A Survey Paper on Enhancing Properties and Economy in Self-Healing Concrete

Prof. P. V. Kapure[1], K. M. Katare[2]

[1]*Lecturer in Department of Civil Engineering, AISSMS Polytechnic, Pune, Maharashtra, India*
[2]*Student of Final Year Diploma in Civil Engineering, AISSMS Polytechnic, Pune, Maharashtra, India*
(Kennedy Road, Near RTO, 411001)

Abstract - *Concrete cracking can reduce durability and service life by allowing the ingress of water and other aggressive agents. Self-healing concrete offers a potential solution by enabling cracked concrete to partially restore its properties. The present study investigates a simplified self-healing concrete system using sodium silicate as the primary chemical healing agent, crystalline admixture as a supporting healing component, and silica fume for matrix densification and strength improvement. A PCE-based super-plasticizer is used to maintain workability while controlling the water-to-binder ratio. M20, M25 and M30 concrete grades are investigated using a common experimental procedure. Controlled cracking is introduced after curing, followed by sodium-silicate treatment and a specified healing period. Compressive strength is evaluated before cracking, after cracking, and after healing to determine the percentage strength recovery. The study aims to address gaps in previous research by using a consistent methodology and quantitatively evaluating mechanical recovery across different concrete grades, providing a simple and practical approach to self-healing concrete.*

Key Words: Self-healing concrete, Sodium silicate, Crystalline admixture, Silica fume, Super-plasticizer, Strength recovery, M20, M25, M30.

1. INTRODUCTION

Concrete is one of the most widely used construction materials because of its high compressive strength, durability, availability, and economical nature. However, cracking is an inherent problem in concrete and may occur due to drying shrinkage, thermal variations, mechanical loading, inadequate curing, and environmental exposure. Even relatively small cracks can provide pathways for water and aggressive agents, which may accelerate deterioration and reduce the service life of concrete structures. Conventional crack-repair techniques such as sealing, grouting, and injection require external intervention and may become difficult when cracks repeatedly occur or are located in inaccessible regions. This has led to increasing interest in self-healing concrete, which can partially restore its properties after cracking through autogenous or autonomous healing mechanisms. Previous studies have investigated bacterial, chemical, mineral and polymer-based approaches; however, differences in concrete grade, healing procedure, crack-generation method, and evaluation criteria make direct comparison of their performance difficult. In the present study, sodium silicate is selected as the primary chemical healing agent because its silicate species can participate in reactions with calcium-bearing phases and contribute to the formation of healing products within cracks. Crystalline admixture is incorporated as a supporting healing material because its moisture-activated action can promote the formation of insoluble crystalline products that contribute to crack sealing. Silica fume is used as a supplementary cementitious material because it is very fine and reactive particles can refine the pore structure, densify the cementitious matrix, and support compressive-strength development. A PCE-based super-plasticizer is used to improve workability while maintaining a controlled water-to-binder ratio. Thus, each material has a specific function in the proposed concrete system rather than being used only for increasing the number of additives. The five research studies considered in this work indicate that existing investigations have mainly focused on individual healing mechanisms, particularly bacterial systems, while comparatively limited attention has been given to a simple chemical healing system evaluated using a consistent methodology. The literature also shows variations in concrete grades, crack widths, healing conditions and testing procedures, with comparatively less emphasis on quantitative compressive-strength recovery. Therefore, this study investigates M20, M25 and M30 concrete incorporating silica fume and crystalline admixture, with sodium silicate used as the principal post-cracking healing treatment. A common experimental procedure is adopted for the three concrete grades, including controlled cracking, healing and compressive-strength evaluation before cracking, after cracking, and after healing. The study aims to determine the influence of concrete grade and the proposed healing system on strength recovery and crack-healing performance, thereby addressing the identified gaps through a simple and practically achievable experimental methodology.

2. LITERATURE REVIEW

Self-healing concrete has been investigated as an approach for reducing the effects of cracking and improving the durability and service life of concrete structures. The reviewed studies mainly investigate biological self-healing, particularly bacterial systems, and demonstrate the potential of such systems to reduce crack width and improve concrete performance. However, differences in concrete grade, healing conditions, crack-generation procedures and evaluation methods indicate the need for a simpler and more consistent experimental approach. Meera and Vishnudas (2025) investigated the mechanical and micro-structural behavior of bacterial and two-component bacterial concrete and evaluated their self-healing capability. Their study demonstrated the potential of bacterial systems for crack healing and improvement in concrete performance, while micro-structural observations supported the formation of healing products. However, the study mainly concentrated on bacterial systems, with comparatively less emphasis on a simple chemical healing system and systematic comparison of strength recovery across different concrete grades. Adil et al. (2024) investigated the ability of Bacillus subtilis to heal cracks and improve the performance of concrete after cracking. The study demonstrated that bacterial activity contributed to crack closure and showed the potential of biological self-healing concrete. However, biological healing involves additional considerations such as bacterial viability and nutrient availability. Therefore, the study indicates the need for investigating comparatively simpler chemical healing approaches for practical concrete applications. Vishal, Chepuri et al. (2025) experimentally investigated bacteria-based self-healing concrete and evaluated the effect of bacterial action on cracked concrete. Their findings indicated that bacterial concrete could reduce crack width and improve concrete properties after the healing period. However, differences in concrete grade, crack-generation procedures and testing methodology limit direct comparison with other studies. A common experimental methodology and systematic evaluation of strength recovery are therefore required. Joshi and Rai (2018) investigated the self-healing characteristics of concrete using Bacillus subtilis and examined factors affecting crack-healing performance. The study demonstrated the potential of self-healing mechanisms for reducing the effects of cracking, and the reviewed manuscript reports approximately 65–70% recovery of original strength after 30–40 days of self-healing in the investigated bacterial specimens. However, greater emphasis was identified as necessary on quantitative post-healing mechanical recovery and comparison between different concrete grades using a common healing system. Meghashree et al. (2025) investigated self-healing behavior and evaluated the effectiveness of a healing technique in improving concrete performance. The investigated approach showed potential for reducing the effects of cracking and improving concrete durability and performance. However, the study identified the need for further systematic investigation using a comparatively simple chemical healing system and quantitative compressive-strength recovery across M20, M25 and M30 concrete grades.

Table -1: Summary of Literature Review and Identified Research Gaps

Sr. No	Title of Research Paper	Author and Year	Aim/ Objective	Major Findings / Conclusion	Research Gap
1	Mechanical and Microstructural Evaluation of Bacterial and Two-Component Bacterial Concretes	Meera and Vishnudas (2025)	To evaluate the mechanical and micro-structural behavior of bacterial and two-component bacterial concrete and investigate their self-healing capability.	Bacterial systems demonstrated potential for crack healing and improvement in concrete performance. Micro-structural observations supported the formation of healing products.	Mainly focuses on bacterial systems; comparatively less emphasis on a simple chemical healing system combined with strength-enhancing matrix modification.
2	Investigation on Self-Healing Concrete Using Bacillus subtilis Bacteria	Adil et al. (2024)	To investigate the ability of Bacillus subtilis to heal cracks and improve the performance of concrete after cracking.	Bacterial activity contributed to crack closure and demonstrated the potential of biological self-healing concrete.	Biological healing requires considerations such as bacterial viability and nutrient availability; a simpler chemical healing approach requires further investigation.
3	Bacterial Self-Healing Concrete / Related	Vishal, Chepuri et al. (2025)	To investigate bacterial self-healing	Bacterial concrete showed potential for	Differences in concrete grade, crack-

	Bacterial Healing Study		behavior and evaluate the effect of bacterial action on cracked concrete.	reducing crack width and improving properties after the healing period.	generation procedure and testing methodology limit direct comparison; a common methodology for quantitative strength recovery is required.
4	Self-Healing Concrete: Related Investigation	Joshi and Rai (2018).	To study the self-healing characteristics of concrete and the factors affecting crack-healing performance.	Self-healing mechanisms demonstrated potential for reducing crack effects.	Greater emphasis is required on quantitative post-healing mechanical recovery and comparison across concrete grades using a common healing system.
5	Self-Healing Concrete: Recent Investigation	Meghashree et al. (2025)	To investigate self-healing behavior and evaluate the effectiveness of a healing technique in improving concrete performance	The investigated approach showed potential for reducing crack effects and improving concrete durability/performance.	Further systematic investigation is required using a simple chemical healing system with quantitative compressive-strength recovery across M20, M25 and M30 grades.

2.1. Research Gap

The reviewed studies demonstrate the potential of self-healing concrete, particularly bacterial systems, for reducing crack effects and improving concrete performance. However, limited attention has been given to simple chemical healing systems that can be practically implemented in conventional concrete. Variations in concrete grades, crack-generation procedures, healing conditions, healing periods, and testing methods also make direct comparison between existing studies difficult. Furthermore, visual crack closure alone does not necessarily indicate recovery of the mechanical capacity of cracked concrete. Therefore, greater emphasis is required on quantitative post-healing compressive-strength recovery using a common experimental methodology across different concrete grades. Accordingly, the present study addresses these gaps by investigating a simple chemical self-healing system using sodium silicate as the primary healing agent, supported by crystalline admixture, while silica fume is incorporated to improve matrix density and strength development. The study considers M20, M25, and M30 concrete grades and applies a common procedure involving controlled cracking, healing treatment, and compressive-strength evaluation. The percentage recovery of compressive strength is used as the principal quantitative measure of healing performance. This approach aims to provide a practical and consistent framework for evaluating self-healing performance across different concrete grades.

3. AIMS AND OBJECTIVES

The present study is focused on evaluating a simple chemical self-healing concrete system using sodium silicate as the primary healing agent, supported by crystalline admixture and silica fume. The study considers M20, M25 and M30 concrete grades and evaluates their self-healing performance through controlled cracking and compressive-strength recovery.

3.1. Aims

- To investigate the self-healing performance of M20, M25 and M30 grade concrete.
- To evaluate the recovery of compressive strength after controlled cracking and healing.
- To study the influence of concrete grade on the healing performance.

3.2. Objectives

- To add and prepare M20, M25 and M30 concrete mixes incorporating/ using sodium silicate as the primary chemical healing agent, silica fume, crystalline admixture and PCE-based super-plasticize to improve workability while maintaining a controlled water-to-binder ratio during concrete production
- To investigate the effectiveness of sodium silicate as the primary chemical healing agent for sealing controlled cracks and improving the mechanical properties with percentage recovery of crack.
- To calculate and compare the percentage recovery of compressive strength after healing and evaluate the influence of concrete grade on the self-healing performance.

Table -2: How the Present Study Fills the Research Gaps

SR. no.	Identified Research Gap	How are practical work fills the Gaps
1	Previous studies mainly focused on bacterial self-healing systems.	The present study investigates a simple chemical self-healing system using sodium silicate as the primary healing agent, supported by crystalline admixture and silica fume, with super-plasticizer for workability control.
2	Different studies used different concrete grades and methodologies, making comparison difficult.	The present study uses a common experimental methodology for M20, M25 and M30 concrete grades to enable systematic comparison.
3	Many studies emphasize visual crack closure as an indication of healing.	The present study quantitatively evaluates compressive-strength recovery before cracking, after cracking and after the healing period.
4	Limited comparison of healing performance across different concrete grades using one healing system.	The present study compares the healing performance of M20, M25 and M30 concrete under the same healing conditions and using the same sodium-silicate-based healing system.
5	Different crack-generation and healing procedures make results difficult to compare.	The present study uses a controlled cracking procedure followed by a defined and consistent healing period for the specimens.
6	Mechanical recovery after cracking and healing is not consistently evaluated.	The present study compares pre-cracking, post-cracking and post-healing compressive strength and calculates the percentage strength recovery to quantitatively assess healing performance.

4. METHODOLOGY

The experimental program was designed to investigate the self-healing performance of M20, M25 and M30 concrete using sodium silicate as the primary chemical healing agent. Crystalline admixture was incorporated as a supporting healing component, while silica fume was used to improve matrix density and compressive strength. PCE-based super-plasticizer was used to maintain workability at a controlled water-to-binder ratio.

4.1 Materials

The materials used were OPC 53 grade cement, fine aggregate, 20 mm coarse aggregate, silica fume, crystalline admixture, sodium silicate solution, PCE-based super-plasticizer and water.

- Silica fume: 5% of cementitious material for matrix densification and strength improvement.
- Crystalline admixture: 0.5% of cementitious material as a supporting moisture-activated healing component.
- Sodium silicate: primary chemical healing agent applied to controlled cracks after pre-cracking.
- PCE super-plasticizer: used to improve workability while maintaining the selected water-to-binder ratio.

4.2 Mix Design

M20, M25 and M30 concrete mixes were prepared using the absolute-volume method as per IS 10262:2019. The same material system and general procedure were followed for all three grades to enable comparison.

Table -3: Mix design (Preliminary values to be verified by laboratory trial mixes)

Parameter to add By weight	**M20**	**M25**	**M30**
Silica fume	0.78%	0.87%	0.97 %
Crystalline admixture	0.08%	0.09%	0.10%
Water/binder ratio	≈0.50	≈0.45	≈0.40
Sodium silica (Post-cracking)	1.0%	1.0%	1.0%

4.3 Casting and Curing

The cement, silica fume and crystalline admixture were dry-mixed with the aggregates. Water containing the required PCE super-plasticizer was then added gradually and the concrete was mixed until uniform. The concrete was cast into 150 mm cube moulds, compacted properly and label. After de-moulding, the specimens were water-cured, with 28 days adopted as the principal curing age.

4.4 Controlled Cracking and Healing

After curing, controlled hairline cracks were introduced using a compression-testing machine. Loading was stopped immediately after the desired crack formation without completely crushing the specimen.

Sodium silicate was then applied directly to the crack as the primary healing treatment. The specimens were maintained under the same controlled healing condition for the specified healing period. Crack-width observations were recorded where possible.

4.5. Compressive Strength and Strength Recovery

Compressive strength was evaluated at three stages:

- Before cracking
- After controlled cracking
- After healing

The percentage strength recovery was calculated using

$$\text{Strength Recovery }\% = \frac{(\text{Post healing} - \text{Cracked})}{(\text{Original} - \text{Cracked})} \text{ X } 100$$

The results for M20, M25 and M30 were compared to evaluate the influence of concrete grade on self-healing performance.

5. RESULTS AND DISCUSSION

The results are evaluated to determine the effect of the proposed self-healing system on M20, M25 and M30 concrete. Compressive strength before cracking, after controlled cracking and after the healing period is considered to assess the mechanical recovery and compare the healing performance of the three concrete grades.

5.1. Results

Expected Compressive Strength:-

The expected compressive-strength results for M20, M25 and M30 concrete are presented in Table 4. The original compressive strength is expected to increase with the concrete grade, while controlled cracking is expected to cause a reduction in strength for all three grades. After the healing period, the sodium-silicate-treated specimens are expected to recover a significant portion of the lost compressive strength. This recovery is primarily attributed to the action of sodium silicate as the main chemical healing agent, with crystalline admixture providing a supporting moisture-activated healing mechanism. The incorporation of silica fume is expected to contribute to matrix densification and improved strength development.

Table -4: Expected compressive-strength results

Concrete Grade	**Original Strength (MPa)**	**Cracked Strength (MPa)**	**Expected Post-healing Strength (MPa)**
M20	24.0	17.0	21.8
M25	30.0	21.5	27.8
M30	36.0	26.0	33.0

Expected Compressive Strength recovery:-

The expected compressive-strength recovery values for M20, M25 and M30 concrete are presented in Table 5. The proposed healing system is expected to restore a considerable portion of the compressive strength lost after controlled cracking. The recovery is attributed mainly to the sodium-silicate treatment, supported by the crystalline admixture and the dense cementitious matrix provided by silica fume. The percentage strength recovery is calculated by comparing the strength lost during cracking with the strength regained after the healing period. The expected results indicate that the proposed system has the potential to provide measurable mechanical recovery across all three concrete grades. These values are provisional expected values and will be replaced by the actual experimental results after cube casting and testing.

Table -5: Expected Compressive-Strength Recovery:-

Concrete Grade	Original Strength (MPa)	Cracked Strength (MPa)	Expected Post-healing Strength (MPa)	Expected Strength Recovery (%)
M20	24.0	17.0	21.8	68.6%
M25	30.0	21.5	27.8	74.1%
M30	36.0	26.0	33.0	70.0%

5.2. Discussion

The expected results indicate that controlled cracking is likely to reduce the compressive strength of M20, M25 and M30 concrete. After the healing period, the sodium-silicate-treated specimens are expected to recover a significant portion of the strength lost during cracking. The expected recovery suggests that the proposed chemical healing system can contribute to restoration of the damaged cementitious matrix.

The healing performance is expected to result primarily from sodium silicate, which acts as the main chemical healing agent and can contribute to the formation of healing products within the cracked region. The crystalline admixture provides a supporting moisture-activated mechanism that may promote additional crystalline products in cracks and pores. The combined action of these materials is expected to improve crack sealing and mechanical recovery compared with the cracked condition.

The incorporation of silica fume is expected to improve the density and compactness of the cementitious matrix because of its fine particle size and pozzolanic activity. This may contribute to higher initial compressive strength and provide a relatively dense matrix for the healing process. The PCE-based super-plasticizer supports the required workability while maintaining the selected water-to-binder ratio.

The comparison of M20, M25 and M30 is expected to show that concrete grade influences both initial strength and post-healing performance. However, a higher concrete grade cannot be assumed to provide a proportionally higher percentage of strength recovery, since healing performance also depends on crack characteristics, moisture availability, healing-agent penetration and the condition of the cementitious matrix.

Overall, the proposed system provides a simple and practical approach to self-healing concrete by combining a primary chemical healing agent with a supporting crystalline mechanism and a strength-supporting silica-fume-modified matrix. The final discussion and conclusions will be updated using the actual experimental values obtained from cube casting and testing. The numerical values currently presented in Tables 4 and 5 are expected values and should not be considered measured experimental results.

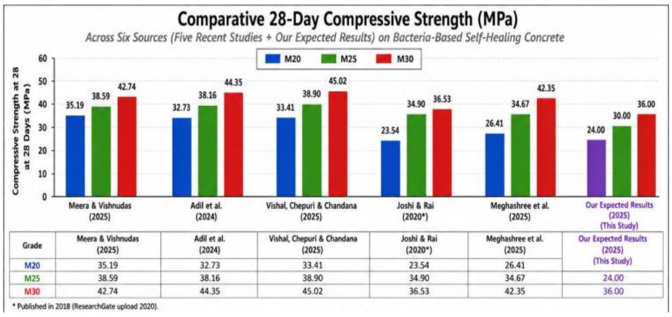

Chart-1: Expected compressive Strength Graph

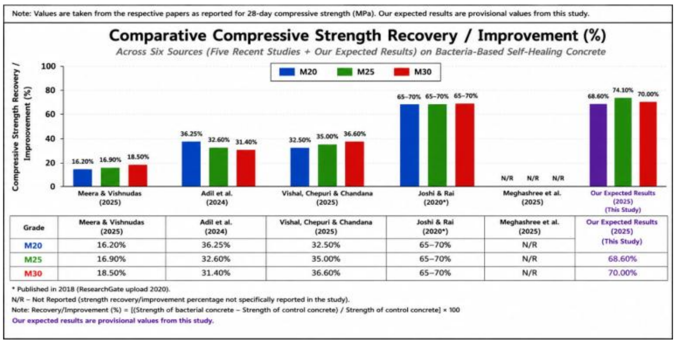

Chart-2: Expected compressive Strength recovery Graph

6. CONCLUSIONS

The present study proposes a simple and practical self-healing concrete system for M20, M25 and M30 grades using sodium silicate as the primary chemical healing agent, crystalline admixture as a supporting healing component, and silica fume for matrix densification and strength improvement. PCE-based super-plasticizer is used to maintain suitable workability while controlling the water-to-binder ratio.

The proposed methodology uses a common procedure involving concrete casting, curing, controlled crack formation, sodium-silicate treatment and subsequent healing. Compressive strength before cracking, after cracking and after healing is considered as the principal parameter for evaluating the effectiveness of the healing system.

The expected results indicate that the proposed system can recover a considerable portion of the compressive strength lost due to controlled cracking. The combined action of sodium silicate and crystalline admixture is expected to promote healing within the cracked region, while silica fume is expected to contribute to a denser and stronger cementitious matrix.

The comparison of M20, M25 and M30 concrete is expected to provide an understanding of the influence of concrete grade on strength recovery under similar healing conditions. The study therefore provides a comparatively simple experimental approach for investigating chemical self-healing concrete and addressing the research gaps identified from the reviewed literature.

The numerical values presented in the present manuscript are provisional expected values and will be replaced by the actual experimental results obtained after casting, cracking, healing and compressive-strength testing.

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BIOGRAPHIES

Author 1:Prof. P. V. Kapure is a Professor in the Department of Civil Engineering at AISSMS Polytechnic Pune, Maharashtra. He has experience in civil engineering areas such as Engineering Mechanics, Construction Materials and Design of Steel & RCC Structures etc. He has guided various academic projects and research activities. His guidance and technical knowledge contributed significantly to the completion of this survey paper.

Author 2**:** K.M. Katare is a 3rd year Civil Engineering student at AISSMS Polytechnic Pune, Maharashtra. He is interested in construction materials, concrete technology and sustainable construction practices. He has worked on the study of self-healing concrete and the application of sodium silicate for improving concrete properties and economy. This research work was carried out as part of his academic project.