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Bacterial Concrete: A Review

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Abstract: Concrete is a construction material that is used world-wide because of its first-rate properties. However, the drawback of this material is that it easily cracks due to its low tensile strength. It is a well-known fact that concrete structures are very susceptible to cracking which allows chemicals and water to enter and degrade the concrete, reducing the performance of the structure and also requires expensive maintenance in the form repair. The micro crack occurs when the load applied is more than its limit and this paves way for the seepage of water and other salts. This initiates corrosion and makes the whole structure vulnerable and leads to the failure of structure. To remediate this type of failure due to cracks and fissures, an approach of using bio mineralisation in concrete has evolved in recent years. In this method enhancing the performance of concrete, the calcite precipitating spore forming bacteria is introduced into concrete. When water enters through the cracks, it reacts with bacteria and forms precipitates of calcium carbonate, as a by-product, which fills the cracks and makes crack free concrete. This type of concrete prepared with bacteria is called as bacterial concrete.
Key words: Concrete, Bacteria, Calcium Carbonate, Bacillus Subtilis, Bacterial Concrete.

I. INTRODUCTION

Cement concrete is one of the most widely used materials for construction works in the field of civil engineering. This is mainly due to low cost of materials and construction, for concrete structures as well as low cost of maintenance. Concrete has a large load bearing capacity for compression load, but the material is weak in tension. Because of this steel reinforcement is provided and the steel bars take over the load when the concrete cracks in tension. However, the cracks in the concrete pose a problem .Due to reasons like freeze-thaw reactions, shrinkage, low tensile strength of concrete etc. cracks occur during the process of concrete hardening and this ultimately leads to weakening of the buildings. If water droplets enter into the concrete structure, due to lack of permeability then it can damage the steel reinforcement present in the concrete member. When this phenomenon occurs, the strength of the concrete decreases and which results in the decay of structure. Synthetic materials like epoxies are used to remediate, but they are costly, not compatible and need constant maintenance. Using chemicals is also causing damage to the environment. It is estimated that cement production alone contributes to about 7% of global anthropogenic CO2 emissions. The need for an environment friendly and effective alternate crack remediation technique leads to the development of using the bacterial concrete. Use of bacteria in concrete remediation is an unorthodox concept in current concrete research. It is however, a new approach to an old idea that a microbial mineral deposit constantly occurs in natural environment. The long term goal is to understand the significance of micro-organisms in concrete structures. Therefore, bacterially induced calcium carbonate precipitation has been proposed as an alternative. Durability problems such as crack formation are typically tackled by manual inspection and repair, i.e. by impregnation of cracks with cement or epoxy-based or other synthetic fillers. An integrated healing agent will save manual inspection and repair and moreover increases the structure's durability. Addition of such an agent to the concrete mixture would save money and environment.

II. SELECTION OF RIGHT BACTERIA

Cement and water have a pH value of up to 13 when mixed together, usually hostile environment for life. Most organisms die in an environment with a pH value of 10 and above. So, it is essential to find bacteria capable of surviving an extreme alkaline environment. Also the bacteria selected should be thermophilic, because during hydration process of cement large amount of heat is developed. Strains of the bacteria genus Bacillus were found to thrive in this high alkaline environment. Bacteria that were able to survive were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate.

Bacillus is the only group of bacteria's that are able to survive this high alkaline environment. Finding a suitable food source for the bacteria that could survive in the concrete took a long time and many different nutrients were tried until it was discovered that ***calcium lactate*** was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete.

Different types of bacteria used by different researchers for the study of bacteria such as Jonker et al. [1] used Bacilllus cohnii bacteria to precipitate CaCo3, Santhosh et al. [2], Day et al. [3], Bang et al. [4] used Bacillus pasteurii while Bacillus lintus used by Dick et al. [5]

III. TYPES OF BACTERIA USED IN CONCRETE

From literature review:

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- Bacillus pasteurii
- Bacillus sphaericus
- Escherichia coli
- Bacillus subtilis
- Bacillus cohnii
- Bacillus halodurans
- Bacillus pseudofirmus etc

IV. CLASSIFICATION OF BACTERIA

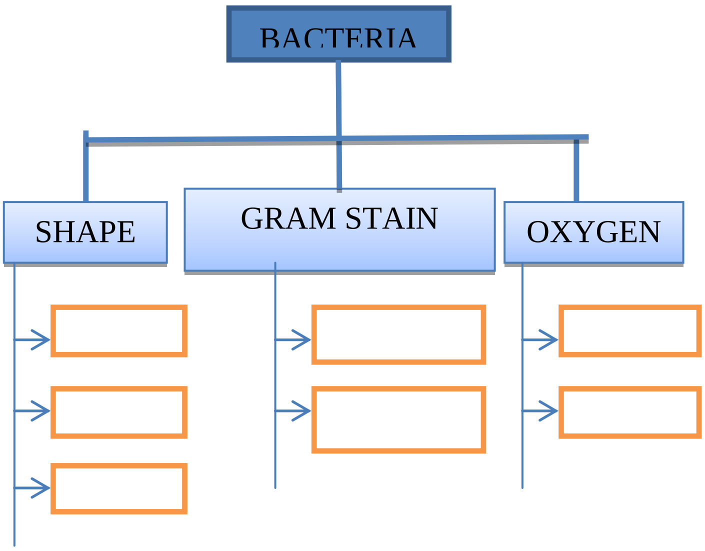

Fig.1 Classification of Bacteria

V. BACILLUS SUBTILIS

- Originally named Vibrio subtilis in 1835, this organism was renamed Bacillus subtilis in 1872.
- Bacillus Subtilis bacteria were one of the first bacteria to be studied. There cells are rod-shaped, Gram-positive bacteria that are naturally found in soil and vegetation.

- Bacillus subtilis grow in the mesophilic temperature range. The optimal temperature is 25-45 degrees Celsius. Stress and starvation are common in this environment; therefore, Bacillus subtilis has evolved a set of strategies that allow survival under these harsh conditions. One strategy, for example, is the formation of stress-resistant endospores.

- Bacillus subtilis can also gain protection more quickly against many stress situations such as acidic, alkaline, osmotic, or oxidative conditions, and heat or ethanol.

- Bacillus subtilis bacteria are non-pathogenic. .It is used as a fungicide fortunately it does not affect humans.

A. LOCAL AVAILIBILITY OF BACTERIA

Microbiology lab, T.Choithram Hospital and Research centre, Indore, M.P.

B. SHAPE OF BACILLUS SUBTILIS

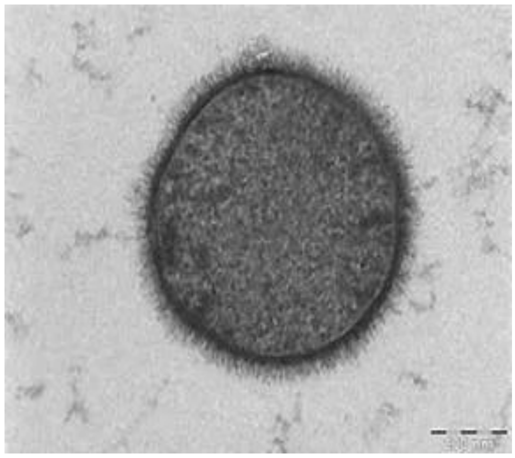

Fig. 2(a)

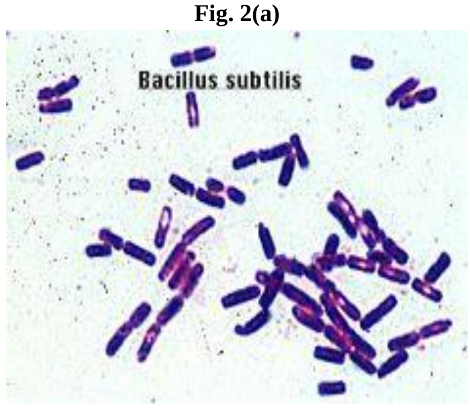

Fig. 2(b)

Fig.2 (a), (b) SHAPE UNDER MICROSCOPE

C. ORIGINAL LOOK OF BACILLUS SUBTILIS

As obtained from T.Choithram Hospital and Research centre microbiology lab, Indore, M.P.

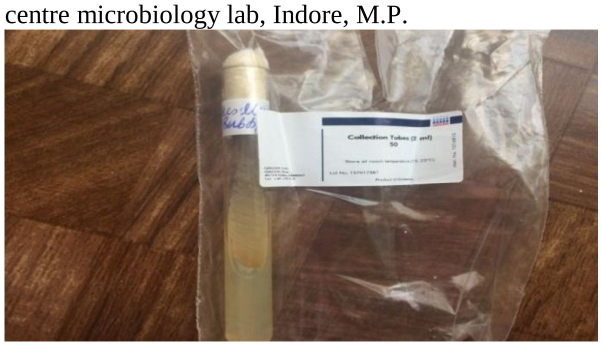

Fig. 3(a)

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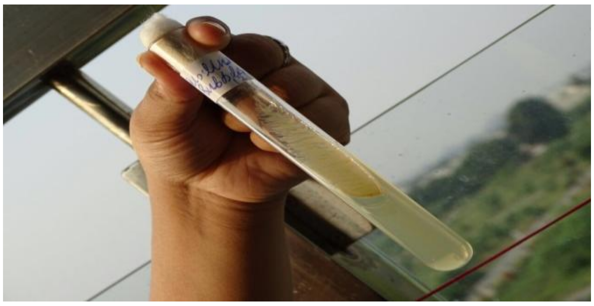

Fig. 3(b)

Fig. 3(c)

Fig. 3(a), (b), (c) Original Look of Bacillus Subtilis

VI.WORKING OF BACTERIAL CONCRETE

Self-healing concrete (bacterial concrete) is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of the bacteria along with a calcium based nutrient known as calcium lactate, nitrogen and phosphorus are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Under favourable conditions, Bacillus bacteria in concrete continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete layer. Calcite has a coarse crystalline structure that readily adheres to surfaces in the form of scales. In addition to the ability to continuously grow upon itself, it is highly insoluble in water. Due to its inherent ability to precipitate calcite continuously, bacterial concrete can be called as a "Smart Bio Material". Cracks in concrete significantly influence the durability characteristics of the structure. The bacterial remediation technique can be used for repairing structures of historical importance to preserve the aesthetics value. Mechanism of Production of Calcite (CaCO3) in natural environments, chemical CaCO3 precipitation (Ca^{2++} CO_3^{2-} □ CaCO3) is accompanied by biological processes, both of which often occur simultaneously or sequentially. This microbiologically induced calcium carbonate precipitation (MICP) comprises of a series of complex biochemical reactions. As part of metabolism, bacteria produce urea, which catalyses urea to carbonate and ammonium, resulting in an increase of pH and carbonate concentration in bacterial environment. These compounds further hydrolyse to ammonia and carbonic acid that leads to the formation of bicarbonate. Finally calcite is precipitated over the cell surface.

$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3$ (1)

$NH_2COOH + H_2O NH_3 + H_2CO_3$ (2)

$NH_3 + 2H_2O_2 \rightarrow NH_3^+ + 2OH^-$ (3)

$2OH^- + H_2CO_3 \rightarrow CO_2^{2-} + H_2O$ (4)

$Ca^{2+} + cell \leftrightarrow cell\text{-}Ca^{2+}$ (5)

$Cell^- Ca^{2+} + CO_3^{2-} \rightarrow cell\text{-}CaCO3$ (6)

VII.OTHER CONDITION OF B.SUBTILIS

1. STORAGE: B.Subtilis are very cold sensitive hence grows best at 37°C and to be kept at room temperature of 15-27°C.
2. SAFTEY: B.Subtilis is safest of all bacillus bacteria. Hence safe for human handling .Human body is not affected by it in terms of fever, nausea or other medical ailments.
3. No need of antibiotic resistance.

VIII. LITERATURE REVIEW

***SakinaNajmuddin Saifeeet .al*[1]**, published a paper on Critical appraisal on Bacterial Concrete. In this paper they discussed about the different types of bacteria and their applications. The bacterial concrete is very much useful in increasing the durability of cementitious materials, repair of limestone monuments, sealing of concrete cracks to highly durable cracks etc. It also useful for construction of low cost durable roads, high strength buildings with more bearing capacity, erosion prevention of loose sands and low cost durable houses. They have also briefed about the working principle of bacterial concrete as a repair material. It was also observed in the study that the metabolic activities in the microorganisms taking place inside the concrete results into increasing the overall performance of concrete including its compressive strength. This study also explains the chemical process to remediate cracks.

***Ravindranatha, N. Kannan, Likhit M.L*[2]**, have published a paper on Self-Healing Material Bacterial Concrete. In this paper a comparison study was made with concrete cubes and beams subjected to compressive and flexural strength tests with and without the bacterium **Bacillus pasteurii.** The concrete cubes and beams were prepared by adding calculated quantity of bacterial solution and they were tested for 7 and 28 day compressive and flexural strengths. It was found that there was high increase in strength and healing of cracks subjected to loading on the concrete specimens. The microbe proved to be efficient in enhancing the properties of the concrete by achieving a very high initial strength increase. The calcium carbonate produced by the bacteria has filled some percentage of void volume thereby making the texture more compact and resistive to seepage.

Chithra.P Bai and Shibi Varghese[3], have published a paper on an experimental investigation on the strength properties of fly ash based Bacterial concrete. In this paper, The bacteria **Bacillus Subtilis** was used for study with different cell concentrations of 103, 105 and 107 cells/ml for preparing the bacterial concrete. Cement was partially replaced by 10%, 20% and 30% of fly ash by weight for making the bacterial concrete. Concrete of grade M30 was prepared and tests such as Compressive strength, Split tensile strength, Flexural strength and Ultrasonic Pulse Velocity were conducted after 28 and 56 days of water curing. For fly ash concrete, maximum compressive strength, split tensile strength, flexural Strength and Ultrasonic Pulse Velocity values were obtained for 10% fly ash replacement. For bacterial concrete maximum compressive strength, split tensile strength, flexural strength, and UPV values were obtained for the bacteria cell concentration of 105cells/ml. The improvement in the strength properties of fly ash concrete is due to the precipitation of calcium carbonate (CaCO3) in the micro environment by the bacteria Bacillus Subtilis.

Jagadeesha Kumar B G, R Prabhakara and Pushpa[4]**,** H5, published a paper on Effect of Bacterial Calcite Precipitation on Compressive Strength of Mortar Cubes. This paper describes about the experimental investigations carried out on mortar cubes which were subjected to bacterial precipitation by different bacterial strains and influence of bacterial calcite precipitation on the compressive strength of mortar cube on 7, 14 and 28 days of bacterial treatment. Three bacterial strains Bacillus flexus, isolated from concrete environment**, Bacillus pasteurii** and **Bacillus sphaericus** were used. The cubes were immersed in bacterial and culture medium for above mentioned days with control cubes immersed in water and was tested for compressive strength. The result indicated that there was an improvement in the compressive strength in the early strength of cubes which were reduced with time. Among the three strains of bacteria, Cubes treated with Bacillus flexus, which is not reported as bacteria for calcite precipitation has shown maximum compressive strength than the other two bacterial strains and control cubes. It was studied that the increase in compressive strengths is mainly due to consolidation of the pores inside the cement mortar cubes with micro biologically induced Calcium Carbonate precipitation. The urease activity was determined for all the bacteria in Urease media by measuring the amount of ammonia released from urea according to the phenol hypochlorite assay method. All the three strains of bacteria were tested for urease activity. The change of the colour of the media from yellow to pink indicated that it is urease positive. All the three strains were urease positive. X-ray diffraction analysis was also carried out to determine chemical composition of the precipitation that occurred due to bacterial mineralization.

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