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A Experimental Study On Strength Characteristics Of Bacterial Concrete

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ABSTRACT

One effective remedy for closure of cracks is the Bacterial Concrete (BC) which will continuously deposit calcite in concrete. This, phenomenon is called as Microbiologically Induced Calcite Precipitation (MICP). The urease enzyme enables the deposition of calcium carbonate (CaCO3) with the help of bacteria. The bacterial remediation technique surpasses other techniques as it is bio-based, eco-friendly and durable. Bacteria need to offer resistance to withstand high pH of concrete and mechanical stresses during mixing. In this paper, investigations are also carried out on durability-related properties such as saturated water absorption, porosity, sorptivity, permeability, acid resistance, sea water resistance, impact strength, rapid chloride penetration, corrosion resistance and alkalinity measurement of M20 grade of Bacterial concrete trial mixes. The results of the investigations demonstrate the superior durability characteristics of bacterial concrete. Based on the results obtained, it is understood that due to the inclusion of bacteria in concrete the durability of concrete can be enhanced. That is, bacteria can effectively be used to repair cracks. It is concluded that BM, BS and PA bacteria can safely be used for improving the performance of strength and durability characteristics of concrete. However, all the three bacteria increase the strength of concrete to a certain level only. BM bacteria is found to be more effective than BS and PA in strength and durability properties. The details of the investigations along with the results are presented.

Key words : Bacterial Concrete ; calcium carbonate; water absorption; porosity.

INTRODUCTION:

The “Bacterial Concrete” is prepared by adding bacteria in the concrete which can constantly precipitate calcite. This process is called Microbiologically Induced Calcite Precipitation (MICP). It helps in enriching strength and durability by filling up voids present in the concrete structure. The Microbiologically Induced Calcite Precipitation (bio deposition) involves various microorganisms, pathways and environments. MICP can be utilized as an effective alternative repair technique for plugging of micro- cracks and pores in concrete. This bacterial remediation technique surpasses other techniques as it is bio based, eco-friendly, cost effective and durable. Urease positive bacteria have been found to deposit calcium carbonate (calcite) with the help of urease enzyme. The increase of pH value and calcite precipitation are obtained by the enzyme, due to hydrolysis of urea to CO_2 and ammonia. Precipitation of calciumcarbonate ($CaCO_3$) crystals occurs by heterogeneous nucleation on bacterial cell walls once supersaturation is achieved. With the calcite precipitation in concrete by the bacteria, the formation and propagation of cracks can be reduced and a concrete with dense microstructure can be obtained. Under favourable conditions, calcite formation due to the activation of bacteria and concrete which is insoluble in water. As a result, more durable structural concrete, with reduced maintenance cost can be produced.

Hammes *et al.* (2003) reported that crystal morphology which was obtained with different bacterial culture could be due to the level of the actual urease activity. Braissant *et al.* (2003) analyzed that morphological effect on concrete by the calcium carbonate precipitation. Liang *et al.* (2004) observed that the morphology of precipitated $CaCO_3$ crystals changed from regular rhombohedral to irregular rhombohedral, then to spherical and finally to peanut-like shape. Bottcher *et al.* (2004) studied that the influence of calcium source is limited to the morphology of the crystals. Whiffin (2004) studied that considering both biocementation and environmental constraints, two organisms have potential as sources of urease for biocementation namely *Sporosarcina pasteurii* and *Proteus vulgaris*. Nemati *et al.* (2005) studied that the production of $CaCO_3$ in the media containing urea and calcium chloride can be induced using bacteria with urease activity. Dick *et al.* (2006) reported that ureolytic bacteria is responsible for carbonate precipitation in concrete. Ercole *et al.* (2007) observed that the amino acids play an essential role in the morphology and mineralogy of bacterially induced carbonate precipitation. Muynck *et al.* (2008) explained by the method of application that there are morphological differences between treatments with pure culture *Bacillus sphaericus* (*B. Sphaericus*) and mixed ureoltic cultures. Wiktior and Jonkers (2011) observed that the change of calcium salt used in bio deposition result in modification of morphology of precipitated $CaCO_3$.

Ramakrishnan *et al.* (2005) reported that Bacillus Pasteruii, is inducing calcite precipitation in the concrete under different environments. Durability aspects on various proportions of concrete also were studied and compared with control beams. X - ray diffraction analysis was used to quantify microbial precipitation. Visualization of cracks was done by SEM. SEM exhibited the calcite precipitation, bacterial impressions and calcite layer. Krishnapriya *et al.* (2015) carried out experimental work to assess the influence of three bacteria namely Bacillus Megaterium, Bacillus Licheniformis and Bacillus Flexus on the compressive strength. The test reported that compressive strength of specimens remarkably increased and cracks were healed completely. SEM visualizes enhancement of strength and healing of cracks in concrete. Mian Luo *et al.* (2015) developed bacteria-based self-healing concrete by adding the microbial self-healing agent which has the potential to improve self-healing capacity mainly by bacteria induced mineral precipitations. The Scanning Electron Microscope (SEM) is used to expose the cracks and voids. The results showed that the microbial self-healing agent could be used to achieve the goal of concrete crack self-healing. The precipitations formed at the cracked surface were calcite. The crack was more and more difficult to be repaired with the increase of average crack width and the repairability of microbial repair agent was limited for specimens with crack width up to 0.8 mm. Water curing was indicated as the feasible solution. When the cracking age was more than 60 days, the crack healing ratio was very small.

2.0 MATERIALS:

The ingredients used for this investigation are the same as those used for normal strength concrete such as cement, Fine Aggregate (FA), Coarse Aggregate (CA) and water except bacteria which is generally not used in conventional concrete. The performance requirements of concrete may involve enhancement of the following properties.

Table 1 Chemical and Physical Properties of 53 grade OPC

Component	Results (%)	Requirements of IS : 12269-2013
Chemical properties		
SiO2	21.8	-
Al2O3	4.8	-
Fe2O3	3.8	-
CaO	63.3	-
SO3	2.2	-
MgO	0.9	-
Na2O	0.21	-
K2O	0.46	-
Cl	0.04	Maximum 0.1
P2O5	< 0.04	-
Loss of ignition	2.0	Maximum 4
Insoluble residue	0.4	Maximum 3
Physical properties		
Fineness, m^2/ kg	320	Minimum 225
Initial setting time, minutes	35	Minimum 30
Final setting time, minutes	430	Maximum 600
Standard consistency, %	27	-
Soundness, Le chatelier , mm	1.0	Maximum 10
Heat of hydration , kj/ kg	266 @ 7days	-
Compressive strength, MPa 3-days 7-days 28-days	37.5 48.0 62.0	Minimum 27 Minimum 37 Minimum 53
Specific gravity	3.15	-

2.1 BACTERIA

Bacillus Megaterium (BM), Bacillus Subtilis (BS) and Pseudomonas Aeruginosa (PA) were found to thrive in this high-alkaline environment under conditions of high pH value up to 13 of the cement-water mixer.Based on the above criteria, the bacteria used in this study are Bacillus megaterium, Bacillus subtilis and Pseudomonas aeruginosa in three concentrations of 10^4, 10^5 and 10^6 cells/ml each of mixing water. The bacterial cultures were obtained from the Department of Microbial Biotechnology, Bharathiar University, Coimbatore. They were suspended in a nutrient broth solution consisting of peptone, NaCl and beef extract. The obtained bacterial cultures were refrigerated until further use.

3.0 RESULTS AND DISCUSSION :

For cube compression testing of concrete, 150 mm x 150 mm x 150 mm size cubes were used. All the cubes were tested in saturated condition, after wiping out the surface moisture. For each mix combination, three cubes were tested at the age of 7 days, 14 days, 28 days, 56 days and 90 days of curing using compression testing machine as per IS : 516-1959.

Fig no 1: Compressive testing equipment

This is an indirect test to determine the tensile strength of cylindrical specimens. Splitting tensile strength tests were carried out on cylindrical specimens of size 150 mm diameter and 300 mm length at the age of 7 days and 28 days curing, using compression testing machine as per IS : 5816 - 1999. To avoid the direct load on the specimen, the cylindrical specimens were kept below the wooden strips. The load was applied gradually till the specimens split and readings were noted. The test set up for the splitting tensile strength on the cylinder specimen, with the wooden strips to avoid the direct load on the specimen and patterns of typical splitting tensile failure mode shapes of bacterial concrete cylinder specimens are shown in Figurre 2.

Fig no 2: Split tensile equipment

3.1 Workability of Concrete

The workability of concrete is mainly influenced by the water requirements at the time of mixing. For conventional concrete, it is decided mainly on the basis of the maximum size of aggregate used. When bacteria are added to concrete, it influences no demand of excess water. It is generally reported that the bacterial concrete requires less water demand of the concrete mix as compared with concrete mix having the same degree of workability.
The test results of workability of this present investigation are presented in Table 6.1.

Table 3 Workability of M20 grade bacterial concrete mixes

Mix designation	Type of bacteria	Cell concentration (cells / ml)	Workability in terms of		
			Slump in 'mm'	Compaction factor	Vee - bee degrees in sec
CS	Control Specimen	-	90	0.93	9
BM1	Bacillus Megaterium	10^4	93	0.94	8.8
BM2		10^5	97	0.94	8.5
BM3		10^6	101	0.95	7
BS1	Bacillus Subtilis	10^4	92	0.95	7
BS2		10^5	98	0.94	7
BS3		10^6	97	0.94	7
PA1	Pseudomonas Aeruginosa	10^4	97	0.94	7
PA2		10^5	102	0.94	7
PA3		10^6	102	0.94	7

Table 6.3 Cube compressive strength development of M20 grade bacterial concrete mixes

Mix designation	Type of bacteria	Cell concentration (cells / ml)	7 days	14 days	28 days	56 days
CS	Control Specimen	-	67.10	84.92	98	102.90
BM1	Bacillus Megaterium	10^4	62.31	84.98	97	103.90
BM2		10^5	61.17	85.91	99	103.66
BM3		10^6	61.98	86.33	96	103.62
BS1	Bacillus Subtilis	10^4	62.06	87.01	99	103.10
BS2		10^5	66.59	81.77	95	101.28
BS3		10^6	67.20	82.00	95	101.35
PA1	Pseudomonas Aeruginosa	10^4	66.92	82.08	98	102.24
PA2		10^5	66.70	82.05	98	103.81
PA3		10^6	67.18	82.05	99	104.14

SEM analysis

The comparison between fracture surface of control concrete and bacterial concrete composites can be understood by inspecting or studying the respective structural morphology at very high magnification level. The scanning electron micrograph of control concrete specimen indicates the presence of limited individual crystals or no signs of CaCO3 crystals. The scanning electron micrograph of bacterial concrete specimen (BMI) showed the presence of large amount of individual crystalline calcium carbonates with bacteria. The scanning electron micrographs of bacterial concrete specimens (BS2 & PA2) also showed the presence of crystalline CaCO3 with bacterial but slightly less amount comparing with BMI specimen. It is evident from the micrograph that pores are partially filled up by material growth with the addition of the bacteria. Reduction in pores due to such material growth will obviously increase the material strength and makes the concrete more and more durable. Also, it is due to calcite crystalline structures found inside the pores of the mortar with addition of bacteria. The spherical crystals of CaCO3 crystals are known as calcites. The microbiologically produced calcite is responsible for filling up the pores in cement composites and hence increasing the strength and durability characteristics.

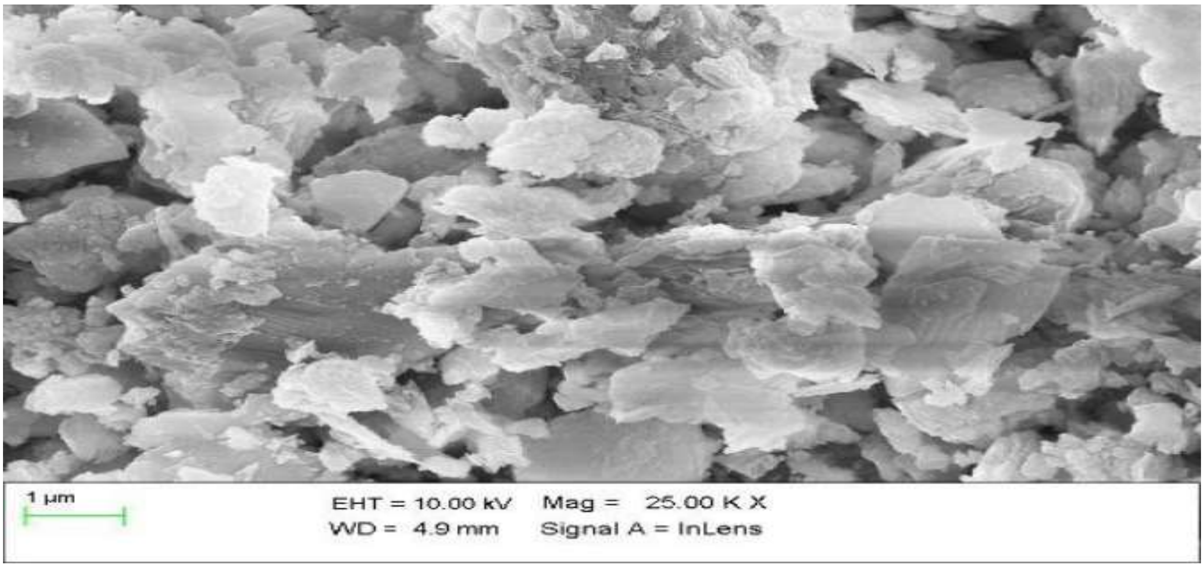

Figure 3 SEM image of fracture surface of bacterial concrete

Energy Dispersive X – Ray Analysis

The ratio of Ca / C-S-H in CS is only 0.69. The ratio of Ca / C-S-H in the bacterial concrete specimens BM1, BS2 and PA2 were found to be 0.81,
0.74 and 0.78 respectively which are more than that the control concrete specimen. This confirms the presence of high amounts of calcite and C-S-H gels in bacterial concrete specimens when compared to the control concrete specimens and this is the reason for the increased strength and durability characteristic of bacterial concrete specimens.

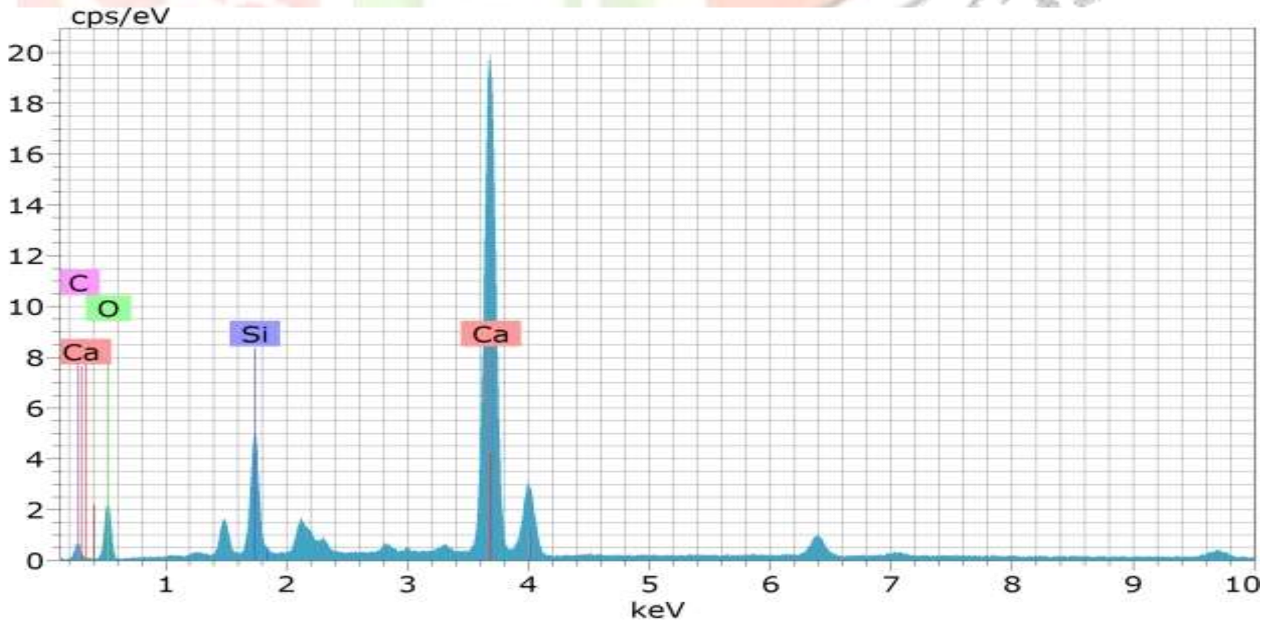

Figure no 4 : Energy dispersive X-ray spectrum of Bacterial Concrete

CONCLUSIONS:

Based on the experimental investigations carried out on the strength and micro structural characteristics of bacterial concrete mixes, the following conclusions are arrived at:

- At the ages of 7, 14, 28, 56 days, the compressive strengths of bacterial concrete mixes were more than those of concrete mix without bacteria. This indicates that addition of bacteria into concrete causes an increase in compressive strength.

- The bacterial concrete mixes showed higher values of cube compressive strength than control concrete mix. The increase in compressive strength was mainly due to plugging of the pores inside the bacterial concrete induced by calcium carbonate (calcite) precipitation.

- The 7 - day compressive strength of the bacterial concrete mixes was 65 to 67 percent of 28 days compressive strength. This indicates that addition of bacteria does not cause early strength.

- The SEM analysis of bacterial concrete specimens revealed distinct calcite crystals embedded in concrete. High calcium amounts in it confirmed that calcite was present in the form of CaCO3 due to bacteria. The deposition of calcite serves as barrier to harmful substance and thus improves impermeability.