A STUDY ON PROPERTY AUGMENTATION OF MICROBIAL CONCRETE AT DIFFERENT CELL CONCENTRATIONS WITH TIME

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ABSTRACT. One of the most effective autonomous crack healing of concrete structures is possible by the use of specific bacteria that have the capability of calcite precipitation in the concrete matrix. Existing research on microbial concrete has shown promising results but most of them are based on short-term experiments, mainly restricted to 28 days. For mass adaptation of microbial concrete in real life structures it is necessary to carry out long-term investigations on various aspects of microbial concrete. In this direction, the current work examines the performance of microbial concrete in terms of compressive strength, water absorption and self-healing characteristics up to 180 days. In this study, three different bacterial cell concentrations of *Bacillus subtilis,* namely 10^3 cells/ml, 10^5 cells/ml and 10^7 cells/ml in mortar samples have been considered. Results indicate that though higher bacterial concentration is more efficient in improving the characteristics of water absorption, water permeability and crack healing of the microbial samples as compared to the controlled samples, enhancement in compressive strength is optimized at an intermediate cell concentration. Further, it is found that with time, especially beyond 28 days, there is a change in the pattern of property augmentation of microbial concrete at different bacterial cell concentrations.

Keywords: Bacteria, Concrete, Self-healing, Long-term properties, Optimum concentration.

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INTRODUCTION

The efficient crack healing ability of microbial concrete constitutes one of the most emerging technologies in the field of concrete research [1]. The three requirements of bacterial selection for microbial concrete are namely, the property of calcite precipitation, survival ability in the alkaline environment of the concrete matrix and non-pathogenicity. These are mostly met by certain bacteria of the *Bacillus* genus, such as *Bacillus, subtilis, Bacillus pasteurii, Bacillus sphaericus, Bacillus cereus, Bacillus magaterium*,[2-9], which have consequently been the primary choice for application in concrete. Studies have shown that these thick membrane spore forming bacteria can survive up to hundreds of years without nutrients and the dormant endospores are able to withstand environmental chemicals, high mechanical stresses as well as ultraviolet radiations [10]. It has also been reported that the addition of bacteria can heal cracks of width up to 970 μm [3]. Additionally, as expected, efficient healing of micro cracks leads to the improvement in various mechanical properties of the concrete, such as enhanced compressive strength and reduced water absorption and water permeability[11-13].Further, it has been reported that, though the efficiency of crack healing increases with higher bacterial cell concentrations, the maximum enhancement in compressive strength is obtained at an intermediate bacterial cell concentration [5,7,13-16]. Recently, Mondal and Ghosh [17] explained the reason for the existence of the optimal bacterial concentration for compressive strength enhancement at an intermediate value of cell concentration.

It is observed from the existing literature on microbial concrete as discussed above that most of the reported results are mainly short-term, limited to 28 days. For practical and mass implementation of microbial concrete, it is extremely important to study its long-term behaviour as well. In this regard, the present study examines the performance of microbial concrete considering three different cell concentrations of *Bacillus subtilis*, in terms of compressive strength, water absorption and self-healing characteristics, at 3, 7, 28, 56, 90 and finally at 180 days. A comparison between the characteristics of short-term and long-term property enhancement of the microbial concrete is presented.

MATERIALS AND METHODS

Materials

Bacillus Subtilis (MTCC 441) obtained from the Microbial Type Culture Collection and Gene Bank, India, is used in this study. The culture was grown in a nutrient broth made with Beef Extract 1.0 gm/litre, Yeast Extract 2.0 gm/litre, Peptone 5.0 gm/litre, NaCl 5.0 gm/litre and distilled water (pH = 7.0). After 5-6 days of inoculation, about 10μl from the culture medium was taken on a Haemocytometer and counted under the microscope. This was followed by serial dilution to obtain the required bacterial concentrations. The live bacterial cells obtained from the pre-culture were added to water at different cell concentrations, namely 10^3 cells/ml, 10^5 cells/ml and 10^7 cells/ml.

Mortar samples were prepared by using Ordinary Portland cement (OPC) of grade 43 and locally available river sand. Mortar cubes of dimension 70.6 mm x 70.6 mm x 70.6 mm were prepared for both control and bacterial mortar samples. The cement to sand ratio was taken as

1:3 (by weight) and water to cement ratio was fixed at 0.4 (by weight). The samples were removed from the moulds after 24 hours and cured at room temperature (27˚C) in fresh water.

Test Methods

To evaluate the long term performance of microbial concrete firstly, the compressive strength and water absorption tests of the control and the bacterial mortar cubes were performed at the age of 3, 7, 28, 56, 90 and 180 days of curing. For water absorption test, initially the mortar cubes were kept in an oven at 105°C and dried for 24 hours and the dry weight measured. The samples were then kept in a saturated condition in water at room temperature for 24 hours and weighed again. The water absorption is expressed as a percentage.
To evaluate the self-healing efficiency at different bacterial concentrations and at different ages, crack healing in microbial concrete was analyzed. At 28, 90 and 180 days of curing, the mortar samples were loaded on the compression testing machine. When visible cracks appeared on the surface, the loading was stopped. Thereafter, the widths of the cracks were measured by the crack-measuring instrument. The widths of the cracks varied from 0.1 mm to 2 mm. Next, the cracked samples were submerged in water. For crack healing quantification, the crack widths were measured after 7 and 28 days of curing.

TEST RESULTS

Compressive strength

The compressive strength of the control and microbial mortar specimens at 3, 7, 28, 56, 90 and 180 days are presented in Figure1. The results indicate that there is an increase in compressive strength by the incorporation of bacteria in all the considered concentrations at all testing ages. The rate of increase of compressive strength in the microbial concrete samples with bacterial concentrations 10^3 cells/ml and 10^5 cells/ml follows the same trend as that of the control samples. However the enhancement rate for the 10^7 cells/ml sample is lower beyond 56 days as compared to other samples. It is observed that at any particular age of testing, the compressive strength of the mortar samples increases with increase in bacterial concentration up to 10^5 cells/ml and then relatively decreases at 10^7 cells/ml. The maximum enhancement in strength is achieved at the cell concentration of 10^5 cells/ml at all ages. Interestingly, it is found that at the initial stage mainly up to 90 days, 10^7 cells/ml delivers better compressive strength in comparison with 10^3 cells/ml, whereas 10^3 cells/ml provides better result especially beyond 90 days.

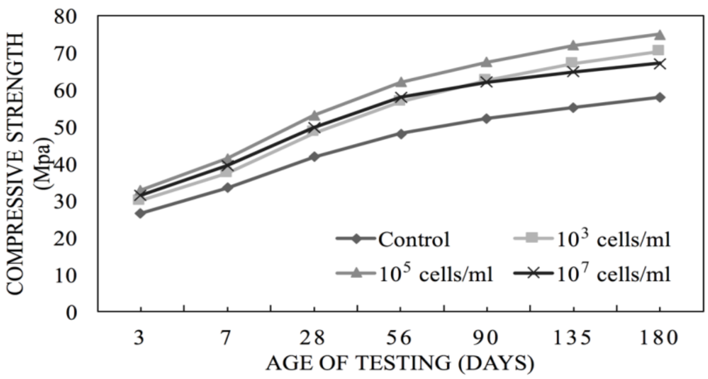

Figure 1 Compressive strength test results for control and microbial mortar at different ages

For example, at 28 days of curing, the compressive strength is increased by 15%, 27% and 19% for cell concentrations 10^3 cells/ml, 10^5 cells/ml and 10^7 cells/ml respectively, but at 180 days of curing the strength is increased by 21%, 20% and 15% in comparison to the control specimen.

Water absorption test results

The water absorption of the control and microbial mortars at 3, 7, 28, 56, 90 and 180 days are indicated in Figure 2. It is clear that the presence of bacteria in the mortar mix reduces the water absorption at all the studied concentrations and ages. Moreover, the water absorption decreases with increase in bacterial concentration, thereby the maximum reduction is obtained at cell concentration 10^7 cells/ml at all ages of curing. However, in comparison with 10^5 cells/ml the reduction in water absorption decreases significantly with curing time. The reduction in water absorption is measured by the difference in the water absorption of microbial mortar and control mortar w.r.t that of control mortar. At 28 days of curing, the water absorption is reduced by 13%, 23% and 27% for cell concentrations 10^3 cells/ml, 10^5 cells/ml and 10^7 cells/ml respectively, in comparison to the control specimen.

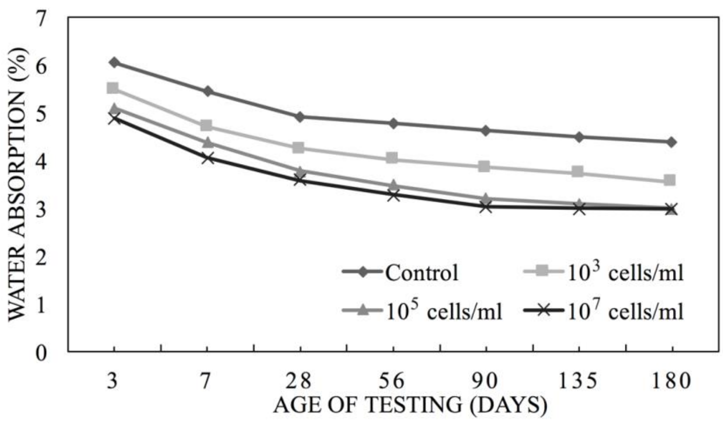

Figure 2Water absorption test results for control and microbial mortar

Crack healing analysis

The images of surface crack healing by the different bacterial concentrations for cracks created at different ages of the mortar specimens are presented in Figure 3 – Figure 5. It can be clearly observed that the visible cracks on the surface of the mortar cubes are healed by white precipitations. The healing efficiency of the different bacterial concentrations for the cracks created at different ages of the mortar specimens are different. It is observed that, for the same curing time, the cracks created at 28 days are healed faster as compared to those created at 90 days and at 180 days. At 7 days of curing, the cracks created at 28 days are almost completely healed at bacterial concentration of 10^7 cells/ml, whereas 90 days and 180 days cracked specimens are only partially healed. However, at 28 days of curing the width of cracks are healed completely for all 28 days, 90 days and 180 days cracked specimens at 10^7 cells/ml. For bacterial concentration of 10^5 cells/ml, almost similar type of healing was achieved for all 28 days, 90 days and 180 days cracked specimens, however the degree of crack healing is comparatively lower than 10^7 cells/ml as expected. For bacterial concentration of 10^3 cells/ml at 7 days curing, the efficiency of crack healing is much lower has been found at 90 days and 180 days cracked samples as compared to the 28 days cracked samples. However, at 28 days of healing, degree of healing was almost identical for all 28 days, 90 days and 180 days cracked specimens.

The probable reason for the reduction in the healing efficiency at 7 days of curing for 90 days and 180 days cracked specimens is probably due to the substantial reduction in water permeability inside the concrete matrix at initial curing of the cracked specimens that restrict the conversion of bacterial spores into vegetable cells. After a certain time, when the water is able to penetrate to the bacterial spores and which lead to the transformation of bacterial spores into vegetable cells and as a result significant precipitation takes place. This is why greater precipitation takes place at later days of curing.

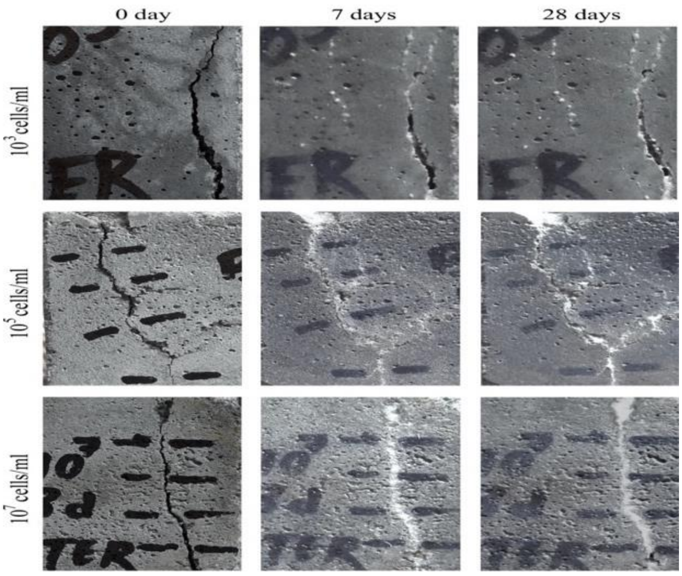

Figure 3 Crack healing at different age of crack with different bacterial concentrations (crack creation – after 28 days of curing)

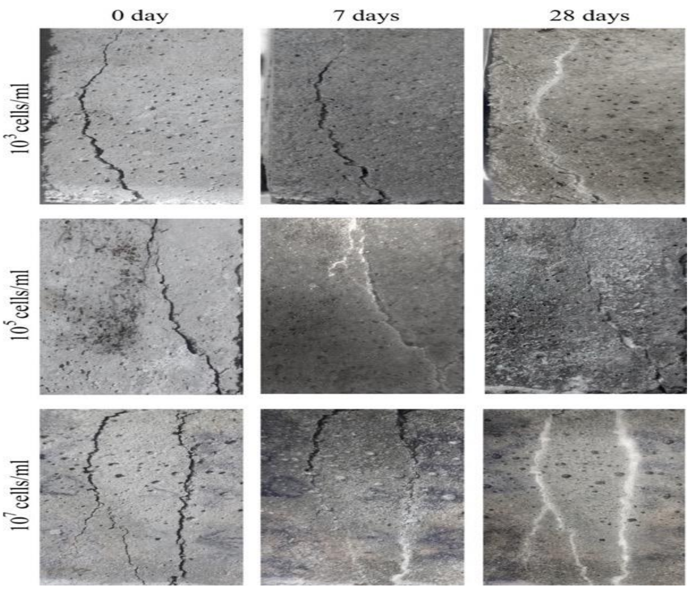

Figure 4 Crack healing at different age of crack with different bacterial concentrations (crack creation – after 90 days)

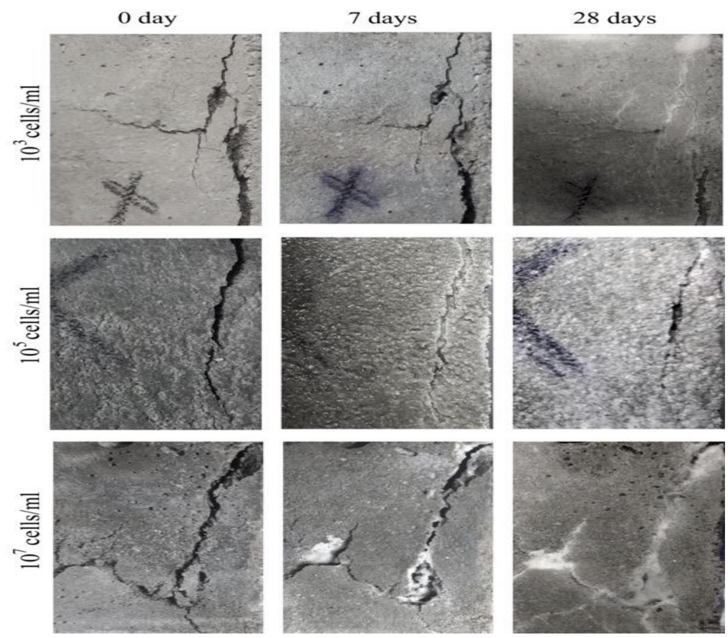

Figure 5 Crack healing at different age of crack with different bacterial concentrations (crack creation – after 180 days)

CONCLUDING REMARKS

An investigation is carried out on the enhancement of various mechanical properties of microbial concrete with time, upto 180 days. The results of the experimental program with three different cell concentrations of *Bacillus subtilis* indicate that with time, especially beyond 28 days, there is a change in the pattern of property augmentation of microbial concrete at different bacterial cell concentrations.Further, it is found that for all the testing ages, while crack-healing and water absorption are maximum at the highest considered cell concentration of 10^7 cells/ml, the maximum compressive strength enhancement occurs at 10^5 cells/ml. The compressive strength enhancement at 10^7 cells/ml, in comparison to that at 10^3 cells/ml, decreases significantly with time and after 90 days of curing 10^3 cells/ml provides better compressive strength than 10^7 cells/ml. It is also seen that the crack healing rate of microbial concrete at the initial stage decreases with time. However, after 28 days the healing efficiency is almost similar at all the testing ages.

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