ABSTRACT

The microcrack of concrete is almost inevitable. If microcrack forms a continuous route, the moisture or corrosive substances in the air will be bring into the concrete. That will cause the durability decrease of concrete. Nowadays the mainly repair materials are environment unfriendly substances such as epoxy systems or a silicon-based organic polymer. In addition, the different ratio of shrinkage and thermal expansion of these substances often makes the cracks or delamination between concrete and the repair material. In this study, the environment-friendly bacterium of *Bacillus pasteurii* was used to implant in concrete and induces carbonate precipitation to repair concrete crack. Series of tests were planning to explore the self-healing behavior of concrete with the biological material. The test results shows that microbial induce carbonate precipitation (MICP) can let not only the microcrack in concrete but the large crack generated by force can be repaired. The conclusion is that self-healing concrete developed by the study has the effect of self-healing indeed.

1. Introduction

In nature, respiration of certain bacteria will release carbon dioxide and transform it into carbonate ions, followed by the formation of calcium carbonate combined with calcium ions. In the case of calcium carbonate as a binder is converted sand into sandstone gradually, this effect is called bio-mineralization.

In many research, they had begun to try to use mineralization technology for cementation of sand column, repair of concrete cracks, coating protection of concrete surface and restorations of ancient architectural relics [1-4]. In 2002, Hill, D. D. and Sleep, B. E. were also suggested that microbial and media were inoculated to silt, sand and other high permeability materials [5]. This can decrease its permeability coefficient value with precipitating of mineralization.
Carbonates precipitation caused by bacterium is considered to be a material of environment friendly and economical. Researchers had proposed to use bacterium as a self-healing agent, and applied this technology to repair concrete crack. In many studied, there had succeeded in using bacterium-generated of carbonates precipitation. This way is a remediation for concrete or limestone surface to enhance concrete strength or durability [6-8]. However, these bacterium was applied to cracks of concrete structure or specimen from externally. So, the repair mechanisms in these researches cannot be defined as self-healing. In this study, we will use the technology by bio-mineralization to carry out study on bio-based self-healing concrete. In order to protect bacterium from destroying, it will be transformed into spores. Then the spores will be implanted to the porous of lightweight aggregate, and used the material in concrete. When concrete cracks caused, bacterium will restart their vitality with air and water, and to carry out mineralization. We will analyze its healing capability of concrete.

We chose *Bacillus pasteurii* for testing in this study. The shape of the bacterium is close to circular rod or spiral, as shown in Figure 1. Its diameter of cells is about 0.5-3 μm, which is generally suitable for growing in soil with sand. Oxygen is lacked inside concrete, caused to bacterium grow difficultly. This shows the reason why bacterium cannot be directly mixed in concrete.

![Fig.1. Bacillus pasteurii outward appearance](image)

2. Planning of experiment

The main purpose of this study is to understand healing capability of cracks in lightweight aggregate concrete. The mix proportion of lightweight aggregate concrete is shown in Table 1.

| Table1. The mix proportion of lightweight aggregate concrete |
|-----------------|-----------------|-----------------|-----------------|
| cement         | water           | lightweight aggregate | sand |
| 400            | 240             | 399              | 524 |
| unit: kg/m³ |

The expanded shale lightweight aggregate with the particle size of 2 mm to 8 mm were used in this study. The test was divided into the control group and the experimental
group. And then, the experimental group is according to curing environments was divided into the experimental group I and the experimental group II. The control group is a kind of lightweight aggregate concrete which is not implanted with bacterium and nutrient source. It is placed directly the test specimen in curing room for standard curing. The experimental group was implanted with bacterium and nutrient source into lightweight aggregate. Curing environment of the experimental group I is taken the same to the control group. The experimental group II is placed in curing solution and curing in air cycling. Curing solution contains 1 mole of urea and 0.5 mole of calcium acetate. The step of curing is placed the test specimen in curing solution for 1 day and taken them out with curing in air for 1 day as a cycle.

The test specimens are planned two type of lightweight aggregate concrete. One is cylinders of $\psi 10 \times 20$ cm, and another one is cuboid of 100 mm $\times$ 100 mm $\times$ 300 mm. The widths of concrete cracks are designed about 0.1 - 2.0 mm. The lightweight aggregate concrete specimens were curing respectively. We will take the test specimens out and observe at the age of 1, 3, 7, 14, 21, 28, 56, 91 days.

3. Results and Discussion

3.1 The observation of concrete crack by splitting test

The concrete cracks of $\psi 10 \times 20$ cm cylinders were caused by splitting test. We will find that the concrete cracks thus produced were deeper and wider. With different curing mode can observe that the effect of *Bacillus pasteurii* for repairing concrete cracks. The results can be seen the effect with the increase of the curing ages. It shows no repair phenomenon, regardless of the width of the test specimen cracks in the control group and the experimental group I. But in the experimental group II, the test specimen cracks began to repair in curing of the third day. It is found that the effect of repairing cracks is better with the increase of the ages in the curing mode of the experimental group II. As shown in Figure 2.

![Fig.2. Splitting crack repair process of the experimental group II](image-url)
3.2 The observation of concrete crack by flexural test

The concrete cracks of 100 mm × 100 mm × 300 mm cuboid were caused by flexural test, which would be wider of closer to surface and more thin of closer to steel parts. The width of the test specimen cracks are designed 0.1 – 1.2 mm unequally. The results of flexural crack in the experimental group II is shown in Figure 3. We can find out the experimental results of splitting test and flexural test are similar. It shows no repair phenomenon, regardless of the width of the test specimen cracks in the control group and the experimental group I. But in the experimental group II, the test specimen cracks began to repair in curing of the third day. It is found that the effect of repairing cracks is better with the increase of the ages in the curing mode of the experimental group II.

![Fig.3. Flexural crack repair process of the experimental group II](image)

3.3 The observation of section for specimen

The cross-section is compared between specimens by adding bio-bacterium or not, the observed results are shown in Figure 4. We can find the cross-section is covered with calcium carbonate crystals in the experimental group II. Under a magnification of 250 times observation, the calcium carbonate crystals produced by the bio-bacterium are generated from the surface of the lightweight aggregate. It can be seen from Figure 5.
From the experimental results found that calcium carbonate crystals are very detailed and compact. As shown in Figure 6, bio-bacterium produce calcium carbonate precipitates to repair cracks. And it should be able to block air and water into the lightweight aggregate concrete.
4. Conclusion

1) The test results show that transforming bacterium into spores, implanted to porous of lightweight aggregate. Then used the lightweight aggregate mix in concrete. It will be feasible to make a self-healing concrete. When concrete cracks are generated, bacterium will restart vitality with air and water, and to carry out mineralization.

2) The experiment results show that self-healing concrete developed by the study has the effect of self-healing indeed. Bacillus pasteurii can be implanted into lightweight aggregate. The calcium carbonate produced by its mineralization will be generated from the interface between the lightweight aggregate and the mortar. And gradually covered with the entire crack surface. When they deposited to a certain thickness, the concrete cracks were repaired. This can prevent air and water into the concrete and enhance the durability of concrete.

References


