

## SELF-HEALING CONCRETE BY USE OF DIATOMACEOUS EARTH IMMOBILIZED BACTERIA

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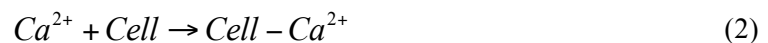
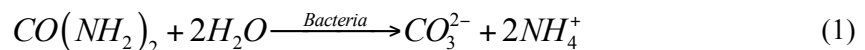
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### ABSTRACT

Microbial CaCO<sub>3</sub> precipitation is being investigated for many applications such as consolidation of sand, surface protection of historical buildings and consolidation of soil. In this research, microbial CaCO<sub>3</sub> precipitated by an ureolytic strain, *Bacillus sphaericus*, was used to heal early age cracks of mortar specimens autonomously. The process of the relevant bio-chemical reaction can be summarized in Equation (1), (2) and (3). The idea of using bacterial CaCO<sub>3</sub> to self-heal concrete cracks is that bacteria are pre-added to fresh cement paste during the process of casting. When cracking occurs, bacteria around the crack wall are considered to be activated by the penetrating oxygen and water, and then produce bio-materials (here CaCO<sub>3</sub>) to fill the cracks. However, bacteria cannot be added into concrete directly. One reason is bacterial activity sharply decreases in the high pH (12~13) environment of concrete. Another reason is the pores inside concrete are mainly smaller than 1µm. During the hydration, the pore size gradually decreases and bacterial cells might be crushed because the size of bacteria is about 1~3µm. Therefore, immobilization of bacteria into a carrier is quite necessary. In this work, diatomaceous earth (DE) was used as a carrier for the bacteria. Diatomaceous earth (DE) is a natural soft siliceous sedimentary rock. It is highly porous, light in weight, chemically stable and inert, properties that allow use in various fields.



*Activity of DE immobilized bacteria and Influence of DE addition on mortar strength.* Bacteria were grown in a sterile medium containing 20g/L yeast extract and 20g/L urea and were incubated at 28°C on a shaker at 120 rpm for 24 h. The cells were harvested by centrifuging the 24h-old grown culture and were resuspended in a saline solution (NaCl, 8.5g/L). The concentration of cells in the suspension was 10<sup>9</sup> cells/mL. The bacterial suspension (BS) was then mixed with a certain amount of DE (20mL BS + 20mL H<sub>2</sub>O + 4g DE) and put on a shaker (100 rpm, 28°C) for 1h to make bacterial cells attach to the DE surface. The activity of bacteria after immobilization into DE was examined in a mimicked high pH concrete environment (cement solution, 20g/L CEM I, pH=12.5). Bacterial activity was indicated by the decomposition of urea by bacteria in the cement slurry (Fig.1). The initial concentration of urea was 20g/L. It can be seen that no urea was decomposed if no bacteria were added to cement slurry. Un-immobilized bacteria can decompose more than 90% of urea at neutral pH but the activity greatly decreased in the high pH cement slurry (only 5% urea was decomposed). However, the DE immobilized bacteria could decompose more than 70% urea in the cement slurry which indicated that DE can protect bacteria in the high pH environment. A series of mortar specimens were prepared to check the influence of the addition of DE with or without bacteria on the strength. The specimens with 5% or 10% (by mass of cement) DE, 5% or 10% DE plus nutrients, 5% or 10% DE loaded with bacteria and nutrients, were represented as DE 5, DE 10, DE 5N, DE 10N, DE 5BN,

and DE 10BN. Half of the specimens (3) were subjected to compressive strength test after 28 days based on the European standard EN 196-1 (Fig.2). It can be seen that DE (with or without bacteria) did not decrease the compressive strength compared with the reference. On the contrary, the strength of the specimens seemed to increase with increasing DE content.

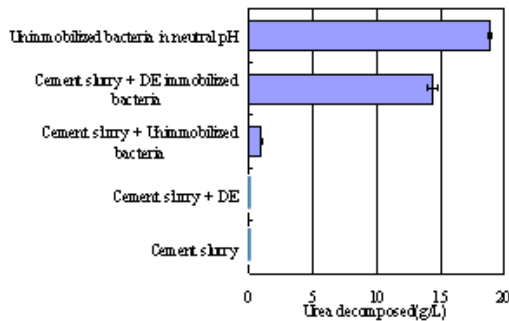


Figure 1: Bacterial activity

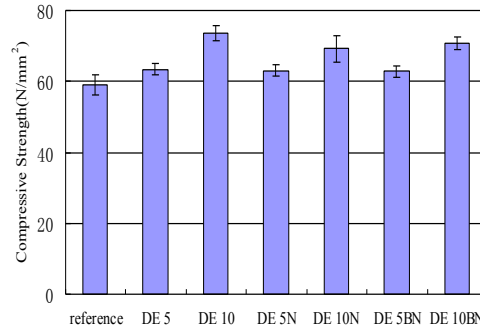


Figure 2: Influence of DE on 28d mortar strength

*Microscopy of crack filling.* The other half of the specimens was subjected to a three-point bending test to make realistic cracks after one week. The cracked specimens were then immersed into water or the medium (consisting of urea and  $Ca^{2+}$ ) for 40 days. Light microscopy was used to visualize the crack filling in each specimen. It is shown in Fig.3 that the crack in the specimen with DE immobilized bacteria immersed into medium was completely filled. The crack in the specimen which was immersed into water was only partly filled even it was incorporated with the same DE immobilized bacteria. It was observed that there was also very small amount of white precipitation in the cracks of the specimens with no bacteria. This is due to the autogenous healing caused by the ongoing hydration in the specimens.

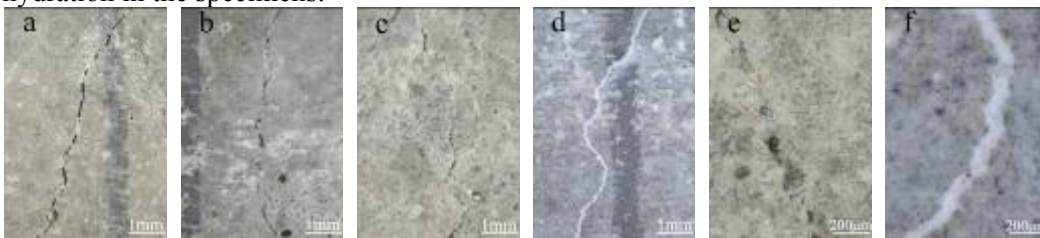


Figure 3: Cracked specimens in water or medium (a: DE 5 in water; b: DE 5 in medium; c: DE 5BN in water; d: DE 5BN in medium; e and f are a magnified part of c and d).

*SEM and EDS analysis of precipitation.* One of the specimens with the completely filled crack was broken along the original crack. The fracture surface was then subjected to SEM and EDS analysis. Some particles (the size was around  $10\mu m$ ) were observed on the crack surface (Fig.4(a)) and the element spectrum of the particles indicated that they were  $CaCO_3$  (Fig.4(b)). Based on the primary results obtained, it could be concluded that DE immobilized bacteria have a great potential to be applied for self-healing of small early age cracks.

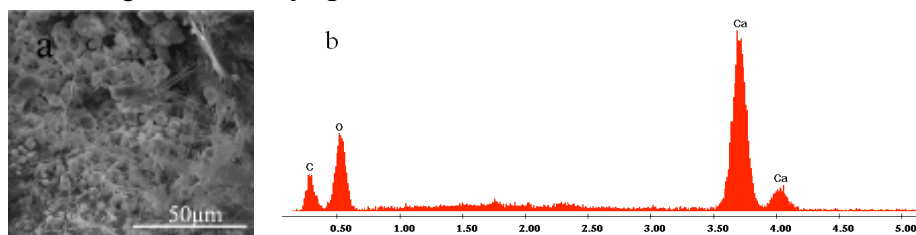


Figure 4: Precipitation on the crack wall

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