Applied Mechanics and Materials
ISSN: 1662-7482, Vols. 249-250, pp 1053-1056
doi:10.4028/www.scientific.net/AMM.249-250.1053 Online: 2012-12-13

Structure Analysis of Microbe-repaired Concrete Using Scanning Electron Micrographs

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Keywords: Microbe-Repaired Concrete, Scanning Electron Micrograph, B. pasteurii

Abstract. As one of the most popular materials used in construction, concrete is prone to superficial flaws, such as crack, due to the load-bearing and external environment. This research manually made cracks of 2 mm with 100 mm length and 30 mm depth on concrete vessels as specimens. Subsequently, bacteria, specifically B. pasteurii, was used in crack rehabilitation to enhance the compression strength of the repaired concrete. The mixture of microbes, urea medium, and urea-$CaCl_2$ medium was added to a sludge and fine aggregate with a weight ratio of 0.6:1:1 to be the repairing material for crack rehabilitation. Crack rehabilitation was conducted by injected the mixture into the test samples after 90 days curing in saturated lime solution.

In addition to the traditional test – compression test, scanning electron microscope (SEM) was used to examine the structure composition of the microbe-repaired concrete for calcium carbonate crystal formation. Various rectangular and polygonal crystals were observed in the SEM photographs of the microbe-repaired concrete samples with high bacterial concentrations demonstrated that bacteria can induce calcium carbonate precipitation to complete crack rehabilitation. The results prove that high concentration of bacterial broth induced a great amount of calcium carbonate precipitate and improved the concrete strength of the microbe-repaired samples.

Introduction

Concrete is the most popular material used in construction. The concrete surface is prone to flaws, such as crack, due to the load-bearing and external environment [1]. To repair these superficial defects, the application of microbial strains to repair concrete cracks has been developing [2-5]. This research uses bacteria, specifically B. pasteurii, in crack rehabilitation to enhance the compression strength of the repaired concrete. In addition to the traditional test – compression test, scanning electron microscope (SEM) was used to examine the structure composition of the microbe-repaired concrete for calcium carbonate crystal formation.

A scanning electron microscope is a type of electron microscope by imaging a sample with a beam of electrons in a raster scan pattern to measure the composition and properties of the specimen. The electrons interact with the atoms to produce signals containing information about the sample's surface topography, composition, and other properties. This research employed SEM Hitachi TM-1000, which is equipped with Solid State Backscattered Electron Detector at accelerating voltage of 15 kV. TM-1000 images show sample surface morphology in contrast due to different average atomic number composition within the sample [6].

Materials and Methodology

B. pasteurii is a gram-positive aerobic bacteria strain commonly present in soil, which can produce large quantities of cellular urease for reducing urea into ammonium ions and carbon dioxide. B. pasteurii can then react with calcium chloride to induce calcite precipitation, facilitating the bonding of sandy soil and transforming quicksand into sandstone. Urease catalyzes the hydrolysis of urea to produce carbon dioxide, ammonium ion, and hydrogen ions. By releasing OH^- so to increase pH, CO_2 turns into CO_3^{2-} which bonds with Ca^{2-} in the surrounding to be $CaCO_3$.[7, 8] Calcite precipitation induced by B. pasteurii was ever studied for concrete remediation and showed a significant increase in compressive strength of the portland cement cubes containing lower concentrations of live cells. [9]

The repairing materials include raw material and fine aggregate obtained from rivers in Taiwan and B. pasteurii strain purchased from the Bioresource Collection and Research Center of Food Industry Research and Development Institute, Taiwan. We selected an absorbance of O.D. 600=1 for the 100% bacteria concentration sample and made another three bacterial concentrations of 25%, 50%, and 75%. In 1L of deionized water, we added 20g urea, 2.8g $CaCl_2$, and yeast extract to create 100% concentration sample of Urea-CaCl2 medium, and used the concentration of 70%. In 1L of de-ionized water, we added 20g urea and yeast extract for Urea medium.

Liquid concrete were poured into 75mm×75mm×75mm vessels as specimens. Cracks of 2 mm with 100 mm length and 30 mm depth (as Fig. 1) were manually made on the surface of the specimen. The mixture of microbes, urea medium, and urea-$CaCl_2$ medium was added to a sludge and fine aggregate with a weight ratio of 0.6:1:1, and fully mixed to be the repairing material for crack rehabilitation.

Crack rehabilitation was conducted by injected the mixture into the test samples after 90 days curing in saturated lime solution. Compression tests were conducted on the repaired samples after 3, 7, 14, and 28 days. The alignment of compression test was arranged as shown in Fig 2. In this experiment, the pre-processing procedures for SEM test include: 1. drying specimen in an oven; 2. taking a test sample with a height smaller than 0.1cm from a large specimen by grinding or peeling; 3. fixing the sample on a 15mm×18mm specimen stage and labeling with carbon tape which can absorb electronics; and 4. vacuuming about five minutes.

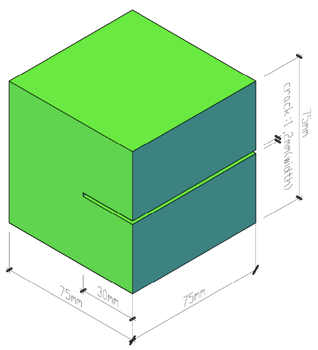

Fig.1. The size of specimen

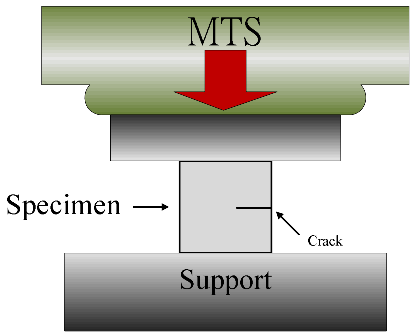

Fig.2. Compression test alignment

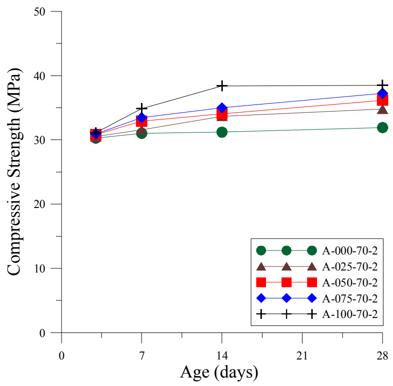

Fig.3. Compression test on repaired samples with 2-mm crack

Tests and Result Analysis

A series of laboratory tests were executed at various bacterial concentrations and the same Urea-$CaCl_2$ medium concentration of 70% for crack rehabilitation. In Fig 3, the compression strength remained constant during the test period for the control group with 0% bacterial concentration and was the greatest for the repaired concrete samples at 100% bacterial concentration, which had significant enhancement with the test time increased. An increase of 23.85% in compression strength was observed by comparing Day-28 test sample (38.51 MPa) with the control sample (31.10 MPa). Figure 4 shows SEM photographs of the control group (no bacterial) and 100% bacterial concentration. Various rectangular and polygonal crystals were observed on the SEM photographs of the experimental samples but not on the SEM photographs of the microbe-absent repaired concrete. A great quantity of rectangular and polygonal crystals were found in samples with high bacterial concentrations demonstrated that bacteria can induce calcium carbonate precipitation in the microbe-repaired concrete to complete crack rehabilitation. The results prove that the high concentration of bacterial broth induced a great amount of calcium carbonate precipitate and improved the repaired concrete strength for the microbe-repaired samples.

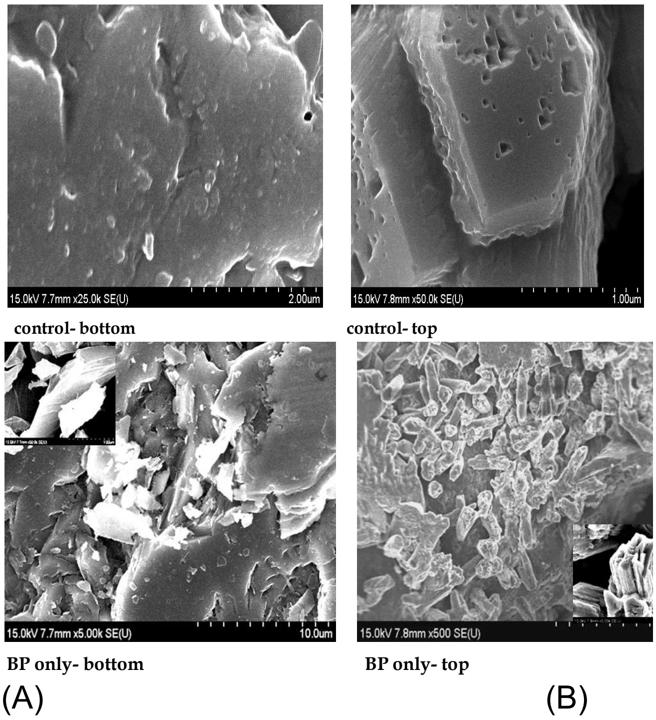

Fig. 4. Day-28 SEM photographs test of the microbe-repaired samples

(A) without bacteria and (B) with 100% bacteria

Conclusion

The crack repairing materials include raw material, fine aggregate obtained from rivers, and B. pasteurii, which all are natural materials and environment-friendly. Serial tests at various bacterial concentrations and the same Urea-$CaCl_2$ medium concentration of 70% for crack rehabilitation were executed and illustrated various rectangular and polygonal crystals on the SEM photographs of microbe-present repaired concrete but not on the SEM photographs of microbe-absent repaired concrete. A great quantity of rectangular and polygonal crystals found in samples with high bacterial concentrations demonstrated that bacteria can induce calcium carbonate precipitation to complete crack rehabilitation. The results prove that high concentration of bacterial broth induced a great amount of calcium carbonate precipitate and improved the strength for the microbe-repaired concrete.

In the future study, different strain bacteria will be employed in crack repairing materials and tested for the evaluation of rehabilitation efficiency. On-site experiments of microbe-repaired concrete will also be implemented for further practical applications. Moreover, image process technologies may be applied to examine SEM photographs of the microbe-repaired concrete for the quantity of rectangular and polygonal crystals.

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