SEM image of a typical microcapsule synthesized in this study. It exhibits a number of favorable physical properties, including rough surface, suitable size, and good sphericity. These mechanical properties illustrate that microcapsule satisfy the self-healing cementitious material. In order to reach the crack-healing purpose, the healing agent must be released from microcapsule after triggering of micro-crack. The study result shows that the healing agent (CSA cement) was released from microcapsule, and then did reacted with free water to create hydration product (Fig. 2).

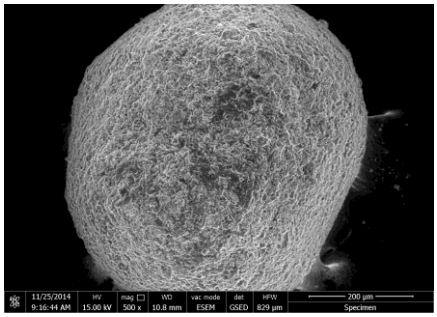


Fig. 1 SEM image of microcapsule

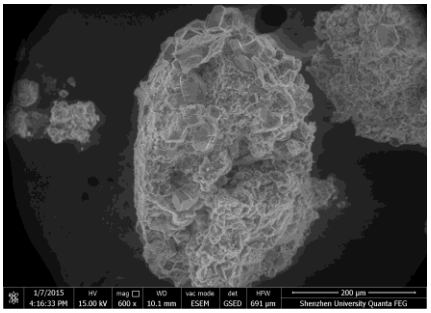
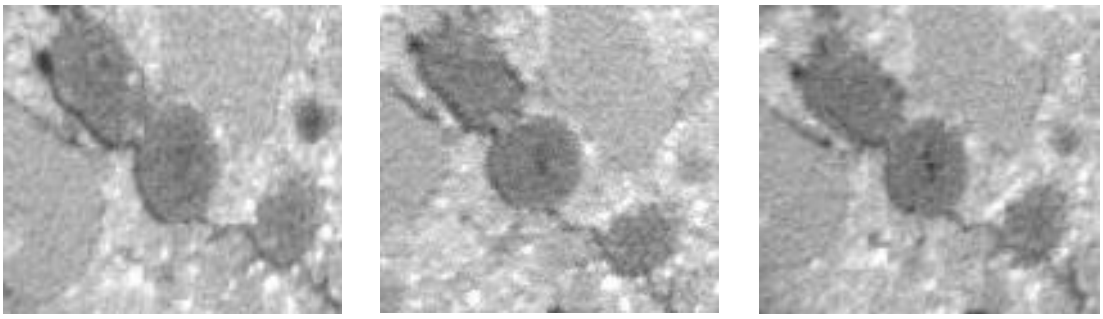


Fig. 2 SEM image of healing agent releasing from microcapsule

As shown in Fig. 3, the same slice of the Sample 1 was measured by X-ray CT at different healing time. Initially the micro-crack was created due to the pre-loading. Accordingly, microcapsules were triggered by the microcracks and the healing agent was then released from the microcapsules. With the permeation of free water, the CSA healing agent reacted with free water to form some hydration products to fill the micro cracks.



(a) 0 days (b) 42 days (c) 84 days

Fig. 3 Cross-sectional images of self-healing sample at different healing time

In order to further study the crack-healing process of self-healing materials, 3D reconstruction model was applied in this research. As shown in Fig. 4 (a), the microstructure of self-healing samples was clearly identified after processing. The interaction between micro-cracks and microcapsules was shown in Fig. 4 (b). The volume of cracks and pores was reduced with the increase of healing time (Fig. 4 (c)).

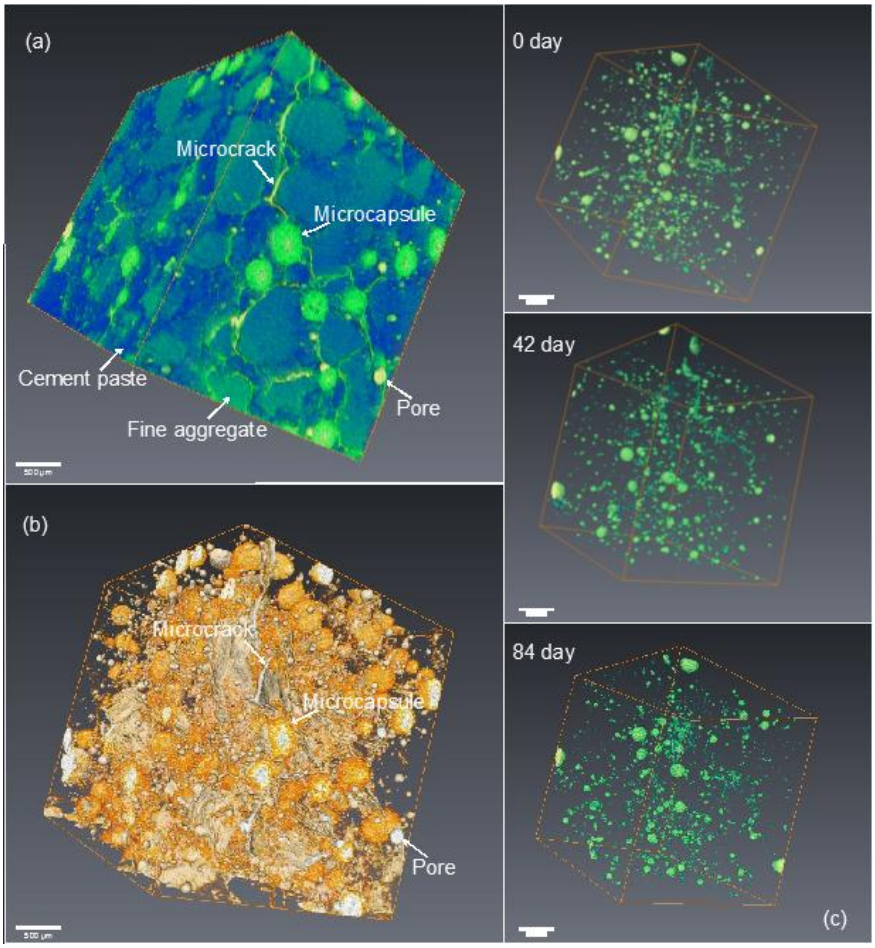


Fig.4 3D reconstruction of self-healing sample at different healing time

With the help of image analysis technique, the total volume of air void (cracks and pores) has been labeled and calculated in the research. As shown in Fig. 5, the

whole volume of air void (cracks and pores) of both samples is decreased as healing time. The healing effect would become stable at the healing time of 84 days. It shows that the CSA microcapsules based self-healing cementitious materials has a remarkable crack-healing effects.

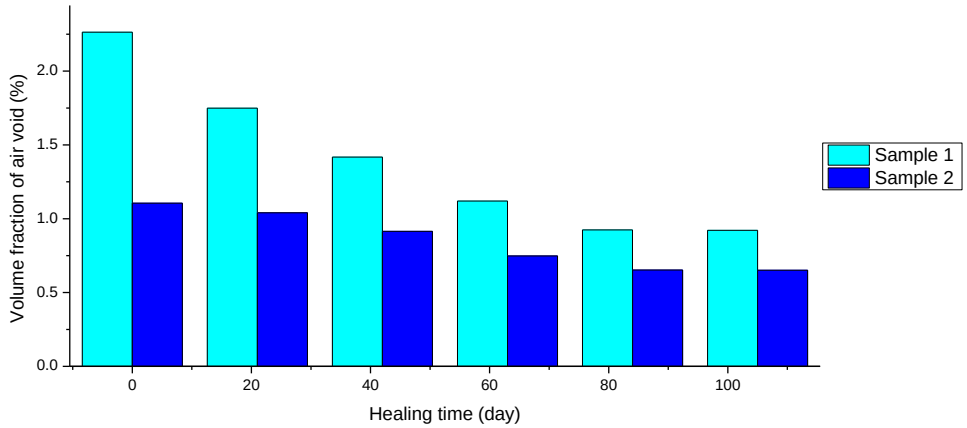


Fig. 5 Volume fraction of air void (cracks and pores) of two samples at different healing time

4. CONCLUSIONS

A new family of microcapsule based crack self-healing system was successfully designed and studied. The X-ray computed tomography (XCT) system and image analysis technique were successfully applied to non-destructively monitor and analyze the crack-healing process and healing effect of the self-healing cementitious materials. The results measured by X-ray CT show that micro-cracks would and did be healed in the self-healing samples and the healing effect is remarkable.

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