



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Issue 3, March 2026

Development and Performance Analysis of Self-Healing Concrete

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ABSTRACT: The concept of self-healing concrete represents a significant innovation in sustainable construction technology. This project aims to explore the potential of *Bacillus subtilis* bacteria in enhancing the self-healing capacity of concrete used for civil engineering structures. The primary purpose of this study is to compare the performance of bacterial concrete with conventional concrete in terms of compressive strength and healing behaviour. The bacteria, when incorporated into the mix, remain dormant until cracks occur. Upon crack formation and contact with moisture, the bacteria become active and precipitate calcium carbonate, effectively sealing the cracks and restoring the integrity of the structure. In this study, 24 concrete cubes of M20 grade were prepared — including conventional concrete and bacterial concrete with 2.5% and 5% bacterial dosages by cement weight. Standard curing was carried out for 7 and 21 days to observe both strength and healing performance. The results indicated that bacterial concrete exhibited a slight reduction in early compressive strength compared to normal concrete; however, the healing potential was observed in the cracked specimens, proving the bacteria's effectiveness in reducing permeability and enhancing durability.

The experiment suggests that optimizing bacterial dosage and using proper encapsulation or nutrient medium can further improve performance. This study contributes to the growing field of self-healing materials and demonstrates that bacterial concrete can be a cost-effective, eco-friendly, and sustainable solution for enhancing the service life of concrete structures, especially under Indian climatic conditions.

KEYWORDS: Self-Healing Concrete, *Bacillus subtilis*, Bacterial Concrete, Compressive Strength, Crack Healing, Sustainable Construction, Durability

I. INTRODUCTION

Concrete is the most commonly used construction material across the world due to its excellent strength, workability, durability, and cost-effectiveness. It is used in almost every type of structure from buildings and bridges to roads and dams. However, despite its widespread use, concrete has one major limitation its tendency to develop cracks. Cracks are unavoidable due to shrinkage, temperature variations, overloading, and other environmental effects.

Once cracks form, they act as pathways for the ingress of water, carbon dioxide, and harmful chemicals such as chlorides and sulphates. These substances reach the steel reinforcement and cause corrosion, leading to a gradual reduction in the strength, durability, and service life of concrete structures. Over time, these cracks can expand and require costly maintenance or repair work. Conventional methods such as epoxy injection, grouting, or surface coating can temporarily repair cracks but are not durable, labour-intensive, and costly in the long term.

To address this challenge, researchers have developed an innovative material known as self-healing concrete. This type of concrete has the remarkable ability to repair its own cracks autonomously without any external human intervention. The concept is inspired by biological systems that naturally heal wounds, such as human skin. In self-healing concrete, special bacteria are introduced into the concrete mix.

Among various bacterial species tested, *Bacillus subtilis* has shown excellent performance because it can survive in the harsh alkaline environment of concrete and form calcium carbonate (CaCO_3) when activated by water and oxygen. These bacteria remain in a dormant state for years. When cracks form and water enters, the bacteria get activated and convert the calcium-based nutrients present in the concrete into calcium carbonate, which fills and seals the cracks. This process is similar to the natural healing of materials and effectively restores the integrity of the structure.

The use of bacterial concrete offers several key benefits:

- It improves the durability and strength of structures.
- It reduces maintenance and repair costs.
- It enhances sustainability by increasing the service life of buildings.

It helps in reducing environmental pollution by minimizing the use of repair materials.

In the present study, an attempt has been made to develop and test self-healing concrete using *Bacillus subtilis* bacteria in different proportions (2.5% and 5% by weight of cement) and compare its properties with conventional concrete of M20 grade. The research mainly focuses on evaluating compressive strength, crack healing efficiency, and overall performance under Indian environmental conditions.

The primary aim of this study is to explore whether bacterial concrete can act as a cost-effective and sustainable solution for repairing and extending the life of structures. By combining modern microbiological concepts with traditional concrete technology, this project aims to take a step toward next-generation smart materials in civil engineering. With rapid advancements in material science, the demand for high-performance heat-resistant tiles is growing across various industries. As modern infrastructure and technology continue to evolve, the need for reliable, long-lasting, and energy-efficient thermal insulation solutions becomes even more critical. This project aims to explore the development, properties, and applications of heat-resistant tiles, shedding light on the latest innovations and their potential impact on industrial and residential sectors.

II. LITERATURE SURVEY

- **Sanjay Chowdhury, Rachita Ray, and Partha Sarathi Ghosh “Self-Healing Concrete – A Sustainable Material,” *International Journal of Civil and Structural Engineering*, 2020.**

The authors studied the concept of bacterial self-healing concrete and concluded that incorporating *Bacillus subtilis* into the concrete mix enhances the ability of concrete to autonomously heal cracks when exposed to moisture. Their results demonstrated significant improvements in compressive strength, reduction in water permeability, and enhanced durability compared to conventional concrete. The research emphasizes the sustainability aspect, as bacterial self-healing concrete can extend the service life of structures while minimizing maintenance costs and material wastage.

- **Mugahed Amran, Ali M. Onaizi, Roman Fediuk, Raizal S. M. Rashid, and Togay Ozbakkalogl “Self-Healing Concrete as a Prospective Construction Material,” *Construction and Building Materials Journal*, 2021.** This paper provides an extensive review of bacterial self-healing mechanisms and the different types of healing agents used. It discusses the biological process of calcium carbonate precipitation through bacterial metabolism and how it helps fill cracks in concrete. The authors concluded that self-healing concrete shows higher compressive strength, reduced permeability, and greater sustainability over long-term exposure. They also identified key challenges such as bacteria.

- **Ramakrishnan Subramanian, Sanjay Kesavan, Sathrapathi Sevugaperumal, Shanthanu Sivakumar. “Strength Behavior Analysis of Self-healing Concrete Using Bacteria and Silica Gel: A Comparative Study,” *Periodica Polytechnica Civil Engineering*, Vol. 68(4), 2024.**

This study examines the flexural (bending) strength of concrete incorporating *Bacillus subtilis*. Results indicate that bacterial concrete exhibits significantly higher flexural strength and smaller crack widths compared to normal concrete after 28 days of curing. The improvement in flexural performance demonstrates the potential of bacterial concrete for structural components exposed to flexural stresses.

- Rakenth R. Menon, Jing Luo, and Hui Zhou et al. “Screening of Fungi for Application of SelfHealing Concrete,” *Cement and Concrete Research*, 2020.

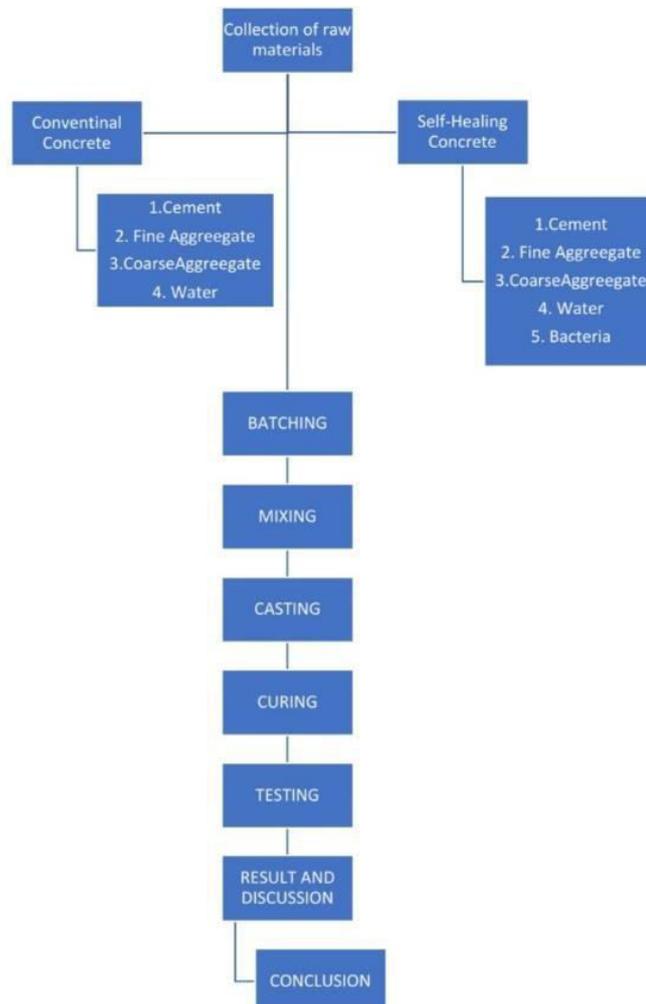
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Concluded that bacterial concrete had lower water absorption and improved impermeability compared to control samples.

- Mir Aijaz Ahmad and Umer Farooq “Self-Healing of Concrete: A Review,” *International Journal of Recent Technology and Engineering*, 2020.

This paper presents a comparative analysis of various self-healing agents, such as bacteria, encapsulated systems, and chemical additives. It concludes that bacterial-based healing offers the most eco-friendly and efficient results. However, the authors emphasize the need to reduce production costs and standardize bacterial concentrations for practical applications in large-scale construction. noted that bacteria-based self-healing concrete resists chloride penetration and reduces microcrack formation over time.

III. METHODOLOGY



The quality of the process in a self-healing concrete project depends on how effectively the healing Mechanism is integrated, tested, and evaluated. Key points:

A. Mixing and Casting

- Uniform distribution of self-healing agents (microcapsules, bacterial spores, etc.) is critical.
- Mixing speed and duration must be optimized to prevent breaking microcapsules or killing bacteria.
- Proper compaction ensures minimal voids and a consistent matrix.

B. Crack Induction & Testing

- Cracks should be induced in a controlled and repeatable way (e.g., using CTM or loading frame).
- The width of the crack (usually <0.3 mm) must be measured precisely.
- Healing conditions (moisture, temperature, and curing duration) must replicate real environmental Conditions.

C. Evaluation of Healing

- Post-healing evaluation should include both visual inspection (crack closure) and mechanical Recovery (strength regain).
- Non-destructive tests like Ultrasonic Pulse Velocity (UPV) or Water Permeability Test help confirm Internal healing.
- Quality control ensures consistency between batches and reproducibility of results.

D. Documentation & Analysis

- Every step—from mixing proportions to test results—should be recorded for quality assurance.

IV. EXPERIMENTAL RESULTS

1. Compressive Strength Test

The compressive strength test was conducted on the concrete samples. The conventional concrete cubes showed a steady increase in strength with curing age, indicating normal hydration and proper mix proportioning. The results confirmed that the control mix achieved the expected compressive strength for M20 grade concrete and served as a reference for comparison.

The concrete mix containing 2.5% bacterial solution showed slightly lower early-age compressive strength compared to conventional concrete, but a noticeable strength gain was observed at later curing stages. This indicates that the bacterial addition influenced the strength development over time while maintaining acceptable structural performance. The concrete mix with 5% bacterial content showed poor compressive strength and structural stability. The cubes exhibited weak bonding, high porosity, and premature failure during testing, indicating that excessive bacterial dosage negatively affected strength development. This confirms that controlled bacterial concentration is essential for maintaining compressive strength.

Conventional concrete (Without Bacteria)					
7 Days			28 Days		
Specimen	Load/(N)	Compressive Strength (N/mm ²)	Specimen	Load/(N)	Compressive Strength (N/mm ²)
1	365	16.22	1	540	24
2	350	15.56	2	544	24.18
3	355	15.78	3	560	24.9
Average		15.83			24.36

Compressive Strength of Conventional concrete

Conventional concrete + 2.5% Bacteria						
7 Days			28 Days			
Specimen	Load/(N)	Compressive Strength (N/mm ²)	Specimen	Load/(N)	Compressive Strength (N/mm ²)	Strength
1	325	14.4	1	410	18.23	
2	330	14.67	2	450	20	
3	325	14.4	3	435	19.34	
Average		14.5			19.2	

Compressive Strength of Conventional concrete + 2.5% Bacteria concrete

Conventional concrete + 5% Bacteria						
7 Days			28 Days			
Specimen	Load/(N)	Compressive Strength (N/mm ²)	Specimen	Load/(N)	Compressive Strength (N/mm ²)	Strength
1	N. A	N. A	1	N. A	N. A	
2	N. A	N. A	2	N. A	N. A	
3	N. A	N. A	3	N. A	N. A	
Average		N.A			N.A	

Compressive Strength of Conventional concrete + 5% Bacteria concrete

V. CONCLUSION

- To prepare self-healing concrete using bacterial culture (*Bacillus subtilis*): - Concrete cubes were prepared with 2.5% and 5% bacterial content. The 2.5% mix showed acceptable workability, while the 5% mix failed due to disturbance in cement hydration.
- To evaluate the crack-healing ability of self-healing concrete: - The 2.5% bacterial concrete showed limited micro-crack sealing after curing, whereas no healing was observed in the 5% mix due to poor bonding.
- To compare the compressive strength of bacterial concrete with conventional concrete: - Conventional concrete showed the highest strength, followed by the 2.5% bacterial mix. The 5% mix showed very low strength, confirming 2.5% as the optimum dosage.
- To analyse the performance of bacterial concrete under Indian climatic conditions: - Bacterial concrete performed moderately under ambient Indian conditions, with temperature and humidity affecting bacterial activity.
- To determine suitable material properties and proportions for M20 grade self-healing concrete: - A mix proportion of 1:1.5:3 was found suitable for M20 grade concrete, with all materials satisfying IS code requirements.
- To study the durability and sustainability aspects of bacterial concrete :- Bacterial concrete showed potential to reduce micro-crack propagation, indicating scope for sustainable construction with further optimization.

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