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Biogenic treatment improves the durability and remediates the cracks of concrete structures

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HIGHLIGHTS

- Biogenic treatment enhanced the durability properties of building structures.
- Permeability of concrete specimens significantly reduced due to bacterial treatment.
- Biogenic treatment remediate the cracks of concrete specimens.
- Compressive strength of cement mortar specimens enhanced due to calcite precipitation.

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ABSTRACT

Microbially induced calcium carbonate precipitation is a naturally occurring biological process that has various applications in remediation and restoration of range of building materials. In the present study the role of bacteria *Bacillus* sp. on the durability properties and remediation of cracks in cementitious structures were studied. "Biocement" induced by a *Bacillus* sp. lead to more than 50% reduction in the porosity of mortar specimens, while chloride permeability of concrete changed from "moderate" to "very low" as indicated by rapid chloride permeability test. The bacteria successfully healed the simulated cracks of depths including 27.2 mm in cement mortars with increase in the compressive strength as high as 40% of that of control. The results clearly showed microbially induced calcium carbonate precipitation can be applied for various building materials for remediation of cracks and enhancement of durability.

1. Introduction

Most of the world population is getting urban centric and as a result use of concrete is rapidly increasing worldwide. It is already the most used manmade material in the world as it is relatively cheap and its basic ingredients (sand/gravel/water) are readily available. However, durability of concrete may be compromised due to many man-made factors and natural consequences. Transport of aggressive liquids including water and harmful substances into concrete results the deterioration of cementitious materials. Thus, the reinforcements become exposed to corrosive environment and the deterioration is accelerated. Thus, healing of cracks in concrete can effectively increase service life of the structures [1].

The pore structure in concrete allows permeation of harmful chemicals. Concrete is also susceptible to cracking due a number of factors such as shrinkage, excessive heating and water, freeze thaw, tensile stresses, and creep. Cracking accelerates further degradation through easy ingress of moisture and ions that react with the reinforcements in concrete and create expansive stresses that lead to spalling. Presently, remediation of cracks is done through application of a surface coating mainly using synthetic polymers. Such materials are toxic and expensive. They also suffer issues of being not eco-friendly, susceptible to ultraviolet radiation, degradation with age, the need for constant maintenance and cracking due to differential thermal expansion [2,3]. Sometimes repair cannot be carried out in the areas where it is not possible to shut down the plant or it is hazardous for human beings. An autogenously healing system that remediates the cracks with materials similar to that of concrete and goes deeper inside the crack rather than the surface treatment would be of great benefit.

In recent years, "Biocement", which consists of alkaliphilic bacteria, substrate and calcium ion solutions, has drawn much attention. It relies on the microbially induced calcium carbonate precipitation (MICP) around individual particles and at

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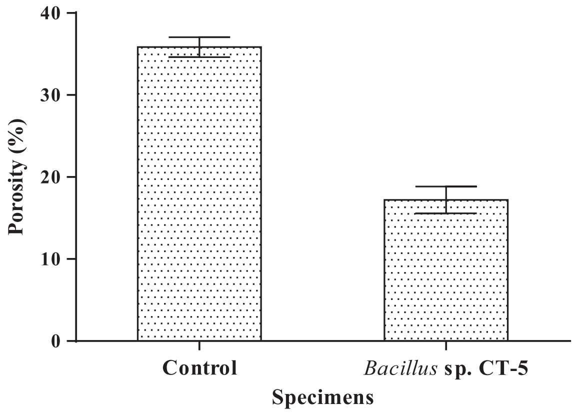

Fig. 1. Total porosity measurement of control mortar specimens and their comparison with those prepared with *Bacillus* sp. CT-5.

particle–particle contacts to bind loose particles [1,3]. The process of MICP depends on urease producing bacteria which are ubiquitous in nature. During microbial urease activity, 1 mol of urea is hydrolyzed intracellularly to 1 mol of ammonia and 1 mol of carbamate, which spontaneously hydrolyses to form an additional 1 mol of ammonia and carbonic acid [4]. These products subsequently equilibrate in water to form bicarbonate and 2 mol of ammonium and hydroxide ions, giving rise to increase in pH and formation of carbonate ions. Finally the reaction results into calcium carbonate precipitation around bacterial cells in the presence of calcium ions. The overall reactions may be summarized as follow:

$$\begin{aligned} CO(NH_2)_2 + H_2O &\rightarrow NH_2COOH + NH_3NH_2COOH + H_2O \\ &\rightarrow NH_3 + H_2CO_3H_2CO_3 \\ &\leftrightarrow HCO_3^- + H^+2NH_3 + 2H_2O \\ &\leftrightarrow 2NH_4^+ + 2OH^-HCO_3^- + H^+ + 2NH_4^+ \\ &\quad + 2OH^- \\ &\leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2OCa^{2+} + Cell \\ &\rightarrow Cell - Ca^{2+}Cell - Ca^{2+} + CO_3^{2-} \\ &\rightarrow Cell - CaCO_3^- \end{aligned} \qquad (1)$$

Biocement has been considered as a novel metabolic product with positive influence in civil and construction engineering. It has been demonstrated to enhance the durability of building materials, consolidation of sand columns, and repair of limestone monuments and concrete [5–13]. The process can be utilized in healing cracks as well.

In the present study, we demonstrate the biocementation ability of a bacterial strain *Bacillus* sp. CT-5 to seal cracks. The bacterial strain was used to reduce the porosity as well as chloride permeability from cement-based materials. Later this strain was applied into cracks in concrete. Compressive strength was measured and compared with those samples not treated with bacterial cells. Further, MICP process was evaluated using scanning electron microscopy to visualize formation of calcite deposits in cracks on or around the bacterial cells.

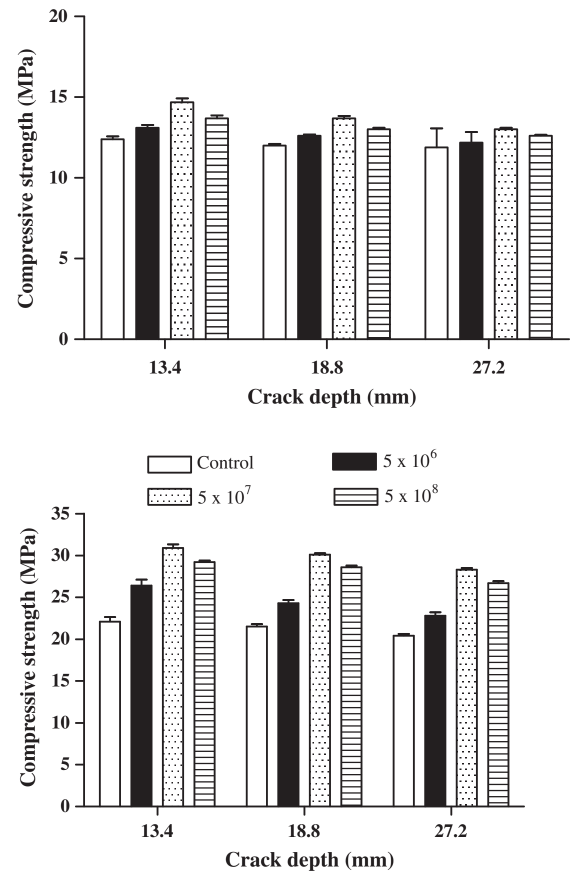

Fig. 2. Compressive strengths of mortar cubes at: (a) 7 days and (b) 28 days with cracks filled with various concentrations of *Bacillus* sp. CT-5.

2. Experimental and methods

2.1. Microorganism and cultivation conditions

Bacillus sp. CT-5 was used throughout the present study. This strain was previously isolated from cement and maintained on Nutrient Agar (pH 8.0) medium in the laboratory [14]. Nutrient broth-urea (NBU) medium (8 g nutrient broth, 2% urea and 25 mM $CaCl_2$) was used to grow the bacteria [15]. Bacterial culture was grown at 37 °C under shaking condition (130 rpm).

2.2. Preparation of cement mortar cubes

A cube mold of dimension 70.6 mm × 70.6 mm × 70.6 mm was prepared as per IS 4031 (1988). Locally available clean, dry, well graded, natural river sand was used as fine aggregate. Ordinary Portland cement conforming to Bureau of Indian Standard (BIS) 8112 was used. The cement-to-sand ratio was 1:3 (by weight), and the water-to-cement ratio was 0.47. Sand and cement were thoroughly mixed along with grown culture of bacterial isolate correspondence to OD_{600} 1.0. The water to bacterial culture ratio was also maintained at 0.47. Cubes were cast and compacted in a vibration machine. After de-molding, all specimens were cured in NBU medium

Table 1
Permeability class distributions based on RCPT report of control and *Bacillus* sp. CT-5 treated concrete specimens.

Treatment	Charge passed (C) (in triplicate)			Average charge passed (C)	Permeability Class as per ASTM C 1202
	1	2	3		
Control	2890	3245	3396	3177.00	Moderate
Bacillus sp.	1023	818	1085	975.33	Very Low