STUDY OF PHYSICAL CHARACTERISTS OF SELF-HEALING CONCRETE

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ABSTRACT

This study explores the effectiveness of Bacillus subtilis in enhancing the self-healing capacity and mechanical performance of concrete. Using the Microbiologically Induced Calcite Precipitation (MICP) technique, bacterial concrete was prepared by incorporating bacterial solution into the mix, replacing conventional water. The performance of bacterial concrete was evaluated through compressive and flexural strength tests. Results demonstrated significant improvements in strength and durability compared to plain concrete, with visible crack healing within a few weeks. The deposition of calcium carbonate by bacterial activity sealed microcracks, reducing permeability and enhancing structural integrity. This research promotes an eco-friendly, cost-effective alternative for sustainable construction and long-term infrastructure performance.

Keyword: - *Self-healing concrete, Bacillus subtilis, MICP, crack mitigation, durability.*

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1. INTRODUCTION

Concrete is the most widely used construction material, but its susceptibility to cracking poses challenges to durability and structural integrity. Traditional repair methods are often costly and environmentally taxing. Recent advancements have introduced the concept of self-healing concrete using microorganisms. This study focuses on the use of Bacillus subtilis, a resilient bacterium capable of inducing calcium carbonate precipitation to heal cracks through the Microbiologically Induced Calcite Precipitation (MICP) process. By integrating bacterial solutions into the concrete mix, this research aims to evaluate improvements in compressive and flexural strength, offering a sustainable, self-repairing alternative for enhancing the lifespan of concrete structures.

1.1 Concept of Biomineralization

Biomineralization is a natural process where microorganisms form minerals as metabolic byproducts. In concrete, this leads to calcite deposition, aiding in self-healing.

1.2 Bio-Concrete Mechanism

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1.4 Crack Remediation by Bacteria

Bacteria like Bacillus subtilis precipitate $CaCO_3$ when conditions like pH, calcium ion concentration, and nucleation sites are optimal, promoting crack healing.

1.5 Objectives

- Optimize bacterial density and dosage
- Study bacterial crack healing
- Improve strength and durability

- Promote sustainable construction materials

2. MATERIALS

2.1 Cement

Cement acts as a binding material in concrete, providing strength and stability. It is commonly used with sand and aggregates. In this study, Portland Pozzolana Cement (PPC) was used, meeting IS standards. Key properties such as specific gravity (3.2), consistency (37%), and initial and final setting times (30 mins and 600 mins) were evaluated to ensure quality and performance.

Particulars (IS 456:2000)	Range
Specific Gravity	3.2
Consistency	37%
Fineness modulus	10% should be retained
Initial setting time	30 mins
Final setting time	600 mins

Table 1 Properties of cement

2.2 Aggregate

Aggregates are essential for providing strength and stability in concrete. They are broadly classified based on source, size, and shape.

2.2.1 Classification of Aggregates

Aggregates are categorized by their origin (natural or artificial), size (fine or coarse), and shape (angular, rounded, etc.).

2.2.2 Fine Aggregate

Fine aggregates consist of natural sand or crushed stone (≤ 4.75 mm). They help in finishing and improving workability.

2.2.2.1 Sand

River sand with a specific gravity of 2.65 and fineness modulus of 5.24 was used, conforming to IS 383 standards.

2.2.2.2 M-sand (Manufactured Sand)

M-sand is a sustainable alternative to river sand. It has a specific gravity between 2.5–2.9 and a fineness modulus of 4.66.

2.2.3 Coarse Aggregate

Coarse aggregates (10–20 mm) were machine-crushed stones with specific gravity of 2.78 and bulk density of 1935.3 kg/m³, ensuring strength and durability in concrete.

2.3 Water

Water is a key ingredient in concrete, essential for hydration and workability. Only clean, potable water free from acids, oils, and organic matter was used. Maintaining the proper water-cement ratio is critical to achieve desired strength and prevent issues like shrinkage or cracks.

2.4 Bacteria

Bacteria play a vital role in self-healing concrete by precipitating calcium carbonate to seal cracks. Specific strains are selected for their durability and calcite-producing ability.

2.4.1 Selection of Bacteria

Strains like Bacillus subtilis are chosen for their high $CaCO_3$ production and ability to survive harsh conditions. Factors like cell concentration, nutrient availability, and environmental conditions affect their performance.

2.4.2 Bacillus subtilis

Bacillus subtilis is a gram-positive, spore-forming, aerobic bacterium known for its stress resistance and ability to survive in alkaline environments. It is ideal for self-healing concrete due to its ability to form calcite and improve concrete properties.

2.4.2.1 Characterization

It thrives at 25–35°C and forms endospores under stress, enhancing its survival in concrete. It is non-pathogenic and widely studied in biotechnology for its robustness and application in bio-concrete.

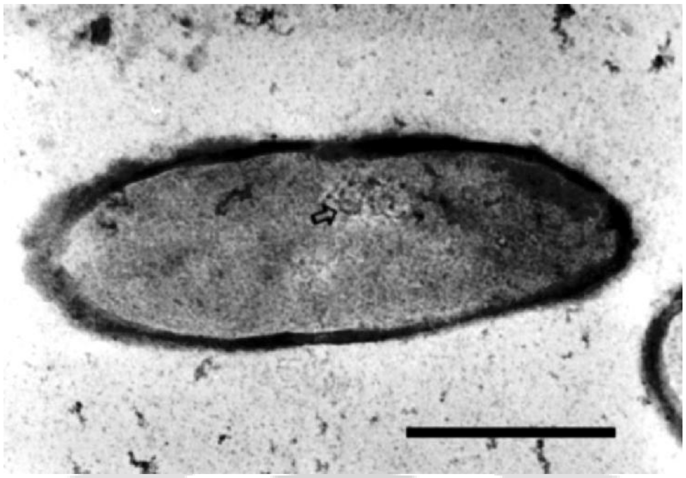

Fig 1 TEM micrograph of B. Subtilis cell in cross-section

3. EXPERIMENT METHODS

Experimental methods explain about the methods used in the preparation of Bacterial concrete and also the types of tests to be conducted for the prepared specimen according to the standard procedure.

Fig 2 Addition of bacteria to water

Fig 3 Adding Bacteria water

Fig 4 Bacterial concrete

Fig 5 Compaction

3.1 Preparation of Bacterial Solution

The bacterial solution was prepared by adding 24 ml of Bacillus subtilis broth to 1000 ml of distilled water. This mixture was divided into four containers of 250 ml each and incubated for 12 hours at 37°C to allow bacterial germination. After incubation, the solutions were combined into a single container and maintained at a controlled temperature to ensure bacterial viability before use in concrete mixing.

3.2 Incorporation of Bacteria into Concrete

The prepared bacterial solution replaced conventional mixing water in the concrete mix. Bacteria were introduced at specific concentrations of 10^5 cells/ml and 10^6 cells/ml, corresponding to 24 ml and 240 ml per litre respectively. This ensured uniform bacterial distribution throughout the concrete matrix to promote effective self-healing.

3.3 Casting of Concrete Specimens

Cube Casting:

- Concrete cubes of dimensions 150 mm × 150 mm × 150 mm were cast as per IS:10086-1982 standards.
- Moulds were cleaned, oiled, and filled in layers of 5 cm thickness with proper tamping using a 16 mm diameter steel rod.

Beam Casting:

- Beams of size 150 mm × 150 mm × 700 mm were prepared following IS 516:1959 specifications.
- Concrete was poured in layers and compacted thoroughly by rodding and side tapping to avoid air voids and segregation.

3.4 Demoulding and Curing

Specimens were carefully demoulded after 16 to 24 hours. If adequate strength was not achieved, demoulding was postponed by another 24 hours. After removal, each specimen was clearly marked for identification, and the moulds were cleaned to maintain shape accuracy for future use. Specimens were then submerged in a curing tank until the designated testing dates.

4. RESULTS AND DISCUSSION

4.1 Compressive Strength Test

Compressive strength tests were performed on both conventional and bacterial concrete cubes (150 mm × 150 mm × 150 mm) using a 400 kN Universal Testing Machine. Cubes were cured and tested at 7, 14, and 28 days.

The results indicated that bacterial concrete exhibited significantly higher compressive strength compared to conventional concrete, confirming the positive impact of bacterial incorporation on structural performance.

Days	Flexural strength of normal concrete (Mpa)	Flexural strength of bacteria concrete (Mpa)	Increased strength
14	2.72	3.10	18.09
28	3.24	3.97	26.48

Table 2 Compression test value of plain and bacterial concrete

The compressive strength was calculated using:

$$Compressive\ Strength = \frac{Maximum\ Load\ Carried\ by\ Specimen}{Top\ surface\ area\ of\ specimen}$$

Example calculation:

Load = 463 kN
Area = 150 mm × 150 mm = 22,500 mm²
Compressive Strength ≈ 20.57 N/mm²

Bacterial activity enhanced strength by promoting calcium carbonate precipitation, improving durability, reducing permeability, and minimizing steel corrosion risk.

4.2 Flexural Strength Test

Flexural strength tests were carried out on concrete beams measuring 150 mm × 150 mm × 700 mm using a flexural testing machine, following the ASTM C293 standard procedure. The aim was to determine the tensile strength of concrete under bending and to compare the performance between conventional and bacterial concrete specimens.

Testing was conducted after 14 and 28 days of curing. The flexural strength, expressed as Modulus of Rupture (MR) in megapascals (MPa), was calculated using center-point loading configuration to ensure consistency.

The results indicated that bacterial concrete showed a significant improvement in flexural strength compared to conventional concrete, with increases of 18.09% after 14 days and 26.48% after 28 days. This enhancement is attributed to the bacterial activity promoting calcium carbonate precipitation, which effectively filled microcracks and improved crack-bridging capability.

Days	Flexural strength of normal concrete (MPa)	Flexural strength of bacteria concrete (MPa)	Increased strength
14	2.72	3.10	18.09
28	3.24	3.97	26.48

Table 3 Flexural strength value normal and bacterial concrete

Thus, bacterial concrete not only increases tensile strength but also enhances the overall durability and self-healing ability of concrete structures, reducing long-term maintenance needs.

5. SUMMARY AND CONCLUSIONS

5.1 Summary

This study explored the development of self-healing concrete using Bacillus subtilis bacteria to enhance durability and crack resistance. Material properties of sand, M-sand, aggregates, and cement were verified against IS standards before mix preparation.

Concrete specimens were cast with bacterial water at a mix ratio of 1:1.3:2.75. During curing, bacterial activity was observed, contributing to the gradual improvement in compressive and flexural strength. The presence of bacterial biomass acted as natural fibers within the concrete, further increasing its mechanical properties.

Bacterial concrete exhibited reduced water absorption, porosity, and permeability, leading to enhanced dynamic modulus and durability. Cracks up to 400 µm were effectively healed within 44 days, demonstrating the potential of Bacillus subtilis as an eco-friendly admixture for sustainable construction.

5.2 Conclusion

Self-healing concrete using *Bacillus subtilis* offers an effective solution for enhancing structural durability by autonomously repairing cracks. The bacterial activity promotes calcium carbonate precipitation, sealing microcracks, reducing permeability, and mitigating steel corrosion.

Although initial production costs are higher, bacterial concrete significantly reduces long-term maintenance expenses and extends service life, making it a sustainable alternative for infrastructure development.

The study confirmed that microbial concrete improves compressive and flexural strength compared to conventional concrete. However, large-scale adoption requires further research to optimize bacterial survivability, reduce costs, and validate long-term performance in diverse environmental conditions.

Overall, bacterial self-healing technology represents a promising step toward greener, longer-lasting construction materials.

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