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Experimental Investigation on Sustainability of Bacterial Concrete in Building Construction – A Review

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***Abstract*— Concrete is the most oft-times used structural material, the cracks in concrete breed problems. Cracks in concrete transpire due to varied mechanisms in nature as - shrinkage, freezing-defrizzing reactions, and mechanical compressive and tensile forces. Cracks formed in concrete are inevitable and are one of the major reasons for the shortcoming of concrete. Cracking of the concrete exterior may enhance the deterioration of enrooted reinforcing bars as the admission rate of harsh harmful and corrosive chemicals such as water and chloride ions into the concrete structure increased. Thereupon, an unprecedented methodology has been developed by using a particular microbial plugging process. Numerous studies have shown positive results by adding calcite depositing bacteria in concrete, also known as bacterial concrete or self-healing concrete. This experimental study was conducted to analyze the characteristics of Bacterial concrete for constructional purposes. In addition to concrete, bacteria named BACILLUS SUBTILIS (along with its nutrients) is added to attain additional strength than conventional concrete and to develop properties of concrete. The study is performed to test and evaluate the compressive strength of concrete specimens, the optimum dosage of bacteria used and to study characteristics of cracked specimens by introducing Bacillus Subtilis, which is ureolytic, gram-positive (spore-forming bacteria), and facultative aerobic. A substantial increase in strength is observed in concrete specimens when cast with a bacterial mixture. Results have been compared with conventional concrete. The biological alteration of construction materials is the need of the hour for strength enhancement and long-term sustainability. The present study proposes a promising sustainable renovative system for concrete.**

Index Terms*— *Bacterial Concrete, Bacillus Subtilis, Cracks, Microbial Process

I. INTRODUCTION

Concrete is a vital structural material. It's of utmost effectiveness when enrooted by reinforcing steel bars because its tensile strength without reinforcement is extensively low relative to its compressive strength. As concrete is a high-maintenance brittle material, it cracks and suffers serious wear and tear over the decades of its anticipated term of service. Most of the crack which forms primarily are due to tension. Cracks can form at any stage of the life of the concrete and where they cannot be seen for until a year, substantial repairs are required to the concrete. Damage is substantially caused by cold snap/thaw, rust, severe loads, chemical reactions, and any other environmental conditioning. Thereupon, maintenance of concrete structures is frequent and expensive. Extra costs are spent every year on the infrastructure of buildings, bridges, and roadways maintenance, and materials requiring less frequent repairs are very pleasing.

The arising technologies towards the progression of concrete from traditional concrete to different types of concrete such as High Strength Concrete (HSC), High-Performance Concrete (HPC), Ultra-High-Performance Concrete (UHPC), Self-Compacting Concrete (SCC), Fiber Reinforced Concrete (FRC), etc., are developing at the faster rate to achieve the objectives in terms of durability and strength. In the foregone few decades, enormous work has been carried out in order to refine the performance by means of the implementation of various materials and technologies. Accordingly, bacteria-induced calcium carbonate (calcite) deposition is recommended as a substitute. When the concrete hardens, fissures are cured by bacterial reaction as water enters through the cracks/fissures. As bacterial concrete carries out the process of self-healing of cracks, this concrete is also known as Self-Healing Concrete.

The induction of calcium carbonate precipitating bacteria has been recommended as a substitute and eco-friendly crack-healing process. The countermeasure will save manual investigation, and repairs and also would raise the durability of the structure. The addition of bacteria as an agent for filling up the cracks in the concrete mixture would not only prove cost-effective but also save the environment from the adverse effects of using other chemical processes of crack treatment. Using bacteria as binders and fillers in concrete would also enhance the performance of concrete in terms of its strength and durability.

A. Bacteria (Bacillus Subtilis)

Bacillus subtilis, known also as the hay bacillus or grass bacillus, is a Gram-positive, catalase-positive bacterium, found in soil and the gastrointestinal tract of ruminants, humans, and marine sponges. As a member of the genus *Bacillus*, *B. subtilis* is rod-shaped and can form a tough, self-protective endospore, allowing it to tolerate extreme environmental conditions. *B. subtilis* has historically been classified as an obligate aerobe, though a testament exists that it is a facultative anaerobe. *B. subtilis* is considered the best-studied Gram-positive bacterium and a model organism to study bacterial chromosome replication and cell isolation.

B. Crack Healing Mechanism

Bacterial concrete is a resultant of the reaction of a calcium-based nutrient and non-reacted limestone. The cracks that appeared on the structure are healed with the help of bacteria. A special form of bacteria belonging to ‘Bacillus’ family, is used along with calcium-lactate as a nutrient. These bacteria can be in the dormant stage for approximately 200 years and after it’s contact with the water it deposits calcite precipitate in cracks.

Once the cracks appear in the concrete, water begins to seep in the concrete through these openings. The bacterial spores unfold and start feeding on calcium as water spatters into the cracks. Conversion of dissolved calcium lactate into insoluble limestone takes place as the oxygen is consumed in the chemical reactions as shown in equation 1 and 2 below.

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \text{……………(1)}$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad \text{…………..(2)}$$

II. NEED FOR STUDY

The infrastructure in industrialized countries accounts for at least 50% of our national wealth. From that, it can be concluded that our infrastructure's exhibiting characteristics and eminence is of foundational significance to urban sustainability and the comfort of our surroundings. In the prospect of a great impingement of the building industry and the environment, advancing self-healing materials can be accounted for as a matter of sustainable environmental management. Since concrete is, quantity-wise, the most frequently used man-made building material, massive savings are potentially feasible and even if we make small advancements. Apart from the lesser consumption of resources, a longer life span of structures is also reducing the cost of construction-associated transport. Significantly in industrialized countries, 30 – 50% of the travel is related to building construction activities, extending the service life of our infrastructure, thus reducing the transport costs related to new construction.

III. LITERATURE REVIEW

V. Ramakrishnan [1] – “Remediation of Concrete Using Microorganisms” (2012) The concept of bacterial concrete was first introduced by V. Ramakrishnan, (USA) a novel technique in remediating cracks in concrete by utilizing microbiologically induced calcite (CaCO3) precipitation (MICP), which is highly desirable chemical reaction because the calcite precipitation induced is a result of microbial activities. The technique can be used to improve compressive strength and stiffness of cracked concrete specimens. The effect of different concentrations of bacteria on the durability of concrete was also studied by him. It was found that all the specimens with bacteria performed better than the control specimens (without bacteria). The durability performance increased with an increase in the concentration of bacteria up to the optimum dosage.

Mayur Shantilal Vekariya [2] – “Bacterial Concrete: New Era for Construction Industry” (2013) Microbial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self-healing abilities and increase in durability of various building materials. Enhancement of compressive strength, reduction in permeability, water absorption, and reinforcement corrosion have been seen in various cementitious and stone materials.

Arivu Thiravida Selvan .et.al., [3] – "An Experimental Investigation Of Bacterial Concrete Incorporated With Bacillus Cereus" (2016) Bio-mineralization precipitation is resultant of microbial actions of some specific bacillus family in concrete to improve the general behavior of concrete has become an important area of research. A bacillus cereus bacterium is incorporated into concrete to improve the strength of the concrete. The Maximum Average Compressive strength for Self-healing concrete of 7, 14, and 28 days is at 35% replacement of Fly ash and it is 22.32 N/mm^2, 29.70N/mm^2, and 37.84N/mm^2 respectively. The 7-, 14-, and 28-days strengths are 11.71% and 7.56%, and 9.93% more than the Controlled concrete. The bacteria-incorporated concrete has less water absorption capacity than controlled concrete due to pore plugging with bacteria-produced calcite minerals.

Pappupreethi K .et.al., [4] – "BACTERIAL CONCRETE: A REVIEW" (2017) Due to the introduction of bacteria into concrete there has been an increase in the compressive and flexural strength with a decrease in permeability, water absorption, and corrosion of reinforcement when compared to conventional concrete. Thus, bacterial concrete can play a major role in modern construction, which requires precise technologies for producing high-quality structures that will be cost-effective and environmentally safe.

Shubham Ajay Puranik et.al., [5] – "Bacterial Concrete- A Sustainable Solution for Concrete Maintenance" (2019) observed that the compressive strength of concrete showed a significant increase with the addition of bacteria. 30 ml of Bacillus sphaericus in concrete mix M20 shows the maximum improvement in compressive strength as compared with the conventional concrete's strength. Upon application of the selected bacteria, it was witnessed that it can also be used as a waterproofing material. Bacillus sphaericus showed better results as a waterproofing material and seepage control as it works better than Bacillus Subtilis.

Likhit M. L et.al.,[6] "SELF-HEALING MATERIAL BACTERIAL CONCRETE" (2014) 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 the calculated quantity of bacterial solution and they were tested after 7 and 28 days for compressive and flexural strengths. It was found that there was a 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 the void volume thereby making the texture more compact and resistant to seepage.

Sakina Najmuddin Saifee et.al.,[7] "Critical appraisal on Bacterial Concrete" (2015) In this paper they discussed the different types of bacteria and their applications. Bacterial concrete is very much useful in increasing the durability of cementitious materials, repair of limestone monuments, sealing concrete cracks to highly durable cracks, etc. It is also useful for the 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 us about the working principle of bacterial concrete as a repair material.

IV. CONCLUSION ON LITERATURE REVIEW

Concrete is one of the most extensively used construction materials. It is a strong, readily available, and relatively less expensive construction material hence used universally. One drawback is the susceptibility of concrete to cracking, a fact that reduces its durability. The effect of life span-associated issues on a country's economy can be marked and are evident from the amount of money spent on the conservation, retrofitting, and reconstruction of concrete structures. The formation of cracks is generally taken care of by observation and renovation by infusing the cracks with epoxy-based, cement-based, or other synthetic filler materials.

A more defendable restoration method which is based on the application of mineral-producing bacteria is currently being studied in several laboratories. Ureolytic bacteria from the family Bacillus were utilized as a medium for biologically producing calcite-based minerals in some of these investigations. Based on the literature review referred, it was found that various studies have been conducted in regard to comparing bacterial concrete with conventional concrete. Studies have results where the cracks have healed by the addition of bacteria of the Bacillus family in concrete. Studies have majorly used methods like encapsulation and bacterial spore addition for concrete testing and seldom used direct bacterial solution addition. The effect of the direct addition of bacterial solution in concrete and surface application of the solution to test its sealing properties needs to be accessed and tested.

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