# An Experimental Investigation on Improvement of Concrete Serviceability by using Bacterial Mineral Precipitation

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*Abstract* - **Concrete, a strong, durable material composed of cement, aggregate and water, is the most used building material in the world. Concrete has an ultimate load bearing capacity under compression but the material is weak in tension. That is why steel bars are embedded in the concrete for the structures to carry tensile loads. The steel reinforced bars take the tensile load when the concrete cracks in tension. On other hand the concrete protects the steel reinforced bars from the environment and prevents corrosion. However, the cracks in the concrete form a major problem which affects the durability of the structures. Here the ingress of water and chloride ions takes place and deterioration of the structure starts with the corrosion of the steel. In earlier days, to increase the strength and durability of the structure, the cracks which are formed will be repaired conventionally using epoxy injection or latex treatment or by providing extra reinforcement in the structure during the design phase to ensure that the crack width stays within a permissible limit. This extra reinforcement is only needed for durability reasons (to keep the crack width small) and not for structural capacity. Especially with current steel prices on rise providing extra steel is not economically viable. Main reason to prevent cracks or limit crack width is to enhance the durability of the structure. A reliable method could be developed that repairs cracks in concrete automatically (i.e) self healing, which would increase durability of the structure enormously. On the other hand it would also save a lot of money, time and energy.**

**A main technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite ($CaCo_3$) precipitation is discussed and called as Bio-Concrete. Microbiologically induced calcite precipitation is a technique that comes under a broader category of science called bio mineralization. It is a process by which living organisms form inorganic solids. Bacillus subtitles, a common soil bacterium can induce the precipitation of calcite. As a microbial sealant, $CaCO_3$ exhibited its positive potential in selectively consolidating simulated fractures and surface fissures in granites and in the consolidation of sand. Microbiologically induced calcite precipitation is highly desirable because the calcite precipitation induced as a result of microbial activities, is pollution free and natural. This technique can be used to improve the compressive strength. The effect of different concentrations of bacteria on the concrete is used to found out optimum content in concrete . It was found that the temperature of bacteria that alive in concrete from -3'c to 80,c. The NDT test were also done on conventional and bio-concrete at the time period of 3,7and 28 days. Micro structure of concrete was visualized by SEM with & without addition of bacteria . This calcite layer improves the impermeability of the specimen, thus increasing its resistance to alkaline, sulphate and freeze-thaw attack. The estimation and costing for bio concrete were compared with conventional and epoxy coating.**

**Keywords** — ***Bacterial Concrete, Bacillus subtilis, Carbonate precipitation, crack healing properties***

## I. INTRODUCTION

Bacteria are the most abundant and metabolically diverse forms of life on earth. They grow under a wide range of geochemical conditions in an unparalleled variety of habitats. In the biosphere, bacteria can act as geo-chemical agents, resulting in the concentration of materials (Ghose and Mandal, 2006). This induces the formation of special minerals, which constitute an area of research of growing interest known as biomineralization (Beneficiaries Omar et al., 1997). Use of this biomineralogy concept leads to the potential invention of a new material bacterial concrete. Bacterial concrete is made by adding bacterial pure culture in the concrete mixing process. It is an inherent and self-repairing biomaterial that can remediate the cracks and fissures in concrete (Ramchandran et al., 2001). Though concrete is quite strong mechanically, it suffers from several drawbacks, such as low tensile strength, permeability due to liquids and consequent corrosion of reinforcement susceptibility to chemical attack and henceforth results in low durability (Mehta, 1999). Modifications have been made from time to time to overcome such difficulties of concrete but all those processes are not easy and good (Kirley, 1999). Recently, microbial remediation of concrete has been put in practice to solve these difficulties. Some bacterial species like Bacillus pasteruii, Bacillus subtilis and Pseudomonas aeruginosa along with cement-aggregates produce minute particles within the matrix that can promote precipitation of calcium carbonate in the form of calcite which remediates cracks in structure (Gollapudi et al., 1995; Ramachandran et al., 2001). This research work aims to use bacteria for calcite formation to repair concrete and this will provide an alternative basis and high quality bacterial concrete that is cost effective and environmentally safe.

## II. MATERIALS AND METHODS

### A. Cement

Portland Pozzolana Cement of brand name 'Ramco' 43 grade conform to IS:1489 (PT1): 1991 was used.

### B. Fine Aggregate

Sand sample conforming to Zone-III as per the test from IS:383-1970 with specific gravity of 2.54 was used.

### C. Coarse Aggregate

Coarse aggregate of specific gravity 2.6 and of maximum size 20.0 mm single sized aggregate were taken.

*D. Water*

Water confirming to the requirements of IS456-2000 was taken with the pH value 7.1 at zero turbidity.

*E. Bacteria*

Bacillus subtilis strain 121 was obtained and used in this study from Microbial Type Culture Collection and Gene Bank (MTCC), Chandigarh (Fig. 1a).

*F. Mix Proportion*

For a concrete mix design of M20 as per IS10262-2009 the ratio of cement, fine aggregate and coarse aggregate was derived to be 1.0 : 1.43 : 3.10 for a water cement ratio of 0.5 by mass for conventional concrete and a water cement ratio of 0.25 and bacterial culture of 0.25 for bacterial concrete by mass.

Samples were prepared in sets of three in a standard cube mould of 15x15x15 cm (Fig. 2a, b, c, d, e & f). The cement concrete cubes were demoulded after 24 h and placed in water for curing process. After removal from water, the surfaced of the cubes were completely dried prior to tests like physical properties, compressive strength bacterial temperature tests and SEM examination.

*G. Preparation of Bacillus subtilis for Bacterial Concrete*

B. subtilis strain 121 was subcultured in Nutrient broth medium and grown at 30$^{o}$ C in shaker for 24 h to reach a late exponential stage (Fig. 1b & c). Absorbance of the cell suspension was measured at 600 nm using spectrophotometer. The cell concentration was determined according to the equation:

$Y = 8.59 \times 10^{7} X^{1.3627}$

where X = reading at OD 600; and

Y = Concentration of bacterial cells per ml.

Fig. 1 Weighted medium

Fig. 2 Prepared 250ml medium

Fig. 3 Petri-dish making

Fig. 4 Cultured Bacterial Sample

## III. RESULTS AND DISCUSSION

*A. Physical Properties of Pozzolano Portland Cement (PPC)*

The physical properties of PPC is presented in Table-1. The compressive strength on 28th day is 43 N/mm2 and the final setting time is 600 min, with the standard consistency of 29% at 3.15 specific gravity.

TABLE- 1
PHYSICAL PROPERTIES OF POZZOLANO PORTLAND CEMENT (PPC)

| Properties | Values |
|---|---|
| 3 day compressive strength<br>7 day compressive strength<br>28 day compressive strength | 27N/mm$^2$<br>35N/mm$^2$<br>43N/mm$^2$ |
| Fineness | 5% |
| Initial setting time<br>Final setting time | 30min<br>600 min |
| Standard consistency | 29% |
| Specific gravity | 3.15 |

*B. Physical Properties of Fine Aggregate*

Table-2 illustrates the physical properties of fine aggregate taken for this case, the fineness modulus 3.225 passing through 4.75 mm with 1% water absorption. The maximum percentage of bulking is 22.8 at 2.54 specific gravity.

TABLE- 2
PHYSICAL PROPERTIES OF FINE AGGREGATE

| Properties | Values |
|---|---|
| Size<br>Fineness Modulus<br>Water Absorption | Passing through 4.75mm<br>3.225<br>1.0% |
| Bulking of Sand<br>Max % of bulking<br>Corresponding water content for max % of bulking | <br>22.8%<br><br>4.0% |
| Specific gravity | 2.54 |

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*C. Physical Properties of Coarse Aggregate*

The physical properties of coarse aggregate taken for this study is presented in Table-3. The fineness modulus is 7.3 with 0.5% water absorption at 2.6 specific gravity.

TABLE- 3
PHYSICAL PROPERTIES OF COARSE AGGREGATE

| Properties | Values |
|---|---|
| Size | 20mm |
| Fineness Modulus | 7.3 |
| Water Absorption | 0.5% |
| Specific gravity | 2.6 |

*D. Compressive Strength*

The cubes were tested in saturated condition after wiping out the surface moisture from bacterial concrete. Cubes were tested by Non-Destructive Testing (NDT) (using Rebound Hammer) and HEICO compression testing machine as per IS: 516-1959 on the 3rd, 7th and 28th days after casting. The tests were carried out at an uniform stress after the cubes has been centered in the testing machine. Loading was continued till the dial gauge needle just reverses its direction of motion. The reversal in the direction of motion of the needle indicates that the specimen has failed. The compressive strength is calculated as per the formula and presented in Table-4.

$$\text{Compressive Strength} = \frac{Load}{Area} \quad \text{N/mm}^2$$

TABLE- 4
COMPRESSIVE STRENGTH OF BACTERIA CONCRETE

| | **3$^{rd}$ day** | **7$^{th}$ day** | **28$^{th}$ day** |
|---|---|---|---|
| Conventional Concrete | 9.10 | 18.50 | 27.88 |
| Bacterial Concrete | 9.70 | 19.0 | 29.13 |

The improvement in compressive strength by B. subtilis strain 121 is probably due to deposition of Calcite ($CaCO_3$) in cement-sand matrix of microbial concrete which remediate the pore structure within the mortar, these results are in accordance with the related investigations by Ramakrishnan et al. (1998), Ramachandran et al. (2001), Ghosh et al. (2005) and Achal et al. (2009).

Fig. 5 Mixing the Ingredients

Fig. 6 Fresh Concrete Cube

*E. Temperature Sustainability Test of Bacteria*

The temperature sustainability test of B. subtilis in bacterial concrete was carried out at various temperatures and the results are tabulated in Table-5. The results revealed that B. subtilis was found to be alive at –3$^o$ C low temperature to 70$^o$ C high temperature.

TABLE- 5
B.SUBTILIS BACTERIA TEMPERATURE SUSTAINABILITY TEST

| Temperature | Bacteria alive condition |
|---|---|
| -3 $^o$C | Alive |
| 10$^o$ C | Alive |
| 20$^o$ C | Alive |
| 30$^o$ C | Alive |
| 40$^o$ C | Alive |
| 50 $^o$ C | Alive |
| 60$^o$ C | Alive |
| 70 $^o$ C | Alive |
| 80$^o$ C | Alive |
| 90$^o$ C | Dead |

*F. SEM Examination*

To determine whether there is increase in compressive strength of the bacterial concrete with B. subtilis bacteria with microbial calcite precipitation in the crack sample was examined in SEM (Fig. 3a, b & c). The sample showed the presence of calcite crystals grown all over the surface of the crack and also the presence of B. subtilis bacteria is the evidence, that suggests microbial remediation properties of bacterial concrete.

The hydrolysis of urea was selected as a very suitable pathway for the production of carbonate ions due to its ability to alkalinize the environment. Stocks-Fischer et al.

(1999) showed that microorganisms directly participated in the calcite precipitation by providing a nucleation site and by creating an alkaline environment which favoured the precipitation of calcite. Bachmeier et al. (2002) investigated the precipitation of calcium carbonate with the urease enzyme. DeBelie and DeMuynck (2008) investigated the use of microbiology induced carbonate precipitation for the repair of cracks in concrete. These results are supporting evidences of microbial calcite precipitation by B. subtilis used in this work.


Fig. 7 Concrete piece for SEM analysis

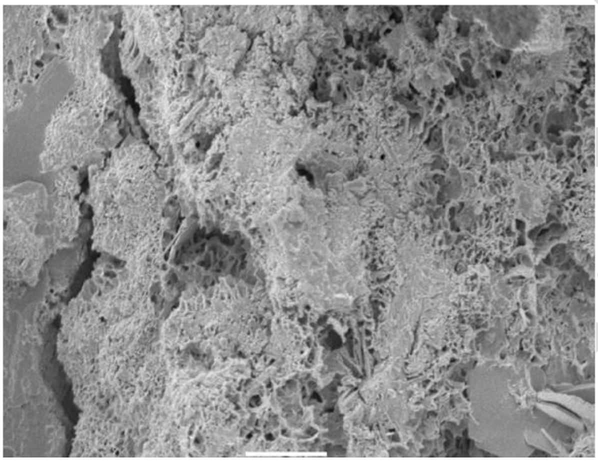

Fig. 8 for conventional concrete shows that more voids in micro structures

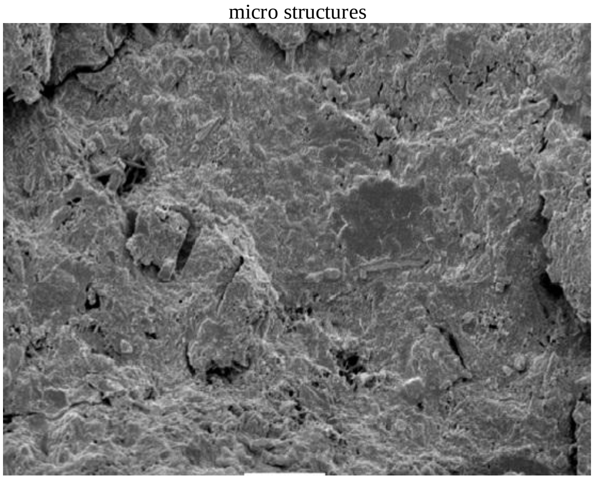

Fig. 9 SEM for bio concrete shows that more dense in micro structures as compare to conventional concrete, which implies that it enhance strength to the concrete.

## IV. CONCLUSION

The significance of this research is that calcite precipitation by B. subtilis is effective in crack remediation. The use of microorganisms, which are found common in soil, in crack remediation of concrete. In addition, this new bacterial concrete concept of calcite formation of microbes is not only environmentally safe but also cost effective. The development of bacterial concrete will provide the basis for an alternative and high quality concrete sealant ultimately lead to enhancement in the durability of building materials.

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