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Comparative Study of Mechanical Properties of Concrete Using Commercially Available Bacterial Strains

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Abstract

Bacteria impregnated concrete is a recent advancement in concrete technology which is being studied extensively by different researchers all around the world. This study aims to study the effect of bacteria on different parameters of concrete and compare the results from compressive test, split tensile test and flexure test with that of a normal mix concrete. The main objective of this research was to study the mechanical properties of concrete upon adding commercially available Bacillus Subtilis (5 billion cells/gm) and laboratory cultured Bacillus Cohnii (10^5 cells/ml) to the concrete mix. Both the bacterial concretes are mixed with calcium lactate and are cured in Calcium Chloride solution. This particular study confirms that commercially available Bacillus Subtilis imparts better concrete properties compared to laboratory cultured Bacillus Cohnii.

Keywords: Bacterial Concrete, Bacillus Subtilis, Bacillus Cohnii, Compressive Strength, Calcium Lactate.

1. Introduction

The purpose of this project is to study the different parameters of bacterial concrete and how these parameters differ from normal concrete. In this project bacteria from bacillus family are impregnated in concrete. Calcium Lactate is externally added to be an additional source of calcium in the concrete. There are some advantages of using bacterial concrete-

- Self healing of micro cracks in concrete.
- Improvement in compressive strength, split tensile strength and flexural strength of concrete.
- Reduction in corrosion of reinforced concrete.

Various types of bacterial strains can be used in concrete but mainly two types of bacterial strains used in this project—

- Bacillus subtilis
- Bacillus cohnii

A commercially available Bacillus subtilis bacteria is used in this project having bacterial population is 5 billion cells/gm. This bacteria is used directly into concrete mixture in dry form with calcium lactate and during curing calcium chloride is added into the curing water. Bacillus cohnii is used in cultured form in concrete mixture and the bacterial population count is 10^6 cells/ml. Calcium lactate is added to the concrete during mixing. On the other hand water with calcium chloride is used for curing. Nele De Belie in his paper *Application of Bacteria in concrete (2016)* [1] mentioned that the literature on strength improvements obtained by mixing bacteria into concrete shows variable results. Several authors have mentioned increases of 28 days compressive strength with 9 to 25% when mixing bacterial cells into mortar or concrete. Others mention both positive and negative effects, depending on the bacterial strain, cell concentration or concrete age. Hereby, it is very difficult to prove the actual influence of living bacteria. Inside the concrete matrix, due to the lack of oxygen, high pH and limited space availability, activity of (aerobic) bacteria would be greatly inhibited. B. R. Gautam in his paper *Bacteria Based Self Healing Concrete – A Bacterial Approach(2018)* [2] mentioned that self-healing concrete is a product which biologically produces limestone by which cracks on the surface of concrete surface heal. Selected types of the bacteria genus Bacillus, along with calcium-based nutrient known as calcium lactate, and nitrogen and phosphorous are added to the concrete when it is being mixed.

When a concrete structure damages and water starts to penetrate in the cracks present in it the bacteria starts to feed on the calcium lactate consuming oxygen and converts the soluble calcium lactate into insoluble limestone. The limestone formed thus seals the cracks present. It is similar to the process of how a fractured bone gets naturally healed by osteoblast cells that mineralize to reform bone. Consumption of oxygen in the bacterial conversion has an additional advantage. Oxygen which becomes an essential element for the corrosion of steel to take place is being used in the bacterial conversion. Hence the durability of steel in

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construction becomes higher. The S Jena and K C Panda in their paper *Effect of bacteria on the properties of concrete* mentioned that Ureolytic bacteria was first time used as healing agent by Gollapudi et al. (1995) for cracks which assists the enzymatic hydrolysis of urea to ammonia and carbon dioxide. On the other hand, Ramakrishnan et. al. (2001) first introduced the concept of utilizing microbiologically induced calcite ($CaCO_3$) precipitation. When bacterial techniques were applied in fresh concrete, it produces calcite precipitation in the void of concrete which decreases the permeability and increases the strength of concrete.

Deposition of calcite on concrete specimen by the bacteria leads to the reduction of gas permeability and uptake of capillary water. Crystals of calcium carbonate deposition on the concrete specimen results in the decrease in water absorption upto 85%. Bacterial carbonate precipitation affects the durability of concrete specimen with different porosity. Due to bacterial calcite precipitation, permeability and sorptivity of concrete decreases. Depending upon porosity, water absorption is reduced from 65-90% due to bacterial carbonate precipitation. Due to the execution of bacterial approach in concrete, durability property of concrete has been improved effectively.

Bhagyashri Pawar, Archana Magdum, Megh Bhosale and Sayali Pol in their paper *Bacterial concrete (2017)* [5] mentioned that self-healing concrete is a product that will biologically produce lime stone to heal cracks that appear on the surface of concrete structure. Specially selected types of bacteria genus Bacillus, along with calcium based nutrients known as calcium lactate & nitrogen phosphorus are added to the ingredients of the concrete when it is being mixed these selfhealing agents can lie dormant within the concrete for up to 200 hundred years. However, when a concrete structure is damaged water start to seep through the cracks that appear in the concrete the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The lime stone solidifies on the crack surface, thereby sealing it up.

Ankita Sikder and Purnachandra Saha in their paper *Effect of bacteria on performance of concrete/mortar: A review (2019)* [6] mentioned that the most effective properties of hardened concrete are compressive strength, by which the strength and durability of concrete are affected. Properties of hardening concrete depend on several factors like cement to sand ratio, water to cement ratio, curing age and other different properties of concrete. When Portland cement partially replaced 10% by bacteria treated cement kiln dust (CKD) concrete matrix achieved a higher compressive strength compared with control concrete might be because of the inappropriate alkalinity that expands the disintegration of silicate and for this arrangement of calcium silicate hydrate likewise increments and in the event of above substitution rate quality declines might be because of lower concrete substance and decreased or delay in the hydration of bond. S. Soundharya and Dr. K. Nirmalkumar on their paper *Study on the Effect of Calcite-Precipitating Bacteria on Self-Healing Mechanism of Concrete(2014)* [7] mentioned that bacteria added to concrete mix in suspension state must meet certain criteria. Concrete is highly alkaline building material, so bacteria used as self-healing agent should be able to survive in this high alkaline environment for long durations and be able to form spores, withstanding the mechanical forces during concrete mixing. A bacterial concrete mix is prepared by using alkali-resistant soil bacteria Bacillus subtilis, along with nutrients from which the bacteria could potentially produce calcite based bio-minerals. Such bacteria are Gram-Positive Bacteria and have extremely thick outer cell membrane that enables them to retain viable until a suitable environment is available to grow. The only factor need to be checked is the effect of nutrients media on the setting time of cement.

2. Objectives

i) To study different characteristics of bacterial concrete namely compressive strength, split tensile strength and flexural strength and compare the same to that of a normal concrete.

ii) To compare the properties of bacterial concrete for two strains of bacteria namely Bacillus cohnii and Bacillus subtilis.

3. Sample Preparation

3.1 Characteristics of most commonly used bacteria

Bacillus subtilis is a Gram-positive bacterium, rod-shaped and catalase-positive. *B .subtilis* cells are typically rod-shaped, and are about 4–10 micrometers (μm) long and 0.25–1.0 μm in diameter, with a cell volume of about 4.6 fL at stationary phase. As with other members of the genus *Bacillus*, it can form an endospore, to survive extreme environmental conditions of temperature and desiccation. *B.*

Subtilis is a facultative anaerobe and had been considered as an obligate aerobe until 1998. *B. subtilis* is heavily flagellated, which gives it the ability to move quickly in liquids. *B. Subtilis* has proven highly amenable to genetic manipulation, and has become widely adopted as a model organism for laboratory studies, especially of sporulation, which is a simplified example of cellular differentiation. In terms of popularity as a laboratory model organism, *B. Subtilis* is often considered as the Gram-positive equivalent of *Escherichia coli*, an extensively studied Gram-negative bacterium. It has the ability to form tough protective spores when subjected to unfavorable conditions which allow it to tolerate extreme environmental conditions and high mechanical pressure.

It can produce $CaCO_3$ through biomineralization which helps in strength gain. On the other hand Bacillus cohnii it is a non-ureolytic, alkaliphilicsporeforming bacteria which can survive up to 70°C. It also helps in strength gain and reduce sorptivity. It is a Gram-positive, coagulase-négative member of the bacterial genus Staphylococcus consisting of clustered cocci.

Fig.1 Cultured Bacillus Cohnii

The species commonly lives on human skin; clinical isolates have shown high levels of antibiotic resistance. A strain of *S. cohnii* was found to contain a mobile genetic element very similar to the staphylococcal cassette chromosome encoding methicillin resistance element seen in *Staphylococcus aureus*.

3.2 Method of sample preparation

For the preparation of concrete grade of concrete is not considered. A nominal mix of 1:1.5:3 has been used for preparation of concrete.

Calcium Lactate is added to the respective batches of concrete during mixing according to the required amount.

The test specimens are stored in moist air for 24 hours and after this period the specimens are marked and removed from the moulds and kept submerged in calcium chloride mixed water for curing.

As *B. subtilis* and Bacillus cohnii both are non-pathogenic bacteria hence there is not much of health hazard associated with it. Whereas for safety purpose proper hand gloves and masks are used during casting.

4. Results

4.1 Comprssive strength test

Table.1 7 days compressive strength

Sample no.	*NC (MPa)*	*BS (MPa)*	*BC (MPa)*
Sample 1	9.3	11.6	13.6
Sample 2	11.6	15.2	14.1
Sample 3	10.6	14.4	12.56

NC=Normal mix of concrete
BS=Sample containing Bacillus Subtilis
BC=Sample containing Bacillus Cohnii

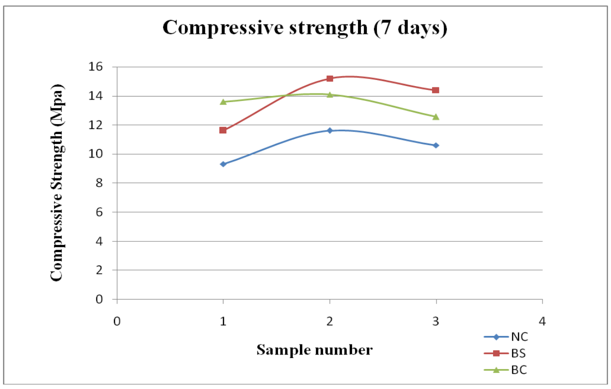

Fig.2 Compressive strength in 7 days

From the above results it is evident that the 7 days compressive strength of Bacillus Subtilis of cubes shows a higher average compressive strength than the normal mix and the mix containing Bacillus Cohnii. The average increase in compressive strength of mix containing Bacillus Subtilis is 30.53% whereas the average increase in compressive strength of mix containing Bacillus Cohnii is 28.75%.

From the above results it is evident that the 28 days compressive strength of Bacillus Subtilis of cubes shows a higher average compressive strength than the normal mix and the mix containing Bacillus Cohnii. The average increase in compressive strength of mix containing Bacillus Subtilis is 27.03% whereas the average increase in compressive strength of mix containing Bacillus Cohnii is 13.66%.

From the above results it is evident that the 28 days compressive strength of Bacillus Subtilis of cubes shows a higher average compressive strength than the normal mix and the mix containing Bacillus Cohnii.

Table.2 28 days compressive strength

Sample no.	*NC (MPa)*	*BS (MPa)*	*BC (MPa)*
Sample 1	13.6	18.85	16.3
Sample 2	15.7	19.5	17.3
Sample 3	14.2	16.8	15.8

NC=Normal mix of concrete
BS=Sample containing Bacillus Subtilis
BC=Sample containing Bacillus Cohnii

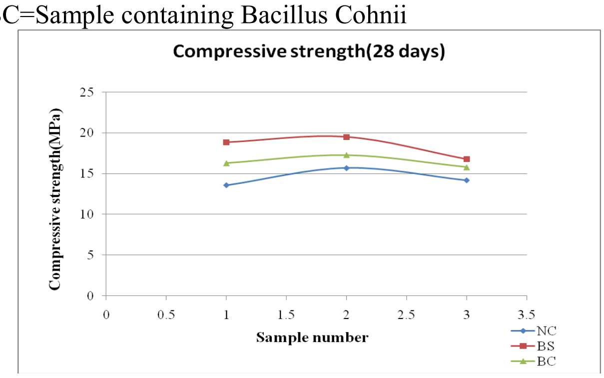

Fig.3 Compressive strength in 28 days

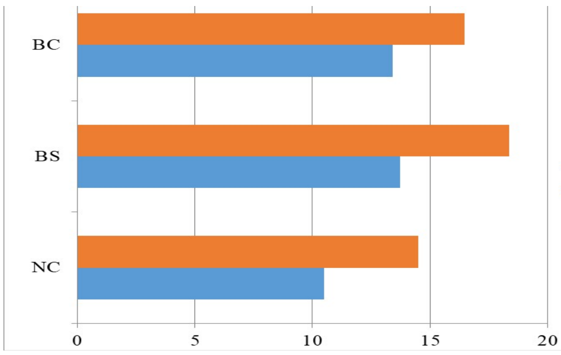

Fig.4 Average Compressive Strength of Cubes (7 & 28 days).

Table.2 28 days split tensile strength

Sample no.	*NC (MPa)*	*BS (MPa)*	*BC (MPa)*

Sample 1	1.31	1.386	1.335
Sample 2	1.287	1.499	1.422

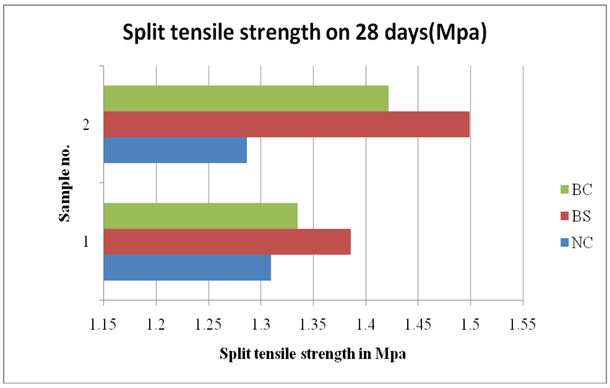

Fig.5 Split Tensile strength in 28 days

The average increase in compressive strength of mix containing Bacillus Subtilis is 27.03% whereas the average increase in compressive strength of mix containing Bacillus Cohnii is 13.66%. Comparasion of average compressive strength of Normal mix, mix containing Bacillus Subtilis and mix containing Bacillus Cohnii on 7 days and 28 days of curing.

4.2 Split Tensile Test

From the above observations it is evident that the split tensile strength of a concrete mix containing Bacillus Subtilis shows a higher split tensile strength that that of a normal mix concrete and a mix containing Bacillus Cohnii. The average increase in split tensile strength of mix containing Bacillus Subtilis is 11.13% whereas the average increase in split tensile strength of mix containing Bacillus Cohnii is 6.19%.

4.3 Flexure Strength Test

From the observations it is evident that the beam casted using Bacillus Subtilis mixed concrete shows a higher flexural strength as compared to the normal mix and the mix containing Bacillus cohnii.

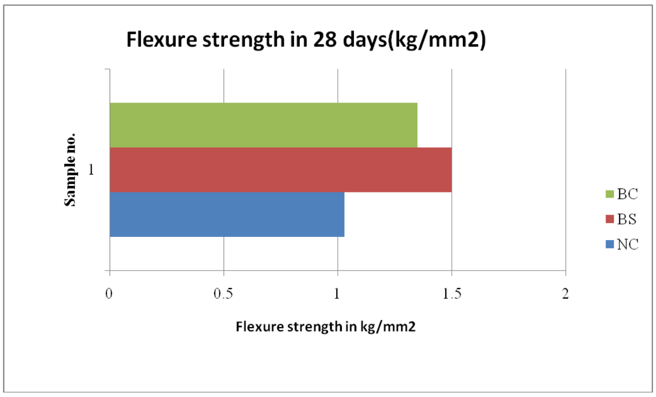

Fig 5- Flexure strength in 28 days

The increase in flexural strength of mix containing Bacillus Subtilis is 45.43% whereas the increase in flexural strength of mix containing Bacillus Cohnii is 30.97%.

5. Conclusion

After conducting different tests namely compressive strength test, Split tensile test and Flexural test on different samples of concrete containing Bacillus Subtilis and Bacillus Cohnii, it is observed that upon adding commercially available Bacillus Subtilis which has a population of 5 billion cells/gm to the concrete mix and adding cultured Bacillus Cohnii which has a population of 10^5 cells/ml to the concrete mix the different parameters of concrete shows variations than that of a normal mix concrete. It was observed that the compressive strength of the mix containing bacteria increased by a certain amount than that of a normal mix. The same scenario was observed in case of split tensile strength and flexure strength. Thus, it can be concluded that addition of bacteria to concrete increases the different parameters of it. But even bacterial concrete comes with its own set of disadvantages-

1. Cost of bacterial concrete is double than conventional concrete.
2. Growth of bacteria is not good in any atmosphere and media.
3. Design of mix concrete with bacteria here is not available any IS code or other code.
4. Investigation of calcite precipitate is costly.

In this study the main aim was to observe how the addition of bacteria in concrete mix affects the different parameters of concrete because of which while adding the two strains of bacteria, exact amount of bacteria was not maintained to both the mixes. It is concluded from this study that addition of bacteria affects the parameters of concrete. Out of the two strains of bacteria used namely Bacillus Subtilis and Bacillus Cohnii it was found that the compressive strength, Split tensile strength and Flexure strength of Subtilis was more in comparison to that of Cohnii.

Disclosures

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