Improvement of Concrete Strength by Bacterial Mineral Precipitation

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Abstract **-** The objective of the present investigation is to obtain the influence of facultative bacteria *(Bacillus Cereus)* on the strength of concrete made with and without bacteria. Three different cell concentrations (10^2,10^7, 10^{10} cells/ml) of bacteria are used in making the concrete mixes. In making concrete, one control specimen is prepared and three more mixes are also prepared by voluntarily replacing of 10, 20 and 30 litres of bacterial nutrient medium with water. Split Tensile strength test is performed at the age of 7, 14 and 28 days. Test results indicate that inclusion of *Bacillus Cereus* in concrete enhances the compressive strength. Maximum 25.64% increase in compressive strength is observed with 10^7 cells/ml of bacteria. The improvement in strength takes place due to microbiologically induced calcite precipitation (MICP). MICP is a layer of highly impermeable calcite deposition on the surface of already existing concrete layer. The effect of MICP is quantified by X-Ray Diffraction (XRD) analysis and visualized by Scanning Electron Microscopy (SEM).

Index Terms **-** Bacillus Cereus, Split Tensile Strength, SEM, XRD.

1. INTRODUCTION

Dam is the structure built across a river or stream to retain water. Now-a-days multipurpose dams are constructed to serve purposes like flood control, supply of water for day to day use, for generation of hydroelectric power, for irrigation purpose, for supply to industry and for recreational activities. Dams can be classified into different categories depending on the type of building materials used. Rigid building materials like masonry, concrete, timber, steel are used for constructing rigid dams where as earth and rock-fill are used for constructing non-rigid dams. In this paper we are going to discuss about concrete dams. Concrete is one of the most durable and long lasting products used in our construction industry. But it is a well known fact that concrete is susceptible to crack. Crack is the separation of portion of a structure into one or more parts. Crack can be categorized into different groups depending on the reasons like structural crack, shrinkage crack and thermal crack. Structural cracking occurs due to poor soil bearing capacity and overloading of structure. Shrinkage crack in concrete occurs due to change in moisture of concrete. Concrete is porous in its structure in the form of inter-molecular space. It expands when it absorbs moisture and shrinks when it dries. This is the main cause of concrete shrinkage crack. Temperature difference within a concrete structure may be caused by portions of the structure losing heat of hydration at different rates or by the weather conditions. Cooling or heating one portion of the structure to a different degree or at a different rate than another portion of the structure leads to thermal crack. Crack enables the entry of foreign materials like chemicals or water to the structure, which further tends to degrade the quality and performance of concrete structure. Nowadays a new technology is used to improve the strength and durability of concrete by self healing process. Self healing can be done by number of ways, out of which bio based healing is one of them. In this process some specific species of bacteria are inserted into the structure during the construction stage. The bacteria in concrete can remain in dormant condition for hundreds of years. When crack occurs, it leads to the entry of foreign agencies like water and oxygen from atmosphere to the structure. After coming in contact with foreign agencies, bacteria become active and react with calcium present in cement composition producing calcium carbonate ($CaCO_3$). This microbiologically induced calcite precipitation (MICP) produces a layer of highly impermeable calcite deposition on the surface of already existing concrete layer that tends to seal the crack.

2. EXPERIMENTAL PROGRAM

2.1 Properties of Bacteria (*Bacillus Cereus*)

For this experiment, bacteria named Bacillus Cereus were collected from the Microbial Type Culture Collection and Gene Bank (MTCC) Chandigarh. Characteristics of bacteria are shown in **Table 1**.

Table 1: Detail description of *Bacillus Cereus*

MTCC No	430
Name of Bacteria	*Bacillus Cereus*
Genus	Bacillus
Species	Cereus
Amount Ordered	1 Culture
Growth Medium	3
Temperature	30ºC
Incubation Time	24 hour
Subculture	30 Day
Special Feature	Assay of chlortetracycline, oxytetracycline and tetracycline
Gram Strain	Positive
Shape	Rod
Oxygen Demand	Facultative

2.2 Properties of Ordinary Portland Cement

Ordinary Portland Cement of 43 grade was used in concrete. It was tested as per Indian Specifications IS: 8112-1989 and the results are shown in **Table 2**.

Table 2: Physical properties of Cement

Characteristics		**Values Obtained Experimentally**
Normal Consistency		32.50%
Fineness		340 m^2/kg
Initial Setting time		121 minute
Final Setting time		410 minute
Specific Gravity		3.15
Compressive Strength	3 days	30 MPa
	7 days	43 MPa
	28 days	51 MPa

2.3 Properties of Fine Aggregates and Coarse Aggregates

Natural sand with 4.75 mm maximum size was used as fine aggregate. Sand was supplied from River Kuakhai for the experiment. For coarse aggregates, crushed stone with maximum 12.5 mm graded aggregates (nominal size) was used. **Table 3** summarizes the test result of fine aggregates and coarse aggregates as per IS: 383-1970.

Table 3: Physical properties of Fine aggregate & Coarse aggregate

Characteristics	**Value obtained experimentally as per IS:383-1970**	
	Fine Aggregate	**Coarse Aggregate**
Size of the aggregate	---	20 mm
Type of aggregate	---	Angular Coarse Aggregate
Specific Gravity	2.68	2.77
Water Absorption	0.8	0.22
Impact Value	---	29.63%
Abrasion Value	---	47.46%
Flakiness Indices	---	21.18%
Fineness Modulus	2.76 (Zone 2)	6.93
Crushing Value	---	24.50%

2.4 Concrete Mix Proportions

Concrete mixtures were designed as per IS: 10262-1982 with and without using bacteria. **Table 4** shows the detail of mix proportion with water cement ratio used in this experiment.

Table 4: Detail of design mix

Ordinary Portland Cement	Cement (Kg/m^3)	Sand (Kg/m^3)	Aggregate (Kg/m^3)	Water (litre)
Mix Proportion 1:1.535:2.746 & Water Cement Ratio 0.43	432.5	664	1186	186

2.5 Preparation of Test Specimens

Concrete cylinder of size 300×150 mm were prepared with different concentrations of bacterial cells (*Bacillus Cereus*). All experiments were performed in triplicates. Specimen properties were determined at the age of 7, 14 and 28 days.

2.6 SEM of Concrete Samples

SEM is an electron microscope producing images of a sample by scanning it with the help of a focused beam which contains electrons. The atoms present in the surface of sample react with electrons and produce different signals which contain information about the composition of sample. Sample of size 1cm×1cm×1mm were prepared from the main sample. The samples were gold coated. The electron beam has a tendency to scan the sample surface, then with the help of detected signal of beam produce image. It can achieve resolution less than 1 nanometre.

2.7 XRD of Concrete Samples

XRD is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material was finely ground, homogenized, and average bulk composition was determined. By using this technique, identification of foreign phases for purity analysis of crystalline powders was done. In XRD analysis, a focused X-ray beam is shot at the sample at a specific angle of Incidence. The X-ray deflects in various ways depending on the crystal structure of the sample. For typical powder patterns, data is collected at 2θ from ~5° to 70° angles that are preset in the X-ray scan.

3. RESULT AND DISCUSSION

The strength of control concrete was calculated after 7, 14 and 28 days of curing. Then by volumetric replacement of water with bacterial nutrient medium three different mixes were prepared with different cell concentrations. Split Tensile strength test was conducted as per BIS: 5816-1970.

The comparison between Control concrete and bacterial concrete is observed in the **Figure 1**. Here three different cell concentrations of bacteria are used, by volumetric replacement of bacterial nutrient medium with water. For cylindrical specimen overly there is an increase in strength as compare to control specimen in all three cases. For MC1 mix BN30, MC2 mix BN20 & MC3 mix BN10 gives good strength as compare to other two nutrient medium. By comparing overall result we can say that MC2BN20 gives best result. With increase in curing period the increase in strength is uniform for all specimens but in case of MC2BN20 after 14 days of curing there is sudden rise in strength takes place. MC3BN30 which has the higher cell concentration with highest replacement gives the least strength for cylindrical specimen. The compressive strength of concrete cubes prepared without and with bacteria is summarized in **Table 5**.

Results of SEM and XRD analysis done on broken samples of without and with bacterial specimen having highest strength i.e. MC3BN10 are shown in **Figure 2** and **Figure 3** respectively.

Table 5: Effect of addition of *Bacillus Cereus* on Split Tensile Strength

Mix Identification	7 Days		14 Days		28 Days	
	Average Split Tensile Strength (Mpa)	% Change in Split Tensile wrt Control Specimen	Average Split Tensile Strength (Mpa)	% Change in Split Tensile Strength wrt Control Specimen	Average Split Tensile Strength (Mpa)	% Change in Split Tensile Strength wrt Control Specimen
MC0BN0	3.00	0	3.50	0	3.90	0
MC1BN10	3.20	6.67	3.65	4.28	4.10	5.12
MC1BN20	3.45	15.0	3.95	12.85	4.35	11.53
MC1BN30	3.90	30.0	4.35	24.28	4.75	21.79
MC2BN10	3.55	18.33	3.80	8.57	4.30	10.25
MC2BN20	3.65	21.67	3.90	11.42	4.90	25.64
MC2BN30	4.00	33.33	4.25	21.42	4.60	17.94
MC3BN10	4.45	48.33	4.50	28.57	4.70	20.51
MC3BN20	4.05	35.0	4.15	18.57	4.25	8.97
MC3BN30	3.60	20.0	3.85	10.00	4.10	5.12

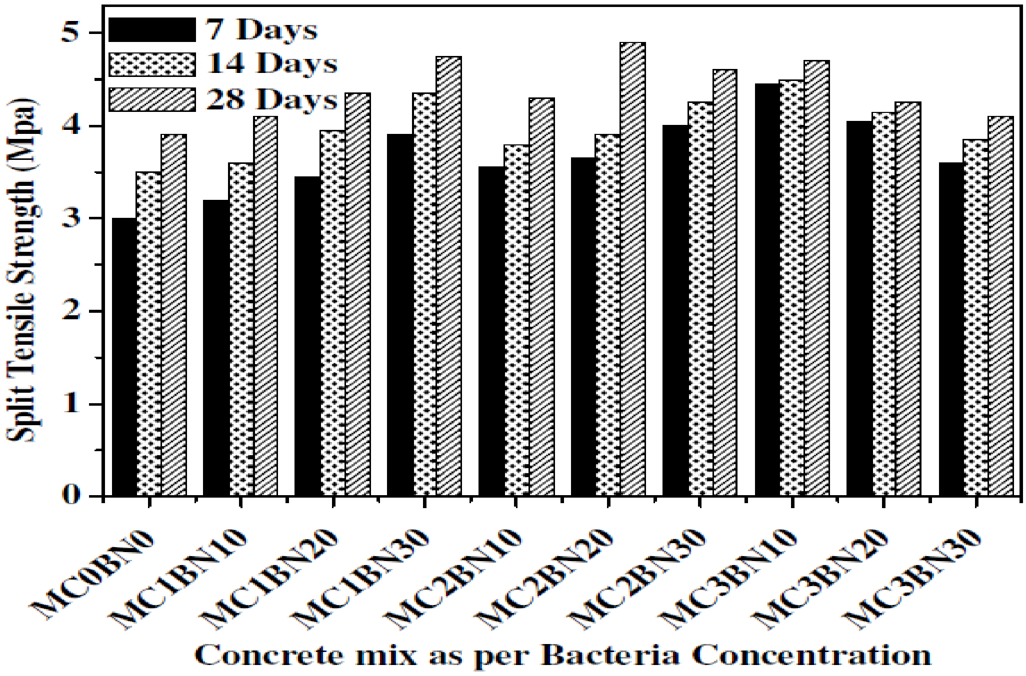
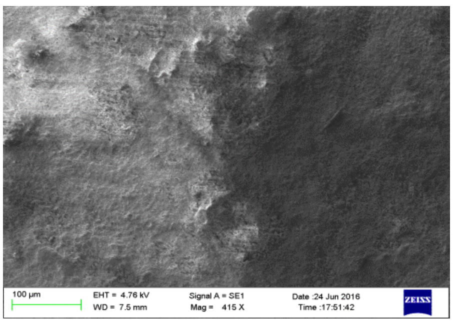
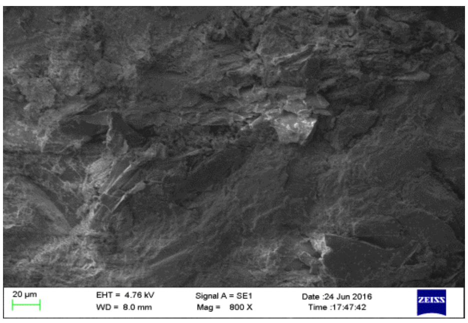


Figure 1 Comparison for split tensile strength between control and bacteria based concrete



Control Sample



Cell Concentration 10^7 cells/ml

Figure 2 SEM of concrete samples without bacteria and with bacteria

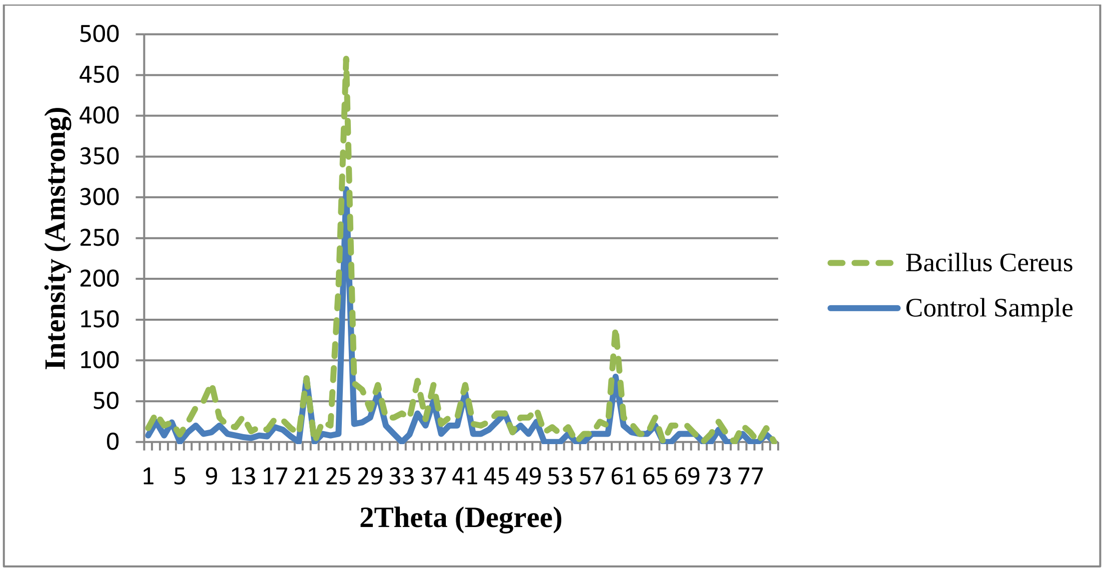


Figure 3 XRD of concrete samples without and with bacteria

4. CONCLUSION

- *Bacillus Cereus* plays a significant role in increasing the compressive strength of concrete by up to 25.64% at the age of 28 days.
- The increase in strength is mainly due to the development of calcite precipitation which tends to fill the pores inside the concrete specimen.
- Highest increase in strength was reported for bacteria with cell concentration of 10^7 cells/ml, so we can assume that higher the cell concentration higher will be the strength.
- But as 20 litres volumetric replacement of bacterial nutrient medium gives better result compared to 30 litres, it can concluded that after reaching a certain level, the strength remains constant and does not increase with increase in bacterial medium.
- As bacteria can live hundreds of years and has an ability of self healing so we can this technique in under water construction can be effectively implemented to decrease the chances of future collapse.

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