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Bacterial Concrete: Development of Concrete to Increase the Compressive and Split-Tensile Strength using *Bacillus sphaericus*

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Abstract

Objective: Microbial induced calcium carbonate precipitation is a novel method for increasing the physical strength of the cement concrete. The objective of the present investigation is to study the potential application of bacteria, *Bacillus sphaericus* to improve the compressive and split-tensile strength of cement concrete after comparing with conventional concrete.
Methodology: Conventional and bacterial concrete was prepared and its strength was evaluated using standard Indian Specifications.
Result and Discussion: A significant increase of 30.84% and 31.11% compressive strength and 3.32N/mm^2 and 3.45N/mm^2 of split-tensile strength was observed for respective B1 and B2 cell concentrations after 28 days of bio-curing. The obtained results revealed that bacterial concreted showed more strength than the conventional concrete. Water which enters the concrete will activate the dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation.
Conclusion: The present study concludes that bacteria will not negatively affect the compressive and split tensile strength of the cement concrete.

Keywords: Bacterial concrete, Compressive strength, Split-tensile strength, *Bacillus sphaericus*, Calcium carbonate precipitation.

Introduction

Concrete is considered as one of the most important building materials around the world in the construction sector (Maheswaran et al., 2014), but the cracks in concrete create problem. Cracks in concrete occur due to various mechanisms such as shrinkage, freeze-thaw reactions and mechanical compressive and tensile forces (Gavimath et al., 2012). Repair of cracks in concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Repairs can be particularly be time consuming and expensive because it is often very difficult to gain access to the structure to make repairs. For crack repair, a variety of techniques is available but traditional repair systems have a number of disadvantageous aspects such as different thermal expansion coefficient compared to concrete and also have impact on environment and health (Seshagiri Rao et al., 2013). Gollapudi *et al.* (1995) introduced the novel technique in fixing cracks employing environment-friendly biological processes. It was found that fracture sites acted as new nucleation sites for capturing bacterial clusters leading to improved selective plugging as well as mineral precipitation i.e., microbial metabolic activities promote calcium carbonate (calcite) precipitation. This technique is referred as Microbiologically Enhanced Crack Remediation (MECR) (Meldrum, 2003). Previous research has shown that *Bacillus sphaericus* bacteria are able to precipitate calcium carbonate on their cell constituents and in their micro-environment by conversion of urea in to ammonium and carbonate.

The bacterial degradation of urea locally increases the pH and promotes the microbial deposition of calcium carbonate in a calcium rich environment. Through this process, the bacterial cell is coated with a layer of calcium carbonate (Dick et al., 2006). Microbial calcium carbonate precipitation in a cement mortar/concrete is a complex mechanism. Based on continuous research a number of innovations have been made from time to time to improve the strength and durability performance (Mehta 1999) of cement mortar/concrete. Abundant significance of microbially induced calcium carbonate precipitation (MICCP) so called carbonatogenesis has put much awareness from both basic and applied point of view in civil engineering field (Rodriguez-Navarro et al., 2007). The CaCO3 precipitation is a function of ionic strength and pH in the medium. The increase of compressive strength of mortar is due to complex interaction between the bacterium and cement matrix (Stooks-Fischer et al., 1999).

The ultimate aim of the present study is to use a bacterial species in the deposition and/or precipitation of calcite minerals in the cement/concrete matrix so that the newly formed calcites may either remediate the cracks or fill up the pores in the concrete. CaCO3 so produced can be useful as a binding agent and also as a pore-filling medium to improve the strength of concrete. It improves the adhesive property within the concrete matrix, thereby increasing the strength of concrete, and also reduces the capillary pores thereby increasing both the durability and strength of concrete.

Materials and Methods

The cement used for mortar/concrete was 53 grade Ordinary Portland Cement (OPC) conforming to IS: 456-2003. Quarry waste (fineness modulus of crushed sand equal to 3.2) conforming to grading Zone III of IS – 383 – 1970 with the material size of less than 4.75mm was used as fine aggregates. The locally available coarse aggregate with equal proportion of 12.5 and 20 mm size conforming to IS: 383-1970 was used. Potable water has been used for casting concrete specimens. The water is free from oils, acids, and alkalis and has a water-soluble Chloride content of 140 mg/lit. As per IS 456 – 2000, the permissible limit for chloride is 500 mg/lit for reinforced concrete; hence the amount of chloride present is very less than the permissible limit.

Selection and cultivation of calcite producing bacteria

The strain *Bacillus sphaericus*, from Microbial Type Culture Collection centre CSIR–Institute of Microbial Technology (CSIR–IMT), Chandigarh, India. The strain was cultured to check their morphology on nutrient agar (NA), which contained peptic digest of animal tissue 5 g/l, sodium chloride 5 g/l, beef extract 1.5 g/l, yeast extract 1.5 g/l, and agar 15 g/l, and the final pH of the medium was found to be 7.4 ± 0.2 at 25°C. The culturing was done by spreading the stock culture of the bacteria onto the plates and allowing it to be incubated for 24 h at 37°C. The plates with pure culture of *Bacillus sphaericus* was stored at refrigeration temperature and used for further studies.

Potential for spore-formation and calcite production of these strains was tested by cultivation in specific media. Basic medium was composed of 0.2 g NH_4Cl, 0.02 g KH_2PO_4, 0.225 g $CaCl_2$, 0.2 g KCl, 0.2 g $MgCl_2{\cdot}6H_2O$ per liter of Milli-Q ultrapure water. For sporulation (spore-formation) experiments, 50mM $NaHCO_3$, 50mM Na_2CO_3 and 20mMsodium citrate was added to the basic medium. To investigate calcite production potential of these bacteria in liquid media, basic medium was amended with 50mM $NaHCO_3$, 100mM sodium citrate and 25mM $CaCl_2$. The high concentration of sodium citrate in the later medium was needed to inhibit abiotic calcite formation.

Preparation of specimen for compressive and split tensile strength test (Maheswaran et al., 2014)

The cubes and cylinders were prepared for concrete mix with (bacterial concrete) and without (conventional concrete) addition of calcite-producing *Bacillus sphaericus* as per Indian specifications. Thus prepared cubes and cylinders were tested for its compressive and split-tensile strength to differentiate the conventional concrete from the bacterial concrete.

Compressive strength test (Gavimath et al., 2012)

The compression test was used to determine the hardness of cubical and cylindrical specimens of the prepared concrete. The strength of a concrete specimen depends upon cement, aggregate, bond, water-cement ratio, curing temperature, and age and size of specimen. Mix design is the major factor controlling the strength of concrete.

Cubes of size 15cm x 15cm x 15cm (IS: 10086-1982) were casted in the present study. All the specimens were provided with sufficient time for hardening and cured for 3, 7, 14 and 28 days. After the specified period (3, 7, 14 and 28 days) all the specimens were tested for its maximum load in the compression testing machine. Compressive strength of the test specimens were calculated by dividing maximum load by the cross- sectional area.
Compressive Strength (N/mm^2) = Ultimate load / Cross sectional area of specimen

Split-tensile strength test **(**Senthilkumar et al., 2014)
Split- tensile strength is indirect way of finding the tensile strength of concrete by subjecting the concrete cylinders to a compressive force. Cylinders of size 150mm diameter and 300mm long were casted. After 24 hours the specimen were demoulded and subjected to water curing. After 3, 7, 14 and 28 days of curing the cylinders were taken allowed to dry and tested in compression testing machine by placing the specimen horizontal. The tensile strength is calculated from the formula as given below (IS: 5816-1970):

$$\sigma Max = 2P/\Pi DL$$

where, P- is the maximum applied load to the specimen, D- is the diameter of the specimen, L- is the length of the specimen.

Results and Discussion
The cubes and cylinders have been tested as per IS specifications. The compressive strength test and split tensile strength test were carried out both on conventional and bacterial concrete specimens. The conventional and bacterial concrete cube specimens after casting were cured for 28 days in the water bath and were tested in compression testing machine.

Compressive strength test
The compressive strength test results revealed that there is an increase in strength for the bacterial concrete when compared to conventional concrete (Table-1). A significant increase of 30.84% and 31.11% was observed for respective B1 and B2 cell concentrations after 28 days. During 3rd day to 28th day of analysis, it was observed that bacterial concrete showed significant increase in ultimate compressive strength than the conventional concrete. Among the two bacterial concentrations used, the higher concentration of *Bacillus sphaericus* (B2) culture proved to increase the compressive strength of prepared bacterial concrete (Fig-1). The improvement in compressive strength by B1 and B2 could be attributed to bio-mineralization of $CaCO_3$ on the cell surfaces and within the pores of the cement–sand matrix, i.e. pore filling effect within the mortar specimens. Increase in compressive strength after 28days may be due to phosphate buffered saline, which enabled high pH level to

provide good nourishment and buffering action to microbial cells within the cement–sand matrix. Due to the high pH in the cement mortar, the microbial cells were able to grow fast by precipitating calcite, subsequently filling the pores; thereafter there could be pore-filling with calcite resulting in subsequent reduction in porosity (Ghosh, 2001). This enhanced variation in compressive strength confirms the chemically produced urease in the form of $CaCO_3$ precipitation between cement and sand matrixes of the cement mortar specimen by the *Bacillus sphaericus*. Because of persistence of nutrition in bio curing process, the bacterial concrete specimen showed higher compressive strength than conventional concrete specimens **(**Senthilkumar et al., 2014).

Table-1: Compressive strength of conventional and bacterial concrete (N/mm^2)

S. No.	No of days	Compressive strength at first crack (N/mm^2)			Ultimate compressive strength (N/mm^2)		
		CC	**B1**	**B2**	**CC**	**B1**	**B2**
1	3	4.30	6.67	6.72	20.21	29.78	29.84
2	7	6.13	6.28	6.34	23.54	24.11	24.25
3	14	5.78	5.92	6.03	27.16	27.56	27.82
4	28	7.56	7.61	7.87	30.52	30.84	31.11

CC: Conventional concrete, B1: Addition of 10ml of bacterial culture, B2: Addition of 20ml of bacterial culture

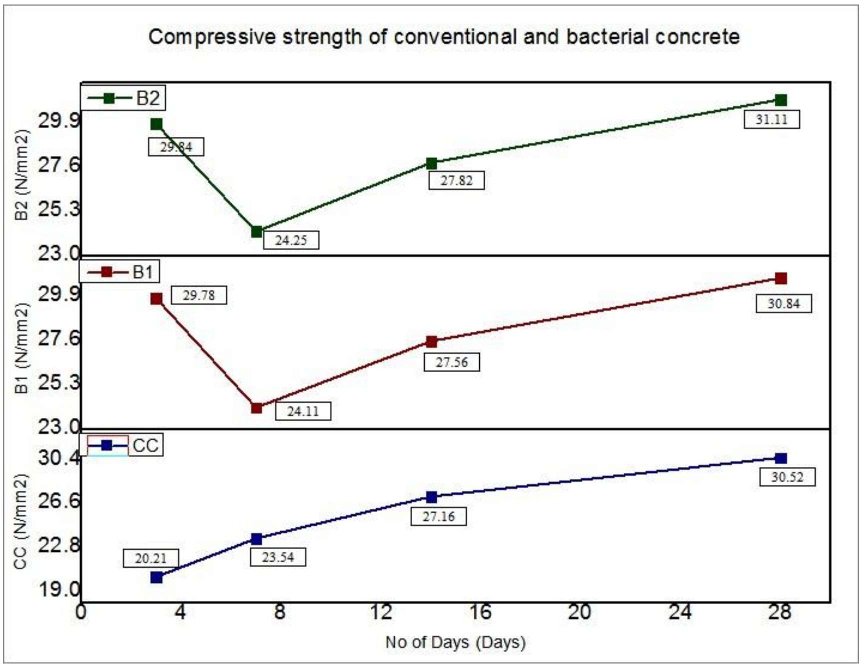

Fig-1: Compressive strength of conventional and bacterial concrete (N/mm^2)
CC: Conventional concrete, B1: Addition of 10ml of bacterial culture, B2: Addition of 20ml of bacterial culture

Split-Tensile strength test

The bacterial culture treated concrete specimens, B1 and B2 are tested and split-tensile strength is given in Table-2. It can be observed that the split-tensile strength is increasing in the bio cured concrete than the conventional concrete specimens. A significant increase of 3.32N/mm^2 and 3.45N/mm^2 was observed for respective B1 and B2 cell concentrations after 28 days. From 3rd day to 28th day like compressive strength, split-tensile strength also increased for bacterial concrete specimens when compared to conventional concrete specimens. Among the two bacterial concentrations used, the higher concentration of *Bacillus sphaericus* (B2) culture proved to increase the tensile strength of prepared bacterial concrete (Fig-2). The significant activity of bacterial culture in B1 and B2 concrete specimens, biochemically induced calcium carbonate precipitation between cement sand matrix, which in turn increased the load resisting capacity.

Table-2: Split-Tensile strength of conventional and bacterial concrete (N/mm^2)

S. No.	No of days	Ultimate tensile strength (N/mm^2)		
		CC	B1	B2
1	3	1.70	1.81	1.86
2	7	2.09	2.12	2.24
3	14	2.12	2.18	2.26
4	28	3.26	3.32	3.45

CC: Conventional concrete, B1: Addition of 10ml of bacterial culture, B2: Addition of 20ml of bacterial culture

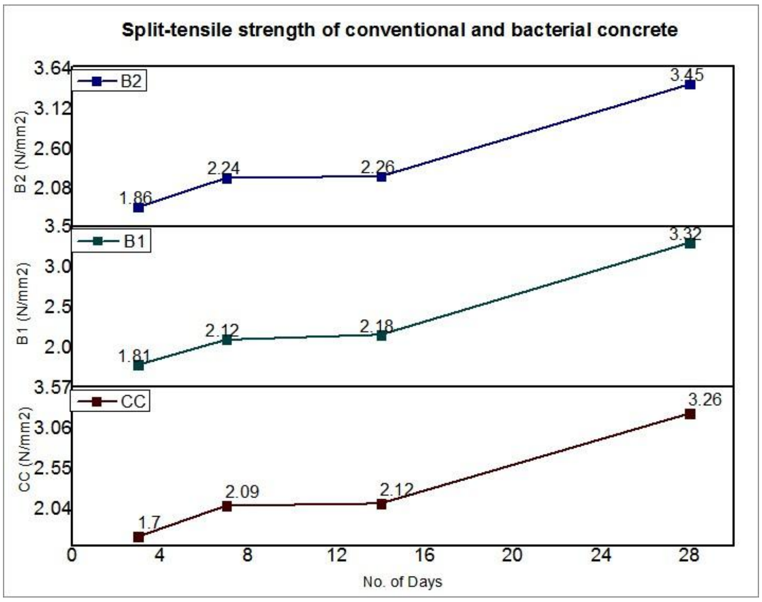

Fig-2: Split-Tensile strength of conventional and bacterial concrete (N/mm^2)

CC: Conventional concrete, B1: Addition of 10ml of bacterial culture, B2: Addition of 20ml of bacterial culture

Conclusion

In this study, the ability of bacterial cultures that act as a potential agent in increasing the compressive and split tensile strength in concrete was investigated. Bacterial cultures used in this study were characterized as spore producers and urease producers. During this study, it was found that the bacterial concrete showed increase in compressive and split tensile strength than the conventional concrete to a significant level. Bacterial spores immobilized in the concrete matrix will become metabolically active when revived by water and calcium media of concrete. The bacteria hydrolyze urea to produce ammonia and carbon dioxide, resulting in an increase of pH in the surroundings where ions Ca^{2+} and CO_3^{2-} precipitate as $CaCO_3$. Due to these properties of bacterial cultures, we conclude that concrete-immobilized spores of such bacteria may be able to seal cracks by biomineral along with improving the strength and durability of cement concrete. These characteristics of bacterial concrete therefore appeared to be promising in near future in the field of structural engineering.

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