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# Feasibility Study on Bacterial Concrete as an Innovative Self-Crack Healing System

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**Abstract-**Cracks in concrete are unavoidable and are one of the intrinsic disadvantages of concrete. Water and other salts percolate through these cracks, corrosion initiates, and thus reduce the life of concrete. So there was a need to develop an inherent biomaterial, a self-repairing material which can remediate the cracks in concrete. Bacterial concrete is such an innovative construction material, which can successfully remediate cracks in concrete without any human intervention. This technique is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution free and natural. From the experimental investigations conducted, it was found that use of bacteria not only improves the strength and durability characteristics of concrete but also recovers the strength lost due to damage. The environmental analysis showed a reduction in carbon dioxide produced per cubic meter of mix concrete projecting to a decrease of carbon dioxide emissions by the cement industry on a global scale.
**Keywords:** Bacterial Concrete, Microbial Concrete, Bio-mineralization, Microbiologically Induced Calcite Precipitation, Self-healing, Bacillus subtilis JC3

## I. INTRODUCTION

Self Healing Materials is a new research area that gets a lot of attention in recent years. Self healing concrete is a term that is used for cement-based materials that repair themselves after the material or structure gets damaged due to some sort of deterioration mechanism**.** The idea of bacteria-based self-healing concrete is that concrete mix is embedded with bacteria during preparation. So when initially a crack occurs, water enters into it which causes bacteria to germinate. The bacteria will multiply, producing limestone ($CaCO_3$) as they go, sealing the crack. The use of bacteriogenic mineral plugging in civil engineering has become increasingly popular. Another issue related with conventional building materials is the high production of green house gases and high energy consumed during production of these materials. Conventionally synthetic materials like epoxies are used for crack remediation. But, they are not compatible, costly, reduce aesthetic appearance and need constant maintenance. The above mentioned drawbacks of conventional treatments have invited the usage of novel, eco-friendly, self-healing and energy efficient technology where microbes are used for remediation of building materials and enhancement in the durability characteristics. Currently, self-healing is merely considered as the recovery of mechanical strength through crack

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healing. However, there are other cases where not only the cracks but also small pores can be filled and healed to have better performance in terms of strength and durability.

## II. MICROBIOLOGICALLY INDUCED $CACO_3$ PRECIPITATION IN CONCRETE

In concrete crack-remediation technique by microbiologically induced calcite precipitation (MICP), a highly impermeable calcite layer formed over the surface of an already existing concrete layer due to microbial activities of the bacteria *Bacillus subtilis* JC3 (cultured at JNTU) seals the cracks and plugs the pores present in the concrete eventually increasing the strength and durability of concrete. This concrete crack remediation technique by Microbiologically Induced Calcite Precipitation (MICP) using environment friendly bacteria to precipitate calcite ($CaCO_3$) during its microbial activities under prevailing Indian conditions is investigated to formulate a strategy to present 'Bacterial Concrete' as best innovative self healing method in concrete structures. Bacterial concrete is a special type of concrete in which microorganisms (*Bacillus subtilis* JC3) is introduced into the concrete during the mixing stage.

## III. MECHANISM OF MICROBIAL ACTIVITY OF BACILLUS SUBTILIS JC3

In nature, microorganisms can induce calcite mineral precipitation through nitrogen cycle either by ammonification of amino acids/ nitrate reduction/ hydrolysis of urea. In the present adopted nutrient environment, *Bacillus subtilis* JC3 is able to precipitate calcium carbonate ($CaCO_3$) in its micro-environment by the process of ammonification, in which amino acids are degraded into ammonium ($NH_4^+$) and carbonate ($CO_3^{2-}$) ions. The precipitated bio-$CaCO_3$ has a great potential ability to heal concrete cracks because it is natural, environmentally friendly and compatibility with the concrete matrix. Bio-mineralization by Ammonification (Ammo acid degradation) comprises of series of complex biochemical reactions. Amino acids released during proteolysis (the process of enzymatic breakdown of proteins by the microorganisms with the help of proteolysis enzymes) undergo de-amination in which nitrogen containing amino ($-NH_2$) group is removed. This process of de-amination which leads to the production of ammonia is termed as "ammonification". This process of ammonification is mediated by Bacillus subtilis JC3. Ammonification usually occurs under aerobic conditions (known as oxidative deamination) with the liberation of ammonia ($NH_3$) or ammonium ions ($NH_4$) when dissolved in water. Calcium chloride was used for precipitation of calcium carbonate, while culture medium consists of Peptone: 5 g/lit., NaCl: 5 g/lit., Yeast extract: 3 g/lit. and beef extract to cultivate microorganisms. B.subtilis cell can attract Ca ions ($Ca^{2+}$), which react with carbonate ions $CO_3^{2-}$ originating from peptone during oxidative de-amination of amino acids. Simultaneously, ammonia ions $NH_4^+$ increase pH value in surrounding medium which improves calcite precipitation efficiency. Once super-saturation is achieved, precipitation of calcium carbonate crystals occurs by heterogeneous nucleation on the bacterial cell wall.

## IV. EXPERIMENTAL INVESTIGATIONS

### 4.1 Effect of Bacterial Cell Concentration on Strength

Effect of cell concentration of *Bacillus subtilis* JC3 on the strength is studied by determining the compressive strength of standard cement mortar cubes incorporated with various bacterial cell concentrations as per IS: 4031-part 6 as shown in Figure 1.

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### 4.2 Compressive Strength Studies on Bacterial Concrete

Compressive strength of bacterial concrete is tested as per IS: 516-1959 and plotted in Figure 2.

### 4.3 Mix Proportions

The concrete mix proportions used are tabulated in Table 1.

***Table 5: Concrete Mix Proportions***

| Grade of Concrete | Mix Proportion | Cement kg | Micro Silica | FA kg | CA kg | Water L | Super Plasticizer L |
|---|---|---|---|---|---|---|---|
| M20 | 1: 2.27: 3.45: 0.54 | 320.4 | - | 727.3 | 1105.4 | 173 | - |
| M40 | 1: 1.73: 2.60: 0.42 | 390.7 | - | 676 | 1019.7 | 164.1 | - |
| M60 | 1:1.25:2.41:0.26 | 436 | 27.8 | 579.9 | 1118 | 120.6 | 1.2 |
| M80 | 1:1.06:1.96:0.23 | 450 | 52 | 532.3 | 984.1 | 115.5 | 1.4 |

*bwc-by weight of cement

The following plot shows effect of bacterial cell concentration on the compressive strengths of cement mortar cubes.

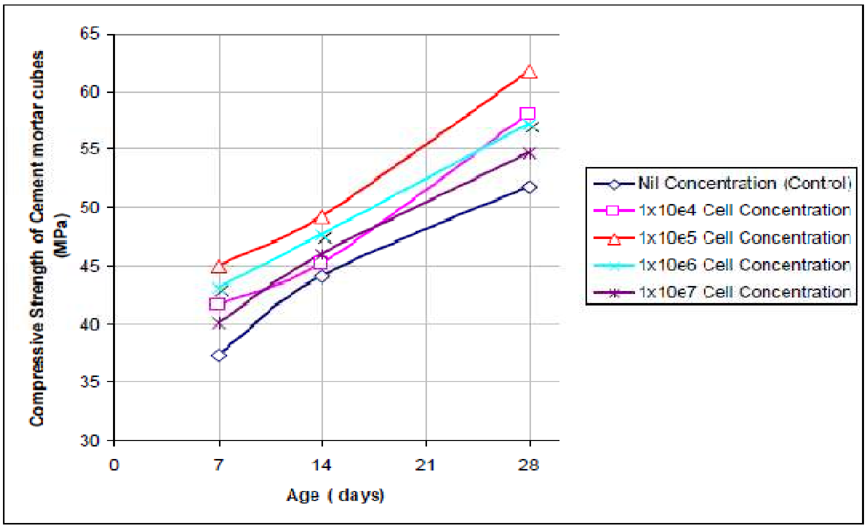


***Figure 1: Effect of bacterial cell concentration on the strength of concrete***

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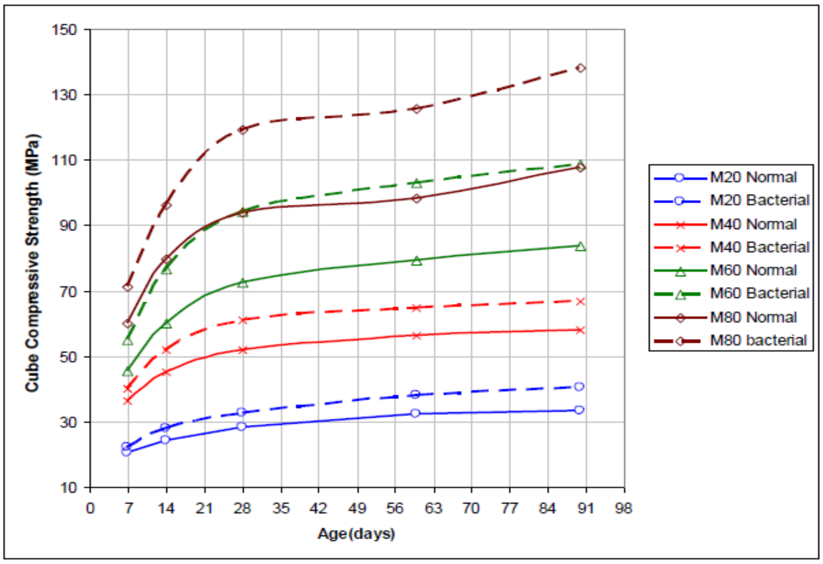


***Figure 2: Strength development of a Normal concrete and Bacterial concrete***

**4.4 Cost Analysis**

The cost of using microbial concrete compared to conventional concrete is critical in determining the economic feasibility of the technology. The cost analysis showed an increase in cost of 2.3 to 3.9 times between microbial concrete and conventional concrete with decrease of grade as shown in Table 2. The major contributor to the cost of the bacterial mix is the nutrient broth, amounting to over 60-75% of the cost per cubic meter of concrete. Therefore, further research needs to be devoted to decrease the amount of the nutrient broth used or to find a cheaper alternative source for bacteria nutrition in order to make the technology financially feasible. Nevertheless, it is believed that microbial concrete will yield cost reductions on the long run through decreased need for rehabilitation and maintenance. Furthermore, the high cost of the technology is outweighed by its positive environmental impact. Only expensive component in the development of bacterial concrete is nutrients. In the market bacteria is available is lyophilized state. So cost depends on the surface treatment area or volume of concrete used. Nutrients used for this study are laboratory nutrients which are quite expensive so other inexpensive nutrient sources can also be tried to reduce the commercial production cost of bacterial concrete. However, any nutrients such as inexpensive, high-protein-containing industrial wastes such as corn steep liquor (CSL) or lactose mother liquor (LML) effluent from starch industry can also be used so that overall process cost reduces dramatically. These industrial effluents which are potential environmental pollutants and also available locally with a price of nearly Rs 100 per liter, which is very economic compared with standard laboratory nutrient medium. In this project, to prepare one liter of nutrients mixed bacterial culture, it required 13 grams of nutrients broth powder. The cost of 500 grams of HIMEDIA M002 nutrient broth powder costs about 2300 rupees so to prepare one litre of nutrients mixed bacterial culture costs Rs 60. In this project nearly 125 liters of nutrients mixed bacterial culture was used costing nearly 7500 rupees.

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***Table 2: Manufacturing Cost of Concrete per Cubic meter***

| Grade of Concrete | Cement 1kg= 6 Rs (a) | Micro Silica 1kg=22Rs (b) | FA (River Sand) 1kg=1.3Rs (c) | CA (20mm) 1kg=0.60Rs (d) | Water (e) | Super Plasticizer 1L=40Rs (f) | Bacteria suspended water 1L=60Rs (g) | Cost of Controlled Concrete cu m in Rs. (a+b+c+d+e+f) | Cost of Bacterial Concrete cu m in Rs. (a+b+c+d+f+g) |
|---|---|---|---|---|---|---|---|---|---|
| M20 | 1922.4 | - | 945.5 | 663.2 | 0.0 | - | 10380.0 | 3531.1 | 13911.1 |
| M40 | 2344.2 | - | 878.8 | 611.8 | 0.0 | - | 9846.0 | 3834.8 | 13680.8 |
| M60 | 2616.0 | 611.6 | 753.9 | 670.8 | 0.0 | 48 | 7236.0 | 4700.3 | 11936.3 |
| M80 | 2700.0 | 1144.0 | 692.0 | 590.5 | 0.0 | 56 | 6930.0 | 5182.5 | 12112.5 |
| | Note: Based on Locally available rates in Hyderabad | | | | | | | | |

### 4.5 Environmental analysis

One of the major advantages of microbial concrete is the possible reduction of the carbon footprint of concrete production. The production of cement, particularly clinker production, is the major contributor to carbon dioxide emissions. The carbon dioxide producing reaction in cement manufacturing is

$$\underset{(1\ \text{kg})}{CaCO_3} \rightarrow \underset{(0.56\ \text{kg})}{CaO} + \underset{(0.44\ \text{kg})}{CO_2}$$

Portland cement consists of 95% clinker of which 64% to 67% is Calcium Carbonate CaCO3; According to equation this results in approximately 0.264 kg of carbon dioxide emissions per kilogram of cement produced. Since microbial concrete yields the same compressive strength with decreased cement content, the amount of carbon dioxide emissions during the production of cement for concrete was obtained for controlled and bacterial grades and are compared. Consequently, the ratio of carbon dioxide reduction was used to obtain the projected global decrease in emissions. Based on the above data, controlled concrete mixes yields 125.4 kg of carbon dioxide during cement production while bacterial concrete mixes yields 89.5 kg of carbon dioxide per cubic meter of concrete, amounting to a 40% and 28 % decrease in carbon dioxide emissions per cubic meter of concrete of M20 and M40 respectively where as 15 to 20% in high strength grade bacterial concretes.

## CONCLUSION

Based on the research and results presented in this paper, the following conclusions are reached: Improvement in compressive strength reaches a maximum at about $10^5$/ml cell concentration. Precipitation of these crystals inside the gel matrix may enhance the durability of concrete significantly. Furthermore, analysis has shown an increase in the cost of production and a significant

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decrease in carbon footprint compared to conventional concrete. Hence, Microbial concrete is thought to be a promising innovation as a self-crack healing material. Nevertheless, research has to be devoted to finding methods to decrease the cost of production and to implement microbial concrete on an industrial scale to ensure the success of the technology.

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