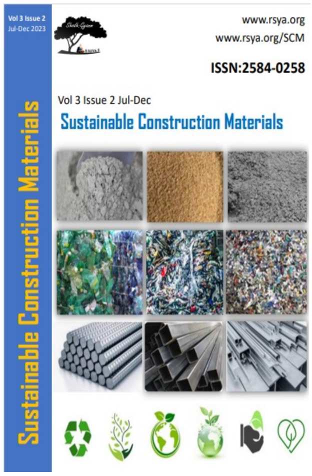

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Utilizing Bacillus Subtilis to Enhance Concrete Self-Healing Abilities and Durability

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Abstract. Bacterial infusion in concrete is a method of repairing surface cracks in concrete by introducing bacteria into the concrete matrix prior to pouring it into the mold. Microbial concrete's crack and corrosion resistance makes it highly appealing, leading to enhanced strength and greater interest. Bacterial activity and their resulting precipitates modify the microstructure of concrete, hence enhancing its impermeability. This study examined the durability and fracture healing characteristics of concrete infused with bacillus subtilis bacteria. Bacterial impregnated concrete exhibited superior durability in comparison to conventional M25 concrete. Submerging bacterial concrete in water resulted in the reduction in crack breadth, demonstrating its inherent ability to self-heal.

Keywords: Self Healing, Sustainable, Durability, Cement concrete, Strength

INTRODUCTION

Concrete has evolved into a highly versatile construction material. In contrast, concrete structures exhibit signs of deterioration prior to reaching the end of their lifespan. Fracturing is the main factor responsible for this problem. Due to the heightened influx of deleterious substances into the concrete, corrosion and structural deterioration ensue. In order to mitigate this problem, the construction industry conducts regular maintenance and repairs. Occasionally, conventional repair techniques including the use of Epoxy-based approaches are employed. Undertaking tunnel constructions and repairs, nuclear power plant projects, and maritime infrastructure development, for instance, poses significant challenges and requires substantial time and effort. Conventional repair methods have drawbacks including high costs, environmental concerns, and varying coefficients of thermal expansion, among other challenges. A contemporary approach to enhancing the durability of structures is necessary due to the difficulties encountered. Self-healing in concrete is an innovative advancement in the construction industry that effectively eliminates cracks in concrete constructions. To achieve self-healing concrete, a healing agent is incorporated into the concrete mix, which effectively prevents micro cracks from developing into larger fissures. Self-healing concrete utilizes microbes to facilitate its own healing process. Bacteria are incorporated into bacterial impregnated concrete during the mixing process. When cracks form in concrete that has been impregnated with bacteria, a healing agent is activated and released into the concrete. This agent then moves towards the fissures and effectively seals all fractures from the inside out. The incorporation of thermophilic and anaerobic bacteria in concrete, via Microbial Induced Mineral Precipitation, led to a 25% enhancement in concrete strength after 28 days [2]. By investigating the influence of bacillus bacteria on water absorption and compressive strength of cement. The addition of bacillus microorganisms to cement mortar leads to an increase in compressive strength due to the deposition of microbial calcite. Furthermore, the cubes mixed with microbes demonstrated a water absorption rate that was six times lower compared to the control cubes. Using bacillus sp. to create "microbial concrete" has the potential to enhance the long-term resilience of construction materials [3]. Concrete infused with microorganisms exhibits resilience against alkali, freeze-thaw cycles, sulphate attack, and drying shrinkage [4]. The research findings indicated that the weight and strength of biological concrete were relatively unaffected when compared to ordinary cement concrete that did not contain bacillus germs. This was seen in a study that aimed to evaluate the enhancement of durability in high strength bacterial concrete grades using various acids. When comparing the effects of immersing the specimen in hydrochloric acid and sulphuric acid, it was found that the specimen exhibited the highest compressive strength and experienced the most weight loss after being immersed in sulfuric acid. The concentration of sulphur and chloride in the bacteria-infused concrete decreased significantly when it was submerged in sulphuric and hydrochloric acid. The experiment suggests that the durability and resistance properties of bacteria can be improved even when exposed to powerful acids such as hydrochloric acid and sulphuric acid, by using an optimum concentration. This aids in the prevention of minor fractures from escalating into significant fissures. Calcite precipitate forms only from the reaction between CO2 and Ca(OH)2. The absence of sufficient CO2 in typical concrete prevents the activation of the self-healing process within the concrete. Additionally, the water infiltration causes the leaching away of Ca(OH)2 due to its solubility [6-8]. The enzyme activity of Bacillus subtilis urease generates urease, which catalyzes the production of CO2 and ammonia from urea. This process leads to an elevation in the pH level of the surrounding environment. Additionally, the presence of Ca2+ and CO3 ions causes the precipitation of calcite in bacterial concrete. Calcite is formed as a byproduct of bacterial metabolism. Through oxygen consumption, crack-free bacterial concrete is produced. The range of values is between 6 and 10. Crystals undergo expansion until the crack is fully repaired. The concentration of dissolved inorganic carbon and the pH level are two parameters that affect the microbiological process of CaCO3 precipitation. The existence of nucleation sites and the concentration of calcium ions The bacteria's metabolic processes contribute the initial three elements, while the cell wall functions as a site for nucleation [9-12]. During the mixing process, bacteria are combined in a suspended state. Bacillus subtilis bacteria exhibit resilience in the adverse conditions present in concrete. Bacillus subtilis possesses a robust cell membrane that functions as a shield against high pH levels. Bacteria belonging to the bacillus genus are capable of entering a state of hibernation for a period of around 200 years when conditions are favorable, specifically when they are present in concrete. Fractures in a concrete structure facilitate the ingress of air and water, leading to a decrease in the pH of the concrete. This acidic environment provides favorable conditions for the growth and proliferation of bacteria. Peptone-based nutrients and microorganisms are included to enhance the process of calcite synthesis.

Materials

Ordinary Portland cement (OPC)

Cement OPC 43 having 3.15 specific gravity was taken for the experiments. This was discovered to be consistent with IS:12269-1987.

Aggregates

For the experimental works, crushed angular aggregate with 20 mm size having 2.65 specific gravity and sand having 2.62 specific gravity conforming IS:383 zone II were utilised, which were tested according to IS:2386-1963.

Bacterial Strains

The microorganisms were obtained from the MTCC Chandigarh and shipped to Jabalpur. Bacillus Subtilis was the microbe employed in this study. Gram-positive, rod-shaped bacillus subtilis bacteria is prevalent in upper layer of earth. Bacillus subtilis bacteria can tolerate severe temperatures and dry environments because to its endospore. It can perform anaerobically when nitrates or glucose are present. It's neither pathogenic nor poisonous, and it does not cause disease.

Water

Tap water that meets IS 456 standards is taken. Mixing and Curing was done with water free from harmful chemicals such as acid, oils, salt, alkali, organic compound, sugar and substances that could harm concrete.

Mix Proportions

Mix proportion 1:1.59:2.28 for M25 mix having water cement ratio 0.5. 90mm slump was obtained and 7^{th} day compressive strength was recorded as 17.48 N/mm^2 and 28^{th} day compressive strength 31.05 N/mm^2. Content, are added to boost calcite synthesis.

TESTS ON CONCRETE

Durability Assessment

Experiment was carried out on concrete specimen with and without the inclusion of B.subtilis on M25 grade concrete cubes with a diameter of 100×100×100mm. Specimens were submerged in 5% NaCl solution for salt durability test and in 5% H2SO4 solution for acid durability test. For 28 days, the tests were conducted at 7 intervals. Solutions were swapped at regular intervals to maintain solution concentration during test. The evaluations were done 14 and 28days after the start of the immersion. Specimens were removed from the solution, the surface of cubes were cleaned and weighed.

Assessment for Water Absorption

In compliance with IS 2185-1979, test for water absorption was performed on 100mm cubes for 28 days. In comparison to bacterial concrete, ordinary concrete absorbs more water. Before drying in a 105°C hot air furnace, the specimens were weighed. The process of drying was repeated till the mass difference between two 24-hour observations was nearly identical. Dry specimens are cooled to room temperature before being immersed in water. At regular intervals, the specimens were removed, weighed, and dried on the surface. To calculate saturated water absorption, divide saturated mass by oven dried mass. The growth in masses by commencing masses for good concrete should be less than 10%.

Self-Healing Assessment

The crack healing properties of bacterial concrete cubes 0.35mm, 0.45mm, and 0.5mm with fracture widths were investigated in this work. Testing is carried out on a regular basis to determine the healing potential. Bacillus subtilis culture was mixed with water having 10^6 cells/ml concentration at the time of mixing. Different thicknesses of feeler gauge blades were used to create different fracture widths. After 24 hours, the specimens were demoulded and the feeler gauge blades were removed, and the specimens were submerged for 100 days in fresh clean water. The capacity of bacterial concrete to repair is constantly being researched.

RESULTS

In line with ASTMC267, the change in bacterial concrete cubes weight after being submerged in salty water was investigated. Bacterial Concrete Specimens and Control Specimens were compared in terms of weight change percentage.

TABLE 1. Salt Test

Mix	Initial Weight	Cube weight 14d	Cube Weight 28d	Percentage Increase 14d	Percentage Increase 28d
Conventional	2.526	2.539	2.55	0.415	0.87
Bacterial Concrete	2.514	2.519	2.522	0.119	0.39

The 0.1mm crack width had healed completely after 98 days curing, whereas the 0.5mm crack shrunk to 0.43mm wide, 0.39mm to 0.26mm, and 0.19mm to 0.13mm. Although the self-healing appears to be taking longer, it is more durable and efficient in the long run. Micro fractures caused by ambient temperature and humidity cycles, as well as mix percent, compaction, and curing, all affect concrete permeability. Micro cracks can be repaired with bacterial-impregnated concrete before they become big fissures. As a result, the structure's longevity has increased. Although the bacterial concrete self- healing process is slow, it is more effective than other crack arresting methods in the long run.

CONCLUSION

Immersion of a normal concrete cube specimen in salt water results in a 0.87 percent weight increase, whereas bacterially impregnated concrete results in a 0.39 percent weight gain. The acquired result is provided in the table (1).

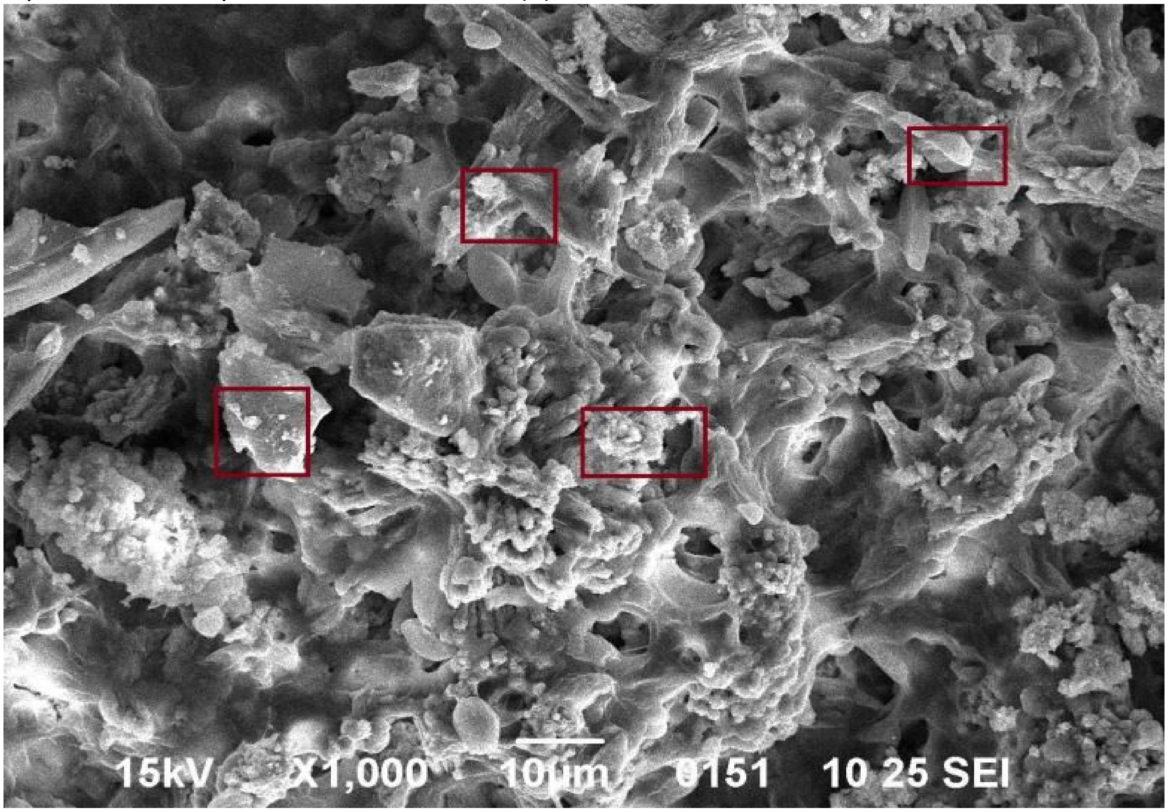

Figure 1.SEM Test result (presence of calcium calcite precipitate inside crack of Concrete specimen)

Bacterial concrete weight loss after exposure to sulfuric acid was investigated using cubes in line with ASTMC267. Bacterial Concrete Specimens and Control Specimens were compared in terms of weight change percentage. When a standard concrete cube specimen is immersed in sulphuric acid, it loses 0.91 percent of its weight, whereas bacterial impregnated concrete loses 0.91 percent. The acquired result is provided in the table (2). The action of acid caused a 36.71 percent drop in compressive strength in conventional concrete, but only 14.48 percent in bacterial concrete. At 28 days, a saturation water absorption test was carried out on 100mm cubes in compliance with IS 2185-1979.When conventional concrete is compared to bacterial concrete, the percentage of water absorption is higher. In traditional concrete, 1.14 percent water absorption was recorded, but in bacterial concrete, it was 0.24 percent (table 3). It was discovered that the bacterial mixed concrete was more durable than the conventional mix. In bacterial mix concrete, microorganisms or $CaCO_3$, precipitate inhabit the pore spaces. The weakest zone is inter-facial transition zone in concrete, narrows because of the high adhesion between cement and particles. Even dead cells function as organic fibres within the concrete matrix. Over the course of 100 days, the sample with 0.1mm crack width recovered fully. According to durability test, concrete with bacteria mixed is denser and lasts much longer than conventional control mix. Bacterial infused mix is one-of-a-kind concrete that has ability to repair surface cracks and boost durability.

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