Self-healing cementitious materials based on bacteria and nutrients immobilized respectively

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Keywords: bacteria, self-healing, cementitious materials, flexural strength, permeation coefficient

Abstract ID No : 67

ABSTRACT

Small cracks in concrete may develop into large cracks to decreased service life of concrete structures. It is necessary to restrict the development of early age small cracks promptly. This study presented a bio-restoration method to improve the self-healing effect of the cement-based materials cracks. Ceramsite carrier was used to immobilize bacteria, while substrate and nutrients mixed evenly were immobilized into other original carrier. The section surface of mortar specimens before and after curing were investigated by staining them. Also water permeation coefficient was applied to characterize the repairing effectiveness of specimens. Experimental results showed that plenty of white precipitation generated on the section surface at 28 days of curing. After 24 days curing, the apparent water permeation coefficient of speciments changed slightly. By testing the mechanical properties, the flexural strength of specimens repaired could be increased from 60% to 85% than other microbiological methods which used to repair the cracks.

1. INTRODUCTION

Microbial calcium carbonate has a promising potential in repairing of defects and flaws, specifically, the cracks of cementitious materials[1]. However, calcium carbonate produced inside the cracks of cement-based materials is minimal because the calcium ion dissolve out from the materials slowly and the diffusion coefficient of carbon dioxide is small in water curing conditions[2]. Accordingly calcium carbonate generated too insufficient to repair the cracks in depth. Therefore, we attempt to provide part of the carbon dioxide extra by yeast fermenting glucose.

Due to the harsh environment inside the concrete, microcapsules, ceramsite or porous expanded clay particle were used to protect the bacteria[3]. Immobilization of bacteria in a protective carrier before adding them to the concrete is preferable [4]. Moreover, nutrients immobilized can be fully utilized. In this case, we presented a bio-restoration method to improve the self-healing effect of the cement-based materials cracks by immobilizing bacteria and nutrients respectively.

2. MATERIALS AND METHODS

Bacillus mucilaginosus LJS14 and Brewers yeast JCS05 (China Center of Industrial Culture Collection, CICC) were used in this study. Ceramsite carrier was used to carry the nutrients, while bacteria was immobilized by other ceramsite carrier. Glucose obtained from the Sinopharm Chemical Reagent Co., Ltd was used for producing CO_2. Calcium nitrate purchased from Sinopharm Chemical Reagent Co., Ltd was analytical grade and diluted into 50 mmol/L. Sudan Red Ⅲ purchased from Sigma(St. Louis, USA) was used to stain the section surface of the specimens before curing.

Bacteria consist of the bacillus mucilaginosus and the Brewers yeast was immobilized into the ceramsite. While nutrients was immobilized into other ceramsite carrier. Then the ceramsite was mixed with cement, sand and water to prepare mortar prism specimens with dimensions of 40mm × 40 mm × 160 mm and cylinders specimens(25mm height × 100mm diameter).

The prism specimens were broken down the middle by Electronic Universal Tester after 28 days' standard curing. The section surface of the specimens were stained by Sudan Red Ⅲ, assembled a whole with tape and maintained in water with a temperature of 30℃.

The crack healing efficiency of specimens was evaluated by water permeation coefficient according to the method reported with a modification[4]. The diagram for measurement of water permeation was as shown in Figure 1. And the 3-point flexural loading setup was from MTS Industrial Systems(China) Co., Ltd. shown in Figure 2. The specimens were firstly loaded under 3-point flexural configuration and then assembled a whole with tape. Nails were inserted the cracks to control those width. After curing 28 days in the water, the specimens were reloaded as the same testing.

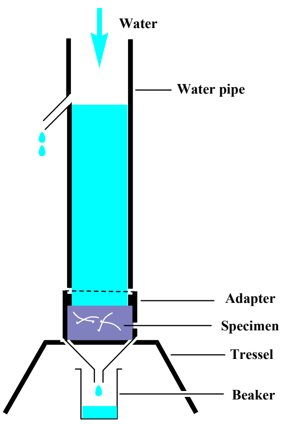

Figure 1: The diagram for measurement of water permeation(left figure).
Figure 2: Three-point flexural loading setup(right figure)

3. RESULTS AND DISCUSSION

Figure 3 showed the images process for section color and repaired section color. It can be seen from Figure 3a that the section color of speciments with ceramsite added changed little after re-curing 28 days in water. There was a slight increase in the section color of speciments with no carrier but bacteria (Figure 3b). Contrarily, the samples with bacteria and nutrients immobilized into ceramsite covered by a great quantity of white precipitation(Figure 3c). Images of the three types of samples gave a contrast obviously befor and after repaired. The results indicated that more white precipitation could be produced with the method of specimens mixed with bacteria and nutrients immobilized into ceramsite carrier respectively.

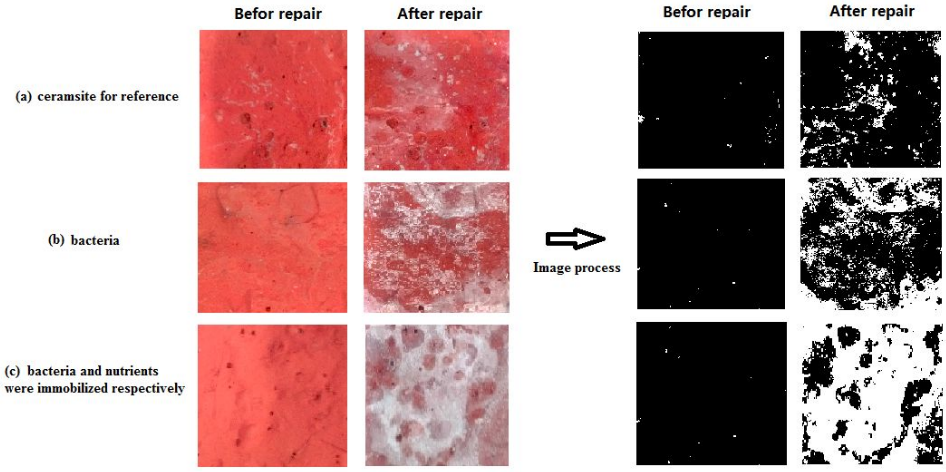

Figure 3: Images process for section color and the repaired section color

Actually, the self-healing rate can be effected by the permeation coefficient of specimens as shown in Figure 4. In this case, the cracks with an initial width of 0.4 mm to 0.6 mm were self-healed after re-curing for 3, 7, 14, 21 and 24 days respectively. The permeation coefficient of specimen reached as high as 7.5～ 8.5×10^{-3} cm/s when the cracks formed at 28 days. After 21 days curing, the permeation coefficient of those specimens C0, C1 and C2 declined to about 5×10^{-4} ～ 10×10^{-4} cm/s, but the specimens C3(the permeation coefficient of specimens with bacteria and nutrients were immobilized respectively) could decline to 1×10^{-5} cm/s. During 24 days of testing, the water permeability coefficient of the C3 specimens gradually reached a stable value. It indicated that this bio-restoration method was more effective in improving the repair speed of the cracks of cement-based materials.

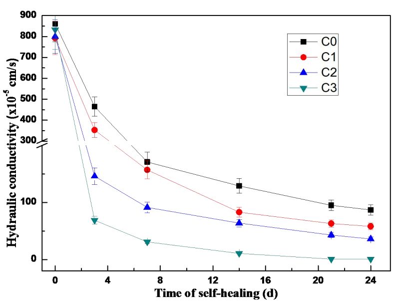

Figure 4: Water permeability of the cracked cylinders after being repaired by different bio-restoration methods(C0: ceramsite; C1: bacteria A; C2: bacteria B; C3 bacteria B and nutrients were immobilized into ceramsite respectively).

Moreover, the flexural strength after repaired at a curing age (28 days) was tested. The results of the flexural strength for the repaired specimens were shown in Figure 5. Compared to the normalized strength of specimens Q0, Q1 and Q2, the normalized strength of specimens Q3 with bacteria and nutrients were immobilized respectively reached to about 2.3. This results indicated that the flexural strength of specimens repaired could be increased from 60% to 85% than other microbiological methods(Q1 and Q2).

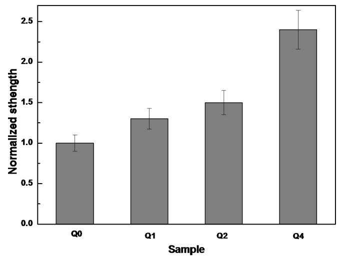

Figure 5: Influence of different bio-restoration methods on flexural strength restoration of mortar specimens(Q0: ceramsite; Q1: bacteria A; Q2: bacteria B; Q3 bacteria B and nutrients were immobilized into ceramsite respectively).

4. CONCLUSION

From the change of section color, it was shown that more white precipitation generated on the section surface of spciments repaired by this bio-restoration method at curing 28 days. Moreover, the results of the water permeation coefficient of speciments and the flexural strength for the damaging specimens with their respective recovered strength indicated that this bio-restoration method was more effective in improving the repair speed and depth of the cracks of cementitious materials.

ACKNOWLEDGEMENTS

The authors greatly appreciate financial support for this research from the National Natural Science Foundation of China (grant no. 51178104), the PhD Program's Foundation of Ministry of Education of China (grant no. 20110092110033) and "333 project" of JiangSu Province.

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