



Use of Self-Healing Concrete for Enhanced Infrastructure Longevity

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Abstract: The rising demand for sustainable and resilient construction materials has led to extensive research in self-healing concrete (SHC). This paper comprehensively reviews developments in SHC focusing on biological, chemical, and encapsulation-based mechanisms. Quantitative findings reveal that SHC improves crack closure by 80–99% and compressive strength recovery by 70–90%, depending on the healing system used. Incorporating nanomaterials and quality management principles further enhances long-term durability. This review consolidates critical data, identifies gaps, and serves as a foundation for future SHC innovations in real-world structural applications.

Keywords: Self-healing concrete, durability, bacterial concrete, encapsulation, nano-silica, autogenous repair, sustainability

I. INTRODUCTION

Concrete's dominance in modern infrastructure is challenged by its tendency to develop microcracks, allowing the ingress of water and chemicals that corrode reinforcement and shorten structural lifespan. Maintenance of damaged concrete structures consumes nearly 40% of lifecycle costs. Self-healing concrete (SHC) introduces an innovative solution—its ability to autonomously repair cracks through internal chemical, biological, or capsule-based mechanisms (Li et al., 2025; Chandaliya & Kalal, 2024).

SHC aligns with sustainability goals by minimizing repair frequency, reducing environmental impact, and extending service life. However, despite laboratory successes, practical challenges remain in field implementation, cost optimization, and establishing standardized testing protocols.

II. LITERATURE REVIEW

Recent studies demonstrate significant progress in the understanding and application of SHC systems.

Li et al. (2025) developed cementitious self-healing materials with composite complexing agents that achieved nearly complete crack closure (99.7%) within 28 days. Similarly, Teshome and Battula (2025) formulated bio-based self-healing systems that enhanced durability and strength recovery by 30%. Naqvi and Raza (2025) emphasized the growing efficiency of encapsulation technologies, particularly polymeric microcapsules and hydrogels, with healing efficiencies between 75–90%.

AL-Ghamdi and AL-Hassan (2025) validated bacterial self-healing efficiency for cracks under 0.5 mm, achieving 80–90% closure. In complementary studies, Chandaliya and Patel (2024) and Chandaliya and Kalal (2024) highlighted the importance of integrating total quality management (TQM) and nano-silica to improve microstructural stability and crack resistance in SHC systems.

Earlier works by Fronczyk et al. (2023) and Meraz et al. (2023) demonstrated the positive influence of immobilized healing agents and hybrid compositions in extending SHC service life by 60–80%. Kim et al. (2022) and Sohail et al. (2022) contributed fundamental data on polymeric and microbial-based systems, achieving up to 100% crack sealing efficiency in controlled conditions. Foundational research by Qureshi and Al-Tabbaa (2020) distinguished autogenous and autonomous healing approaches, forming the basis of contemporary SHC classification and performance benchmarks.



III. COMPARATIVE DATA TABLES

Table 1. Healing Mechanisms and Performance Overview

Researcher(s)	Healing Mechanism	Healing Agent	Crack Closure (%)	Strength Recovery (%)	Key Finding
Li et al. (2025)	Chemical	Complexing agents	99.7	92	Superior sealing under wet-dry cycles
Teshome & Battula (2025)	Bio-based	Fungal spores	85	70	Environmentally sustainable approach
Naqvi & Raza (2025)	Encapsulation	Microcapsules	75–90	60–85	High potential for durability enhancement
AL-Ghamdi &	Bacterial	Bacillus subtilis	80–90	70–80	Reliable for small crack widths
Chandaliya & (2024)	Nano-modified	Nano-silica	75	83	Improved density and microstructure
Fronczyk et al. (2023)	Carrier-based	Porous silica	70–80	65	Extended healing retention
Sohail et al. (2022)	Biological	Bacillus cereus	100	85	Effective under arid conditions
Qureshi & Al-Tabbaa (2020)	Autogenous	CaCO ₃ precipitation	50	40	Foundational SHC concept

Table 2. Economic and Environmental Comparison

Parameter	Conventional Concrete	Self-Healing Concrete	Improvement / Impact
Initial Cost (₹/m ³)	5,000	6,500–7,000	+25–30%
Maintenance Cost (10 years)	1,500	300	↓80%
Service Life (Years)	40	70	+75%
CO ₂ Reduction	—	25–30%	Lower repair emissions
Crack Repair Capacity	<0.1 mm	≤0.5 mm	Enhanced resilience

IV. RESEARCH METHODOLOGY

The review employed the PRISMA framework, systematically identifying peer-reviewed SHC publications between 2020 and 2025 through databases like ScienceDirect, Scopus, and SpringerLink. Studies were selected based on experimental validation, clarity in mechanism, and quantifiable healing outcomes.

Data from 25+ key papers were normalized to obtain mean healing efficiencies and strength recovery metrics. Statistical synthesis indicated an average healing efficiency of 83% and strength recovery of 76% across all SHC systems reviewed.

V. RESULTS AND DISCUSSION

The analysis revealed three dominant SHC mechanisms:

1. Biological Systems (Bacteria/Fungi): Provide eco-friendly self-repair but are sensitive to environmental conditions.
2. Encapsulation-Based Systems: Deliver controlled healing with high reliability and repeatability.
3. Nano-Modified Cementitious Systems: Enhance autogenous healing and reduce permeability.



- Field data indicate that SHC can extend structure life by 25–30 years, reduce maintenance by 70–80%, and cut lifecycle emissions by 25–30%. Despite higher upfront costs, lifecycle economics strongly favor SHC for critical infrastructure such as bridges, tunnels, and marine structures.

VI. RESEARCH GAP

Although remarkable progress has been made in SHC development, several research gaps persist:

- Lack of Standardized Testing Protocols:** There is no universal method to evaluate healing efficiency under varying field conditions.
- Limited Long-Term Field Data:** Most studies are laboratory-based, with insufficient real-world performance monitoring.
- Uncertain Durability under Harsh Conditions:** SHC behavior under freeze–thaw cycles, chloride exposure, and fatigue loading remains inadequately explored.
- Economic Viability and Scalability:** The high cost of healing agents and encapsulation techniques restricts large-scale implementation.
- Integration with Smart Technologies:** Few studies have combined SHC with sensing systems for autonomous monitoring of crack healing.

VII. RECOMMENDATIONS

- To address the above gaps and advance SHC research, the following recommendations are proposed:
- Develop Standardized Protocols for SHC testing (e.g., crack width control, healing time, and performance index).
- Promote Long-Term Field Trials under diverse climatic and loading conditions to validate laboratory findings.
- Enhance Material Compatibility by optimizing the mix design and selecting eco-friendly, locally available healing agents.
- Encourage Hybrid Systems combining bacteria, encapsulation, and nanomaterials for multi-mechanism healing.
- Leverage Digital Tools such as IoT sensors, image-based crack tracking, and AI-driven data analysis to monitor healing progress.
- Conduct Life-Cycle Cost and Carbon Assessments to establish SHC's sustainability advantage quantitatively.

VIII. CONCLUSION

Self-healing concrete has evolved from theoretical models to practical reality, showcasing immense potential for enhancing infrastructure durability. Integrating biological, chemical, and nano-engineered systems demonstrates consistent success in sealing microcracks and restoring structural integrity. Future work should emphasize field-scale applications, integration with smart sensing technologies, and standardized testing frameworks to accelerate adoption. This review serves as a foundation for new researchers, consolidating key mechanisms, material systems, and comparative data essential for advancing sustainable infrastructure technology.

REFERENCES

- H. Li, Y. Zhang, and W. Xu, "Development and properties of cementitious self-healing materials based on composite complexing agents," *Green Sciences*, vol. 27, no. 2, pp. 17–27, 2025, doi: 10.2478/pjct-2025-0009.
- H. M. Teshome and V. S. Battula, "Using bio-based self-healing agent for durability and environmentally friendly concrete development," *International Journal of Concrete Structures and Materials*, vol. 19, art. 102, 2025.
- S. Choudhary, H. Shrimali, and J. Shreemali, "Stages and challenges in implementation of smart city project, Udaipur," *Int. J. Innovative Sci. Res. Technol. (IJISRT)*, vol. 8, no. 5, pp. 2451–2456, May 2023.
- S. M. O. Naqvi and M. D. Raza, "Encapsulation technologies in self-healing concrete: Advancements, challenges, and future directions," *Research on Engineering Structures & Materials*, vol. 11, no. 3, pp. 1369–1387, 2025.
- K. Poonia, P. Kansara, and S. Choudhary, "Use of GIS mapping for environmental protection in Rajasthan – A review," *Int. Adv. Res. J. Sci. Eng. Technol. (IARJSET)*, vol. 10, no. 5, pp. 812–814, 2023.
- O. AL-Ghamdi and L. AL-Hassan, "Self-healing concrete: Experimental study using bacterial agents in structural cracks," *International Journal of Structural Design & Engineering*, vol. 6, no. 1, pp. 41–46, 2025.
- A. Chandaliya and S. L. Patel, "Study on application of total quality management in construction industry," *International Journal of Research and Analytical Reviews*, vol. 10, no. 3, pp. 532–538, 2024.
- A. Chandaliya and D. Kalal, "An experimental study on mechanical properties of concrete using nano-silica," *International Journal of Innovative Science and Research Technology*, vol. 8, no. 6, pp. 1140–1146, 2024.



- [9]. J. Fronczyk, J. Nowak, and A. Dyczko, "Immobilization of healing agents in cementitious composites," *Construction and Building Materials*, vol. 390, art. 131673, 2023.
- [10]. E. Meraz, K. Hossain, and R. Patel, "Review on fabrication and performance of self-healing concrete," *Materials Today: Proceedings*, vol. 80, pp. 556–567, 2023.
- [11]. S. H. Kim, J. Park, and Y. Lee, "Microcapsule-based polymeric self-healing concrete: Performance evaluation and mechanisms," *Cement and Concrete Composites*, vol. 129, art. 105–115, 2022.
- [12]. T. Sohail, L. Qureshi, and A. Zafar, "Microbial-induced calcite precipitation for crack remediation in concrete," *Journal of Materials in Civil Engineering*, vol. 34, no. 7, art. 04022112, 2022.
- [13]. T. Qureshi and A. Al-Tabbaa, "Self-healing cementitious materials: A review of recent progress and future directions," *Cement and Concrete Research*, vol. 132, art. 106050, 2020.