INTERACTION BETWEEN MICROCAPSULES AND CEMENTITIOUS MATRIX AFTER CRACKING IN A SELF-HEALING SYSTEM

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ABSTRACT

A new type of self-healing cementitious composites by using organic microcapsules is designed in Guangdong Key Laboratory of Durability for Coastal Civil Engineering, Shenzhen University. For the organic microcapsules, the shell material is urea formoldehyde (UF), and the core healing agent is Epoxy.

The effect of organic microcapsules on mechanical behaviors of the composite specimens and the interaction between an organic microcapsule and an approaching crack is investigated in this study. The mechanical behaviors of bending and compression strengths for mortar specimens are tested. The results show that the strength may increase with a small amount of microcapsules and then decrease with increasing of microcapsules.

The FEM numerical simulation is carried out to study the interaction between a crack and a microcapsule in the concrete matrix. It is known that there exist two possibilities when a crack approaches a microcapsule, the microcapsule is ruptured or debonded from the matrix. The self-healing function is based on the rupture of microcapsules. Thus determination of judgment criterion (The physical trigger mechanism-cracking) that under what condition a microcapsule ruptures is necessary. For simplicity, a two-dimensional plane square area is considered, in which the side length is 1 cm. A microcapsule of radius 0.1mm is located at the center of the area. Left hand side is a line crack. The interface between the microcapsule and the mortar matrix, as well as the bonding behavior of the microcapsule shell wall is modeled using the cohesive traction-separation constitutive relationship. The actual parameters of the materials may lead to rupture or debonding of a microcapsule. Through numerical simulation, the criterion of the possible failure pattern for a microcapsule is obtained in terms of the intensity of microcapsule wall, the intensity of the interface, thickness of the microcapsule wall, location of the crack, and the microcapsule radius.

1. INTRODUCTION

It is known that crack formation is prone to present in concrete structures due to its low tensile strength, which may lead to deterioration and durability problem, and may also affect its serviceability. To prevent such deterioration, a self-healing strategy has been being developed in these years. van Breugel [1] summarized the research history of self-healing phenomena in cementitious materials. Wu et al [2], and Mihashi and Nishiwaki [3] present a review on self-healing in cementitious materials and engineered cementitious composite as a self-healing material.

Though there has been classification in the review papers, from the point of view of the authors, at present, there are two ways to achieve self-healing function for concrete structures. One is based on material level, such as making use of bacteria, microcapsules or expansive agents and mineral admixtures. Usually at this level, the self-healing is in passive way. That is, mix the healing agent uniform distributed into the concrete matrix and let it be. When a crack propagates to meet the healing agent, it will start to function and fill the crack faces. The other way to achieve self-healing is based on structural level, such as using of hollow fibers or shape memory material fibers et al. In this way, structural or location design is needed, independent or alliance sensor may also be arranged, the self-healing can be in both active and passive modes. In this study, a self-healing system of mortar is developed using organic microcapsules incorporating healing agent.

2. EXPERIMENTS

Standard prismatic mortar specimens with dimensions of 40 mm × 40 mm × 160 are prepared for the tests. To investigate the self-healing effect on the strength recovering rate, the experiments are designed for three factors: W/C, amount of organic microcapsules, preloading rate, in which preloading applied to the specimens is to obtain initial damage for investigating the self-healing phenomenon. The reference groups are tested to obtain the reference strengths, on which preloading rates are determined. In the experiments, 3 levels are considered for each factor, i.e. W/C: 0.45, 0.50, and 0.55; amount of microcapsules: 0%, 3% and 6%; preloading rate: 30%, 50% and 70%. An orthogonal test plan is set up and carried out to investigate the strength recovering rate due to self-healing. The strength recovering rate is defined by

$$Recovering\ rate = \frac{strength\ after\ healing}{original\ strength} \times 100\% \tag{1}$$

where the original strength denotes the specimen strength at 28 days, the strength after healing is obtained in the following steps: first, apply the prescribed preloading to the specimen at 28 days; then, leave the specimen curing for 3 days; finally, test the strength.

A plan of $L_9(3^4)$ array is used [4], in which column 4 is used for error analysis. The reliability of the test results and the role of each factor have been investigated by using variance analysis. The results show that the amount of microcapsules is the control factor, whereas W/C is the weakest one.

The curves of Intuitive analysis are given in Figure 1 for both bending and compressive tests. The horizontal axis represents different levels for corresponding factors, while the vertical axis denotes the average recovering rate K_{ij}.

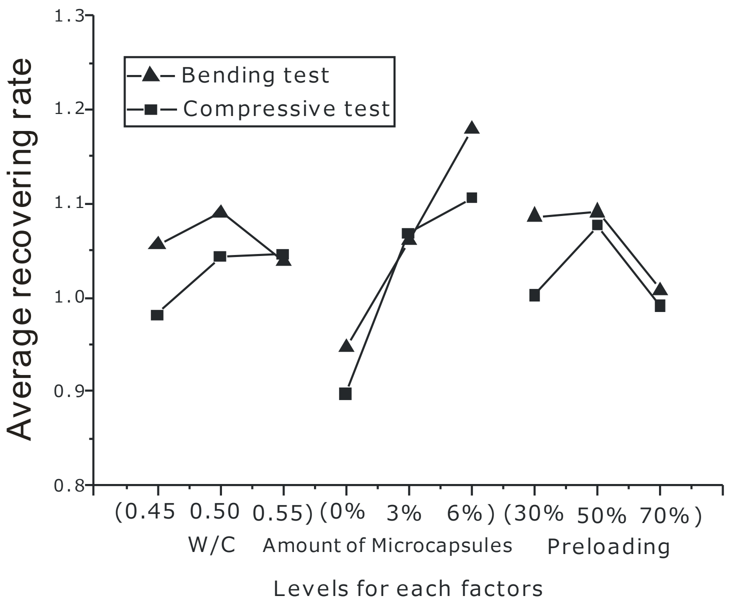

Figure 1: Relationship between the factors and strength recovering rate

3. NUMERICAL STUDY

It is known that there exist two possibilities when a crack approaches a microcapsule, the microcapsule is ruptured or debonded from the matrix. The self-healing function is based on the rupture of microcapsules. Thus determination of criterion that under what condition a microcapsule ruptures is necessary. In this study, a numerical model, as depicted in Figure 2, is setup to investigate this condition using Abaqus [5].

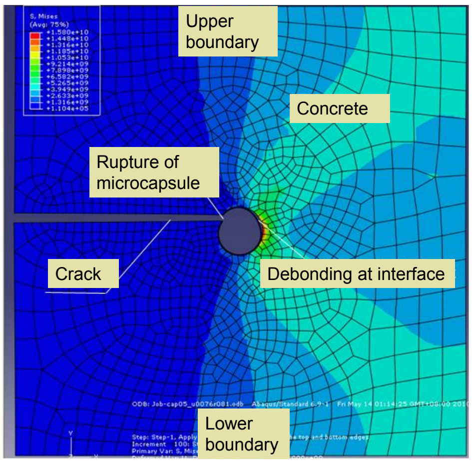

Figure 2: Computing model for a crack approaching a microcapsule

From the limiting status between a microcapsule rupture and debonding, a function is defined as follows:

$$Q = \frac{\sigma_C}{\sigma_D} - \frac{K_C}{K_D} \quad \begin{cases} >0 \text{ Microcapsule rupture} \\ <0 \text{ Microcapsule debonding} \\ =0 \text{ limiting state} \end{cases} \tag{2}$$

where σ_C, σ_D are the effective stresses at microcpsule wall and the interface between the microcpsule and concrete matrix, respectively. K_C, K_D are the corresponding strengths. Then the criterion for a capsule rupturing or debonding can be expressed as in three normalized parameters t/R, h/R, and ${K_C}/{K_D}$:

$$Q = F(\frac{t}{R}, \frac{h}{R}) - \frac{K_C}{K_D} \tag{3}$$

where R and t represent the outer radius and the thickness of the microcapsule, respectively; h denotes the height coordinate of the crack. Using this model, varying t/R and h/R, forty points on the limiting surface are obtained. Then the following polynomial of 4th power is obtained by regression

$$\begin{aligned} Q &= F(\frac{t}{R}, \frac{h}{R}) - \frac{K_C}{K_D} \\ &= 110.8 + 539.5(\frac{h}{R}) - 5438(\frac{t}{R}) - 1774(\frac{h}{R})^2 - 1823(\frac{h}{R})(\frac{t}{R}) + 159900(\frac{t}{R})^2 + 1701(\frac{h}{R})^3 + \\ &26810(\frac{h}{R})^2(\frac{t}{R}) - 249100(\frac{h}{R})(\frac{t}{R})^2 - 1296000(\frac{t}{R})^3 - 419.8(\frac{t}{R})^4 - 23770(\frac{h}{R})^3(\frac{t}{R}) + 116000(\frac{h}{R})^2(\frac{t}{R})^2 \\ &+ 957100(\frac{h}{R})(\frac{t}{R})^3 + 3252000(\frac{t}{R})^4 - \frac{K_C}{K_D} \end{aligned} \tag{4}$$

This is the criterion which means that, a point under the surface means Q > 0, corresponds to that a microcapsule ruptures, otherwise, the microcapsule is debonded. With this criterion, we can judge a microcapsule behavior using the parameters without need of simulation.

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