

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 9, Issue 3, March 2020

Strength Evaluation of High Strength Concrete by Bacterial Mineral Precipitation

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ABSTRACT: A new technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite (CaCO₃) precipitation is discussed. Microbiologically induced calcite precipitation (MICP) 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 subtilis, a common soil bacterium can induce the precipitation of calcite. The objective of the present investigation is to study the potential application of bacterial species i.e. Bacillus subtilis to improve the strength of cement concrete. Here we have made an attempt to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength of the concrete. In this project, bacterial concrete is prepared under grade of concrete M25. The design mix proportioning also carried under IS code provision. Testing of specimens are carried at 7 days, 14 days and 28 days of curing by Compression Testing Machine and Universal Testing Machine for corresponding specimens. The Compressive Strength, Split Tensile Strength and Flexural Strength of Bacterial Concrete are to be found and it compared with controlled Concrete.

KEYWORDS: Bacteria, Bacillus subtilis, minerals, strength, concrete.

I. INTRODUCTION

Concrete is the most widely used construction material. Despite its versatility in construction, it is known to have several limitations. It is weak in tension, has limited ductility and little resistance to cracking. Based on the continuous research carried out around the globe, various modifications have been made from time to time to overcome the deficiencies of cement concrete. The ongoing research in the field of concrete technology has led to the development of special concrete considering the speed of construction, the strength of concrete, the durability of concrete and the environmental friendliness with industrial material like Fly Ash, Blast Furnace Slag, Silica Fume, Metakeolin etc. Recently, it is found that microbial mineral precipitation resulting from metabolic activities of favorable microorganisms in concrete improved the overall behavior of concrete. The process can occur inside or outside the microbial cell or even some distance away within the concrete. Often bacterial activities simply trigger a change in solution chemistry that leads to over saturation and mineral precipitation. Use of these Bio mineralogy concepts in concrete leads to potential invention of new material called Bacterial Concrete.

II. REVIEW OF LITERATURE

The Literature available reveals that bacteria can be used to enhance the performance of the concrete. The concept of bacterial concrete was first introduced by V.Ramakrishnan (2002), a novel technique in remediating cracks in concrete by utilizing microbiologically induced calcite (CaCO₃) precipitation. The pioneering work on repairing concrete with microbiologically induced calcite precipitation (MICP) is reported by the research group of Ramakrishnan V. and others at the South Dakota School of Mines & Technology, USA.

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B. M. MALI (2012)

Investigated the potential application of bacterial species i.e. B.sphaericus to improve the strength of cement concrete. Here an attempt to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength of the 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. Concrete, however, is due to its high internal pH, relative dryness and lack of nutrients needed for growth, a rather hostile environment for common bacteria, but there are some extremophilic spore forming bacteria may be able to survive in this artificial environment and increase the strength and durability of cement concrete. In this study we found that incorporation of spore forming bacteria of the species Bacillus will not negatively affect the compressive and split tensile strength of the cement concrete.

SRINIVASA REDDY, (2012)

A potentially enormous lengthening in service-life of public infrastructure/buildings and also considerably reduces the maintenance costs. In addition, concrete by its nature is very prone to deformations that expose its reinforcements, corroding them. Self-healing concrete offers a solution to prevent this. A novel eco-friendly self-healing technique called Bio calcification is one such approach on which studies were carried out to investigate the crack healing mechanism in enhancing the strength and durability of concrete.

Microbiologically induced calcite precipitation (MICP), a highly impermeable calcite layer formed over the surface of an already existing concrete layer, due to microbial activities of the bacteria (Bacillus subtilis JC3) seals the cracks in the concrete structure and also has excellent resistance to corrosion.

S. SUNIL PRATAP REDDY, (2010)

Presented the performance of the concrete by the microbiologically induced special growth/filler. One such thought has led to the development of a very special concrete known as Bacterial Concrete where bacteria is induced in the mortars and concrete to heal up the faults. Researchers with different bacteria have proposed different bacterial concrete's. Here an attempt was made by using the bacteria "Bacillus subtilis". Calcite formation by Bacillus subtilis a model laboratory bacterium, which can produce calcite precipitates on suitable media supplemented with a calcium source. Cement mortar cubes with four different cell concentrations were cast and control specimen was also cast. This study showed a significant increase in the compressive strength was observed due to the addition of bacteria for a cell concentration of 10^5 cells per ml of mixing water. From Scanning Electron Micrography analysis, it is noted that pores were partially filled up by material growth with the addition of the bacteria. Reduction in pore due to such material growth will obviously increase the material strength. Concrete cubes with and without addition of bacteria were cast and it is observed that there is an improvement in the compressive strength for the cubes with the addition of bacteria. Concrete cylinders with and without additions of bacteria were cast and it is observed that there is an improvement in the Split tensile strength for the cylinders with the addition of bacteria. From the durability studies, the percentage weight loss and percentage strength loss with 5% H₂SO₄ revealed that Bacterial concrete has less weight and strength losses than the conventional concrete and it also revealed that bacterial concrete is more durable in terms of "Acid Durability Factor" and "Acid Attack Factor" than conventional concrete.

JAGADEESHA KUMAR B G, (2009)

A concrete which is low in permeation properties lasts longer without exhibiting signs of distress and deterioration. Therefore, the permeation properties have been used principally for the comparison of the effectiveness of different surface treatments enhancing the durability and strength of concrete. Cracks and fissures are a common problem in building structures, pavements, historic monuments, stabilized soil and other structural members which are subjected to stress in different service conditions. Methods currently used for crack remediation often use synthetic polymers that need to be applied repeatedly, which requires continuous monitoring and recurring expenses.

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HENK M. JONKERS & ERIK SCHLANGEN (2008)

Developed a new type of self-healing concrete in which bacteria mediate the production of minerals which rapidly seal freshly formed cracks, a process that concomitantly decreases concrete permeability, and thus better protects embedded steel reinforcement from corrosion. Initial results show that the addition of specific organic mineral precursor compounds plus spore-forming alkaliphilic bacteria as self-healing agents produces up to 100- μm sized calcite particles which can potentially seal micro- to even larger-sized cracks. Further development of this bio-concrete with significantly increased self-healing capacities could represent a new type of durable and sustainable concrete with a wide range of potential applications.

DE MUYNCK W. et al., (2007)

Shortcomings of conventional surface coatings have drawn the attention to alternative treatments for the improvement of the durability of concrete. Promising results of an innovative biotechnology based on microbial carbonate precipitation have led to research concerning the use of bacteria in or on concrete. In our research groups, first the criteria for the selection of calcium precipitating *Bacillus* strains were established. *Bacillusphaericus* strains capable of the remediation of Euville limestone, by precipitating a dense and coherent calcium carbonate layer and concomitantly inducing a reduction of capillary water absorption, were characterized by a high urease activity, abundant EPS-production, a good biofilm production and a very negative ζ -potential. Reported the effects of bacterial CaCO_3 precipitation on parameters affecting the transport processes and durability of concrete and mortar. Pure cultures of ureolytic bacteria were compared for their effectiveness depending on the presence and type of calcium source (calcium chloride or calcium acetate). Treatments were evaluated according their influence on transport processes such as water vapour permeability and water absorption. The durability of the treated substrate has been studied by measuring the resistance to carbonation and chloride ingress. Microbial calcite precipitation was quantified by X-ray diffraction (XRD) analysis and visualized by SEM. The results indicated the presence of a newly formed layer on the surface of the mortar specimens, consisting mainly of calcite. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surfaces.

J.Y. WANG (2007)

Studied a large costs are involved in crack repair, the potential of self-healing of these cracks by means of calcium carbonate (CaCO_3) precipitating bacteria was investigated in this study. First, the survival of the bacteria was tested. Next, the optimal concentrations of bacterial cells, urea and Ca^{2+} were determined in order to obtain a maximum amount of CaCO_3 precipitation. Finally, self-healing of cracks in mortar specimens, by means of bacteria, was investigated. Glass tubes, containing the healing agent were provided inside the mortar matrix.

III. SCOPE AND OBJECTIVES

Cracks widths in concrete structure should be limited, mainly for durability reasons. If cracks widths are too large the cracks need to be repaired or extra reinforcement is needed in the design. If a method could be developed to automatically repair cracks in concrete this would save an enormous amount of money, both on the costs of injection fluids for cracks and also on the extra steel that is put in structures only to limit crack widths. For structural reasons this extra steel has no meaning. A reliable self-healing method for concrete would lead to a

- Chemicals
- Potassium permanganate
- Nutrient Broth
- Urea
- NaHCO_3
- NH_4Cl
- CaCl_2

new way of designing durable concrete structures which is beneficial for national and global economy. The Bacterial

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Concrete can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. As per the present investigation it has been shown that under favourable conditions *Bacillus subtilis*, a common soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer. Furthermore the bacteria should be suspended in a certain concentration in a certain medium before they are mixed through the concrete ingredients. Optimization is needed here, which involves experimental testing. Detailed investigations carried out by V. Ramakrishnan have shown that *Bacillus pasteurii* bacteria can be used for improving the strength and durability of concrete. However, not much investigation is carried out in India for producing bacterial concrete. Keeping this in view, the present experimental investigations are taken up to study the strength in M25 grade concrete with and without addition of bacteria *Bacillus subtilis*.

The main objectives of the present experimental investigation are

- To increase the compressive strength of concrete
- To increase the split tensile strength of concrete
- To increase the flexural strength of concrete
- To reduce plastic shrinkage cracks through the action of bacteria
- To reduce the maintenance cost

IV. STUDY OF MATERIALS AND TESTING

Material Requirements

The required materials are,

- Cement
- Coarse aggregate
- Fine aggregate
- Water
- Bacteria
- Aluminum Foil

V. MATERIALS USED AND THEIR PROPERTIES

CEMENT

In general, cement is described as a material used to bind the mineral fragments called aggregate. The cement paste acts as glue which makes a cohesive mass with all the aggregates. This bonding is very important of the concrete fails not because of less strength of aggregates but mainly due to failure of bonding. Production of cement is only a recent development. It was conceived on 1824 by William aspidin, but it was developed in the form of present day cement by Isaac Charles Johnson on 1845. He produced the modern cement by burning a mixer of chalk, clay and silica up to a temperature of 1400° C to 1450°C. In market various types of cements are available but our present investigation ordinary Portland cement of 53 grade is used. OPC is the most commonly produced and used cement. The properties of cement tested as per IS: 4031-1988 and found to be conforming to various specifications of IS: 12269-2009.

Test for Setting Time

This test is carried out to find whether cement sets at a rate of suitable for a particular work. There is no necessary relationship between the time of setting and that of hardening or attaining the maximum strength. Slow setting cement may harden more rapidly than a quick setting one, and vice versa. The hardening of cement is actually a continuation of the chemical action which began with setting if the cement is placed in the mould. After initial setting time the cement mould can be detached and after final setting time the Vicat's apparatus plunger gives no impression.

The initial setting time can be measured as "time taken by paste to stiffen to such an extent that the Vicat's needle is not

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permitted to move down through the paste through 25 mm. The final setting time can be defined as “it is the time after which the paste becomes so hard that Vicat’s 5mm needle doesn’t sink visibly and leave no impression. With Portland cement and rapid hardening cement the normal initial setting time should not be less than 30 minutes and the final setting time should not be more than 10 hours. With quick setting cement the initial setting time should not be less than 5 minutes and the final setting time should not be more than 30 minutes.

Test for Consistency

Bacillus subtilis, known also as the hay bacillus or grass bacillus, is a Gram-positive, catalase-positive bacterium. A member of the genus *Bacillus*, *B. subtilis* is rod-shaped, and has the ability to form a tough, protective endospore, allowing the organism to tolerate extreme environmental conditions. Unlike several other well-known species, *B. subtilis* has historically been classified as an obligate aerobe, though recent research has demonstrated that this is not strictly correct.

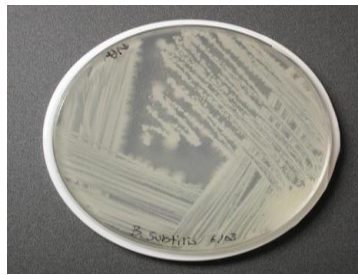


Figure 4.1 *Bacillus subtilis* in Nutrient Agar Plate

Although this species is commonly found in soil, more evidence suggests that *B. subtilis* is a normal gut commensal in humans. A study compared the density of spores found in soil ($\sim 10^6$ spores per gram) to that found in human feces ($\sim 10^4$ spores per gram). The number of spores found in the human gut is too high to be attributed solely to consumption through food contamination. Soil simply serves as a reservoir, suggesting that *B. subtilis* inhabits the gut and should be considered as a normal gut commensal.

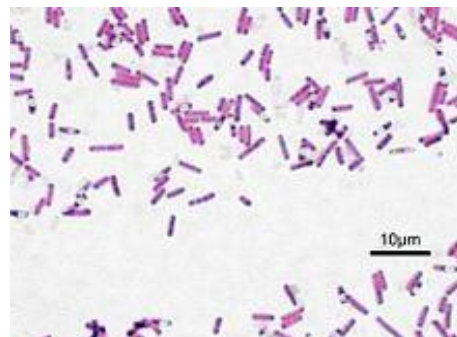


Figure 4.2 Gram-stained *Bacillus subtilis*

In 1835, the bacterium was originally named *Vibrio subtilis* by Christian Gottfried Ehrenberg, and renamed *Bacillus subtilis* by Ferdinand Cohn in 1872. It was used by the German medical corps in 1941 to treat dysentery during the North African campaign after seeing local Arabic population using it for this purpose. It was marketed throughout America and Europe from 1946 as an immunostimulatory aid in the treatment of gut and urinary tract diseases such as Rotavirus and *Shigella*, but declined in popularity after the introduction of cheap consumer antibiotics, despite causing

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less chance of allergic reaction and significantly lower toxicity to normal gut flora.

Safety of bacillus subtilis

The Bacillus subtilis species has a long history of safe use. It has been granted Qualified Presumption of Safety (QPS) status by the European Food Safety Authority (EFSA) and is part of the authoritative list of microorganisms with a documented history of safe use in food established by the International Dairy Federation (IDF) in collaboration with the European Food and Feed Cultures Association (EFFCA) in 2002 and updated in 2012. B. subtilis has approximately 4,100 genes. Of these, only 192 were shown to be indispensable; another 79 were predicted to be essential as well. A vast majority of essential genes were categorized in relatively few domains of cell metabolism, with about half involved in information processing, one-fifth involved in the synthesis of cell envelope and the determination of cell shape and division, and one-tenth related to cell energetic.

Characterization History of Bacillus Subtilis

On nutrient agar plate, colonies of bacillus subtilis were round, convex, smooth and translucent. Size of the colony may reach up to 2-3 mm diameter after 24hrs of incubation in dark aerobic conditions at 37°C. The organism produced a bluish green pigment that diffused into the medium. Individual cells of bacillus subtilis were Gram positive, oval to rods, 0.6-0.8 µm in width and 2.0 to 3.0 µm in length, motile and multiplied by quorum sensing process.

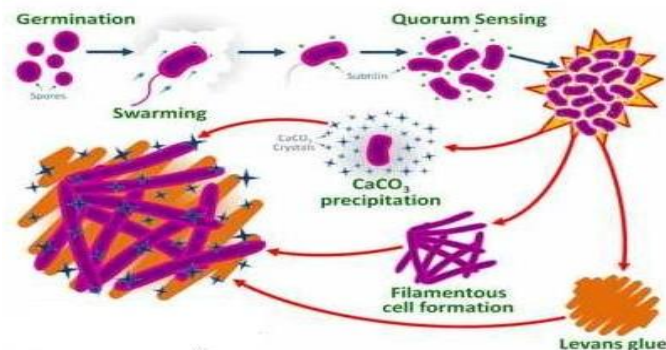


Figure 4.3 Process involved in the growth of Bacillus Subtilis

Formulae for Flexural Strength of Concrete

$$f_b = (3Pa) / (bd^2)$$

Where

f _b	=	Flexural Strength or Modulus of Rupture	=	Concentrated Load
a	=	Distance measured from support to load point	=	Measured Width of the Specimen
d	=	Measured Depth		

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ISSN(Online): 2319-8753
ISSN (Print): 2347-6710

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