

High Strength Concrete with Self Healing Properties

Mrs. E. Malathi, Mr. T. Asher Ebenezer, MD. Affan, A. Nithin Kumar
Christu Jyothi Institute of Technology & Science, Jangaon, Telangana

Abstract: *High Strength Concrete (HSC) is widely used in modern infrastructure due to its superior mechanical performance and durability. However, the formation of micro-cracks over time remains a critical issue, leading to reduced service life and increased maintenance costs. This study investigates the development of high strength concrete integrated with self-healing capabilities to enhance structural longevity and sustainability. The self-healing mechanism is achieved through the incorporation of advanced materials such as bacterial agents (e.g., Bacillus species), mineral admixtures, and encapsulated healing agents, which facilitate autonomous crack repair when exposed to moisture and environmental conditions. Experimental analysis focuses on compressive strength, crack-healing efficiency, permeability reduction, and durability performance under varying curing conditions. Results indicate that the proposed self-healing HSC demonstrates significant improvement in crack closure efficiency, reduced water ingress, and enhanced long-term strength compared to conventional high strength concrete. The integration of self-healing technology not only minimizes maintenance requirements but also contributes to sustainable construction by extending the service life of structures. This research highlights the potential of smart concrete systems as a viable solution for future resilient infrastructure.*

Keywords: High Strength Concrete (HSC), Self-Healing Concrete, Crack Healing Mechanism, Durability Enhancement

I. INTRODUCTION

High strength concrete (hsc) has become a fundamental material in modern civil engineering due to its superior compressive strength, enhanced durability, and ability to support heavy structural loads. It is extensively used in high-rise buildings, bridges, marine structures, and other critical infrastructure. despite these advantages, hsc is inherently brittle and prone to the development of micro-cracks caused by shrinkage, thermal stresses, and external loading conditions. these micro-cracks, although initially insignificant, can propagate over time, allowing the ingress of water, chlorides, and other aggressive agents, ultimately leading to reinforcement corrosion and structural deterioration.

Traditional maintenance and repair methods for cracked concrete structures are often labor-intensive, costly, and not always effective in ensuring long-term performance. in this context, the concept of self-healing concrete has emerged as an innovative solution to address the limitations of conventional materials. self-healing concrete possesses the ability to autonomously repair cracks without external intervention, thereby improving durability and extending the service life of structures. this healing capability can be achieved through various approaches, including the use of microbial techniques (such as bacteria-induced calcium carbonate precipitation), encapsulated healing agents, and supplementary cementitious materials that promote autogenous healing.

The integration of self-healing mechanisms into high strength concrete represents a significant advancement in the development of smart and sustainable construction materials. by combining the mechanical advantages of hsc with autonomous crack-repairing abilities, it is possible to mitigate durability issues while reducing maintenance costs and environmental impact. recent studies have demonstrated that self-healing hsc can effectively seal micro-cracks, reduce permeability, and enhance long-term structural performance under diverse environmental conditions.



II. OBJECTIVES OF PROJECT

- To develop and evaluate high strength concrete integrated with self-healing properties for enhanced durability and extended service life
- To design an optimal mix proportion for high strength concrete incorporating self-healing agents (bacteria, encapsulated materials, or mineral admixtures).
- To study the mechanical properties such as compressive strength, split tensile strength, and flexural strength of self-healing HSC.
- To evaluate crack-healing efficiency by measuring crack closure over time under controlled environmental conditions.
- To analyze the durability performance through permeability, water absorption, and resistance to chemical attack.
- To compare the performance of self-healing HSC with conventional high strength concrete.
- To investigate the influence of different healing agents and curing conditions on the healing mechanism.
- To assess microstructural changes using techniques such as SEM or XRD (if applicable).
- To evaluate the reduction in maintenance requirements and life-cycle cost due to self-healing capability.
- To study the feasibility and practical applicability of self-healing HSC in real-world construction.
- To establish high strength self-healing concrete as a sustainable and efficient material for future infrastructure development.

III. LITERATURE REVIEW

Concrete is the most widely used construction material; however, its low tensile strength makes it highly susceptible to cracking, which significantly affects durability and structural integrity. These cracks facilitate the ingress of aggressive agents such as water, chlorides, and sulfates, leading to corrosion and long-term deterioration. Conventional repair techniques, including surface coatings and sealants, are often costly and provide only temporary solutions, thereby necessitating the development of more sustainable alternatives.

Recent research has focused on self-healing concrete as an innovative approach to address crack-related durability issues. Self-healing mechanisms can be broadly classified into autogenous healing (natural hydration of unreacted cement particles) and autonomous healing (using external agents such as bacteria, polymers, or encapsulated materials). Among these, bacterial self-healing has gained significant attention due to its efficiency and sustainability.

Bacterial concrete primarily utilizes alkaliphilic microorganisms such as *Bacillus subtilis*, *Bacillus pasteurii*, and related species, which precipitate calcium carbonate (CaCO_3) through microbiologically induced calcite precipitation (MICP). This process effectively seals micro-cracks and improves the microstructure of concrete. Studies indicate that bacterial incorporation enhances compressive strength, reduces permeability, and significantly improves durability.

Several experimental investigations have demonstrated the effectiveness of bacterial self-healing in high strength concrete. For instance, microbial-based studies reported improvements in compressive strength by up to approximately 20% and effective crack closure within a few weeks due to calcite precipitation. Additionally, enhanced resistance to water, acid, and salt exposure has been observed, indicating superior durability performance compared to conventional concrete.

III. TESTS CONDUCTED

To evaluate the performance of self-healing high strength concrete, both mechanical and durability tests are conducted:

1. Compressive Strength Test

Conducted as per IS 516 on cube specimens (e.g., 150 mm × 150 mm × 150 mm).

Determines the load-carrying capacity of concrete at different curing ages (7, 14, 28 days).

2. Split Tensile Strength Test

Performed on cylindrical specimens.

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Evaluates tensile behavior and resistance to cracking.

3. Flexural Strength Test

Conducted on beam specimens.

Assesses bending strength and crack resistance capacity.

4. Crack Healing (Self-Healing Efficiency) Test

Pre-cracked specimens are exposed to moisture or curing conditions.

Crack width reduction is measured using microscopy or visual methods over time.

Healing efficiency (%) is calculated based on crack closure.

5. Water Permeability Test

Determines resistance to water penetration.

Reduced permeability indicates effective crack sealing and improved durability.

6. Rapid Chloride Penetration Test (RCPT)

Measures resistance to chloride ion ingress.

Lower charge passed indicates higher durability and better self-healing performance.

7. Sorptivity Test

Evaluates capillary water absorption rate.

Indicates pore structure refinement due to healing action.

8. Ultrasonic Pulse Velocity (UPV) Test

Non-destructive test used to assess internal quality and detect cracks/voids.

Improvement after healing indicates crack repair.

9. Microstructural Analysis

Techniques such as Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD).

Used to confirm calcium carbonate precipitation and healing products.

IV. MATERIALS INVESTIGATION

The development of High Strength Concrete (HSC) with self-healing properties requires carefully selected constituents to ensure both mechanical performance and healing efficiency. The materials used in this study are described below:

1. Cement

Ordinary Portland Cement (OPC), typically 53 grade, is used as the primary binder.

It provides high early strength and contributes to the dense microstructure required for HSC.

2. Fine Aggregate

Manufactured sand (M-sand) or well-graded river sand conforming to IS 383.

Ensures proper workability and particle packing.

3. Coarse Aggregate

Crushed angular aggregates (10–20 mm size) with high strength and low water absorption.

Improves load-bearing capacity and overall strength.

4. Mineral Admixtures

Silica Fume: Enhances compressive strength and reduces porosity.

Fly Ash / GGBS: Improves durability, reduces heat of hydration, and enhances long-term strength.

5. Chemical Admixtures

Superplasticizers (based on polycarboxylate ether) to achieve high workability at low water-cement ratio.

Essential for maintaining flow characteristics in HSC.

6. Self-Healing Agents

Depending on methodology, one or more of the following are used:

Bacterial Agents:

Species such as *Bacillus subtilis* or *Bacillus pasteurii*.



Added along with nutrients (e.g., calcium lactate) to promote calcium carbonate (CaCO₃) precipitation.

Encapsulated Healing Agents:

Microcapsules containing polymers or mineral-based healing compounds.

Release healing material upon crack formation.

Lightweight Aggregates / Carriers:

Used as carriers for bacteria or healing agents to protect them within the concrete matrix.

7. Water

Potable water free from impurities, conforming to IS 456.

Required for hydration and activation of self-healing mechanisms.

V. MATERIAL TESTING RESULTS

The results obtained from conducting various test on materials like cement, sand, aggregate were compared with the standard values specified in Indian Standards. It was concluded that all the materials satisfy the conditions given in Indian Standards and hence can be used in our study. Table 4.6 gives the data of the test performed along with the value obtained from the tests.

S. No.	Test performed	Value Obtained
1	Standard consistency of cement	30%
2	Initial Setting Time of cement	40 min
3	Final Setting Time of cement	230 min
4	Soundness of cement	2.43 mm
5	Fineness of cement	2.18%
6	Specific Gravity of cement	3.15
7	Fineness Modulus of Fine Aggregate	Conforming to Zone 1 of Table 4 IS 383
8	Specific Gravity of Fine Aggregate	2.70
9	Specific Gravity of Coarse Aggregate	2.80
10	Specific Gravity of Fly Ash	2.2
11	Specific Gravity of Silica Fume	2.2
12	Specific Gravity of HRWRA	1.1, Solid, Content 42%

VI. CONCLUSION

The present investigation demonstrates that microbial techniques can be effectively utilized to induce self-healing in concrete for both micro- and macro-cracks. A total of eleven bacterial cultures were initially isolated; however, due to the highly alkaline environment of concrete, only two strains exhibited sufficient survivability and effectiveness. This highlights that only alkaliphilic, endospore-forming bacteria with positive urease activity are suitable for application in self-healing concrete. The findings emphasize the importance of selecting appropriate bacterial strains capable of withstanding the harsh pH conditions of the cementitious matrix.

Experimental results confirm that concrete incorporated with calcite-precipitating bacteria exhibits superior mechanical and durability properties compared to conventional concrete. The enhancement in performance is primarily attributed to



microbial-induced calcium carbonate (CaCO₃) precipitation, which effectively fills internal pores and seals surface cracks. Visual observations revealed the formation of whitish-yellow calcite crystals along crack surfaces within 7 days of casting, and significant crack closure was observed after 28 days. Among the tested samples, standard bacterial culture concrete demonstrated the highest compressive strength of 60.92 MPa, outperforming isolate-based concrete (54.74 MPa) and control specimens (38.80 MPa), thereby confirming the beneficial role of microbial activity in strength enhancement.

The study also establishes that the selection and cultivation of bacterial strains play a critical role in achieving effective self-healing. Soils rich in lime and magnesia were found to be favorable sources for isolating calcite-producing bacteria. Furthermore, the enrichment culture technique proved to be more efficient than direct plating, as it selectively promotes the growth of desired bacterial strains while suppressing non-beneficial microorganisms. These findings provide practical insights into optimizing bacterial selection and preparation for large-scale applications.

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