Enhancing the Self-Healing Properties of M25 Concrete Using Silica Fume and Superabsorbent Polymer: An Experimental Approach

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Abstract**:** ***Concrete is a widely used construction material, but one of the significant problems is cracking in structures, which may later cause severe damage to the structure. An ultimate solution for this problem is the self-healing of concrete. This study employs an experimental approach to investigate self-healing in M25 grade concrete using silica fume and a superabsorbent polymer. This experimental approach utilised a fixed proportion of silica fume and SAP. The amount of silica fume was 10% of the cement weight, and 0.45% of SAP was added to increase the self-healing efficiency. The strength of the concrete specimen was also tested. It was found that concrete specimens made with silica fume, along with SAP, exhibit greater stability compared to concrete specimens made with silica fume alone. It was observed that crack closure in concrete made with silica fume took 33 days, while concrete specimens made with silica fume along with SAP took 17 days. This study demonstrates the potential of using silica fume and SAP in concrete to enhance the durability and lifespan of structures, thereby promoting sustainability.***

Keywords**:** ***M25 concrete, Silica Fume, Super absorbent polymer, Self-healing***

Abbreviations:
SAP: Super Absorbent Polymer
OPC: Ordinary Portland Cement

I. INTRODUCTION

The study investigates the synergistic effects of silica fume and superabsorbent polymer (SAP) in promoting self-healing, particularly for crack widths. The combination of these materials is expected to result in faster and more efficient crack closure, improved durability, and reduced maintenance, making this approach highly advantageous for sustainable construction.

The experimental investigation of silica fume as a partial replacement [1] in M25-grade concrete explores its potential to enhance self-healing properties and mechanical strength. Special attention is given to its self-healing ability, assessed through crack closure observation and strength tests. The results indicate that silica fume promotes the formation of calcium silicate hydrates, which helps seal cracks and enhances the material's durability. Additionally, the microstructure becomes denser, contributing to improved mechanical properties. This investigation highlights silica fume as a promising material for sustainable and durable construction, particularly in applications that require self-healing concrete.

Superabsorbent polymer (SAP) is a unique additive used in concrete to enhance its performance and durability. SAP is a hydrophilic material capable of absorbing and retaining large amounts of water relative to its weight, forming a gel-like structure [3]. This capability makes SAP highly effective for applications such as internal curing and self-healing of concrete cracks. The primary aim of this project is to investigate the self-healing properties of M25-grade concrete incorporating silica fume and SAP. The study aims to enhance concrete's durability and sustainability by leveraging the pozzolanic reaction of silica fume to improve its microstructure and strength, while utilising SAP as an internal curing agent to facilitate autonomous crack healing. The project aims to evaluate the effectiveness of these materials in improving mechanical properties, reducing water permeability, and promoting crack closure, thereby contributing to the development of low-maintenance, cost-effective, and durable concrete structures. Furthermore, the project aims to assess the effectiveness of these materials in improving mechanical properties such as compressive, tensile, and flexural strength while also reducing water permeability and supporting crack closure over time. Additionally, the study seeks to optimise the dosages of silica fume and SAP for maximum self-healing efficiency. By evaluating these modified concretes' long-term durability and crack-healing capabilities, the project aims to reduce maintenance costs, extend the service life of concrete structures, and contribute to more sustainable and cost-effective construction practices.

II. OBJECTIVES

This project aims to define the key objectives, deliverables, and boundaries to ensure a clear understanding of its scope and boundaries. The scope of our project is mainly to investigate the individual effects of silica fume

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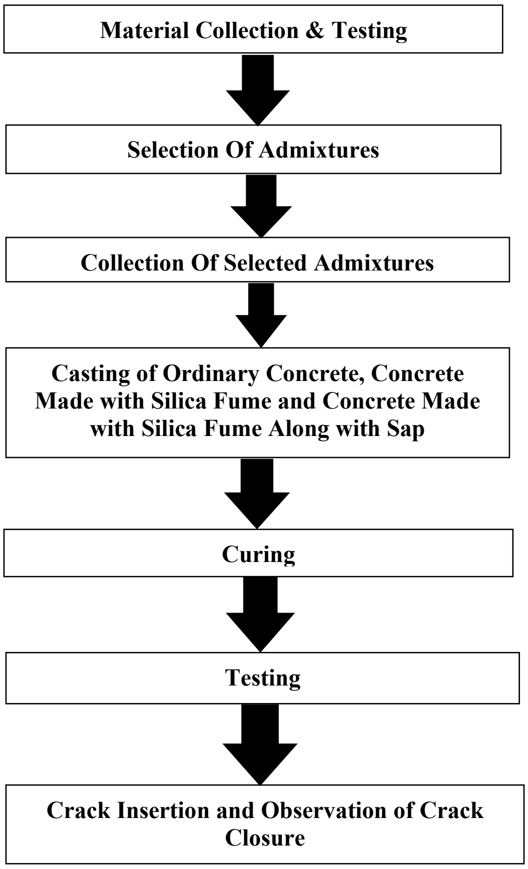
on the self-healing ability of concrete, to analyse the combined effect of silica fume and superabsorbent polymers on the self-healing properties of concrete, to evaluate the impact of silica fume and superabsorbent polymers on the compressive, tensile, and flexural strength of concrete and to compare the self-healing performance of concrete with silica fume and SAP against ordinary concrete

III. METHODOLOGY

Figure 1 illustrates the methodology, which involves several steps, including material collection and testing, crack insertion, and observation of crack closure.



[Fig.1. Flowchart]

IV. TESTS ON MATERIALS

We used ordinary Portland cement (OPC) of grade 53, took M-sand for fine aggregate, and gravel of nominal size 20 -40mm as coarse aggregate, and added potable water for mixing.

To improve the self-healing property, we used silica fume in combination with sap, as opposed to using silica fume alone.

A. Tests on cement

The tests on cement conducted are:

- Standard consistency of cement
- Initial setting time of cement

The value of the standard consistency of cement was obtained as 32%

The result for an initial setting time was greater than 30 minutes.

B. Test on aggregate

The tests conducted were

- Bulk density, void ratio, porosity & specific gravity of aggregates
- Sieve analysis

The test results obtained are

i. Coarse aggregate

- Bulk density = 1.44 g/cc
- Void ratio = 79%
- Porosity = 0.442
- Sp. Gravity = 2.6

ii. Fine aggregate

- Bulk density = 1.71 g/cc
- Void ratio = 45%
- Porosity = 0.313
- Specific Gravity = 2.49

From sieve analysis, the fineness of fine aggregate was 3.2, and the fineness of coarse aggregate was 7.64

V. MIX DESIGN

The mix design is critical to ensuring the desired properties of concrete, including strength, durability, and workability. In this study, the mix design was developed for three types of concrete: Ordinary Concrete, Concrete Made with Silica Fume, and Concrete Made with Silica Fume and Super Absorbent Polymer (SAP). The proportions and calculations for each mix design are provided below:

A. Ordinary Concrete

For the ordinary concrete mix (M25 grade), the mix design was conducted based on the conventional 1:1:2 mix proportion, which consists of one part cement, one part fine aggregate, and two parts coarse aggregate by weight. The following parameters were utilized for the mix design.

- Total Volume = 49235.1754 cm^3
- Specific Gravity of Cement = 3.1
- Specific Gravity of Fine Aggregate = 2.5
- Specific Gravity of Coarse Aggregate = 2.6
- For M25 Concrete, the proportion is 1:1:2
- Weight of cement required = 25.37kg
- Weight of Sand Required =25.37kg
- Weight of Coarse Aggregate = 50.37kg
- Weight of Water = 11.92 l

The water-to-cement ratio for this mix was maintained at 0.47 to ensure workability and sufficient hydration for the cement particles. The mix was designed to achieve the target compressive strength of 25 MPa (M25-grade).

B. Concrete Made with Silica Fume

The mix design for the concrete made with silica fume is the same as that of ordinary concrete. The amount of silica fume used is 10% by weight of cement, and the water content is taken as 0.5 [1]. That 10% of silica fume replacement by weight of cement shows maximum compressive strength, maximum split tensile strength, and maximum flexural strength [1]. The main goal of adding silica

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fume is to improve the concrete's resistance to cracking, shrinkage and increase its overall strength. Thus,

- weight of cement = 22.26 kg
- weight of silica fume = 2.474 kg
- weight of water = 12.37 liters

C. Concrete Made with Silica Fume Along with Sap

An amount of 0.45% by weight of cement [2]. Concrete specimens of 6 cubes, six cylinders, and six beams were made with silica fume with SAP, with the mentioned amount.

The SAP was introduced into the mix with silica fume to create a more efficient self-healing mechanism. The amount of SAP is carefully controlled to ensure that it does not adversely affect the workability of the concrete while still providing sufficient healing potential.

D. Test on concrete

To evaluate the performance of the concrete mixes to understand the effects of silica fume and Super Absorbent Polymer (SAP) on concrete's strength and workability, a series of tests were conducted on both freshly prepared concrete and hardened concrete specimens. These tests were performed at varying curing ages of 7, 14, and 28 days to assess the evolution of the concrete's mechanical properties over time.

E. Workability Test (Slump Test)

The slump test was conducted on freshly prepared concrete to assess its workability and consistency. The slump test is an indicator of the fluidity and ease with which the concrete can be mixed, transported, and placed. It provides an assessment of the concrete's cohesion and homogeneity, ensuring that the mix design is appropriate for the intended application.

F. Tests on Hardened Concrete

After the concrete was cured for specific durations (7, 14, and 28 days), various strength tests were conducted to determine the mechanical properties of the concrete, including compressive strength, splitting tensile strength, and flexural strength. These tests are critical for understanding how the addition of silica fume and SAP influences the overall strength and durability of the concrete.

G. Compressive Strength Test

Compressive strength is a fundamental property of concrete, indicating its ability to withstand axial loads. Concrete cubes were cast and cured for 7, 14, and 28 days, after which they were subjected to the compressive strength test using a compression testing machine. The cubes were loaded until failure, and the maximum load was recorded. The compressive strength was calculated by dividing the maximum load by the cross-sectional area of the cube. This test provides insight into the concrete's ability to bear load and its suitability for structural applications.

H. Splitting Tensile Strength Test

To evaluate the tensile behavior of the concrete, splitting tensile strength tests were conducted on cylindrical specimens. The cylindrical samples were subjected to an axial load applied diametrically across the specimen. The maximum load at failure was recorded, and the splitting tensile strength was determined using the standard formula for tensile stress. This test assesses the concrete's resistance to tensile forces and is particularly relevant for concrete in structures subjected to bending or tensile stresses, such as pavements and beams.

I. Flexural Strength Test

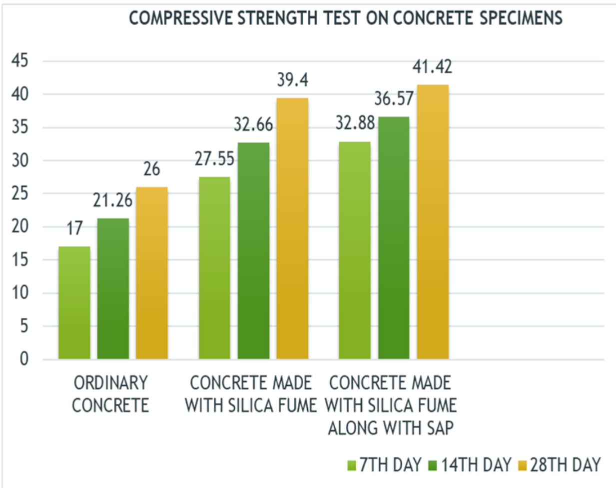
The flexural strength of the concrete was assessed using beam specimens. These beams were supported at both ends, and a load was applied at the centre to induce bending. The maximum load at failure was recorded, and the flexural strength (modulus of rupture) was calculated based on the dimensions of the beam and the applied load. This test evaluates the concrete's ability to resist bending and is essential for understanding the performance of concrete in structural elements subjected to bending, such as beams. Slabs and pavements.

VI. RESULTS

The results from these tests are crucial for comparing the performance of the different concrete mixes (ordinary concrete, concrete with silica fume, and concrete with silica fume and SAP). These tests help determine the effectiveness of silica fume in enhancing the compressive strength and durability of concrete, as well as the role of SAP in improving the concrete's self-healing properties.

The graphs shown below compare the strength of ordinary concrete, concrete made with silica fume alone, and concrete made with silica fume along with SAP.

Compressive Strength: Concrete with silica fume showed improved compressive strength compared to ordinary concrete, and the combination of silica fume and SAP exhibited further enhancement in strength.



[Fig.2. Compressive Strength Test on Concrete Specimens]

Splitting Tensile Strength: The addition of silica fume and SAP contributed to an increase in tensile strength, which is critical for the durability of concrete under various loading conditions.

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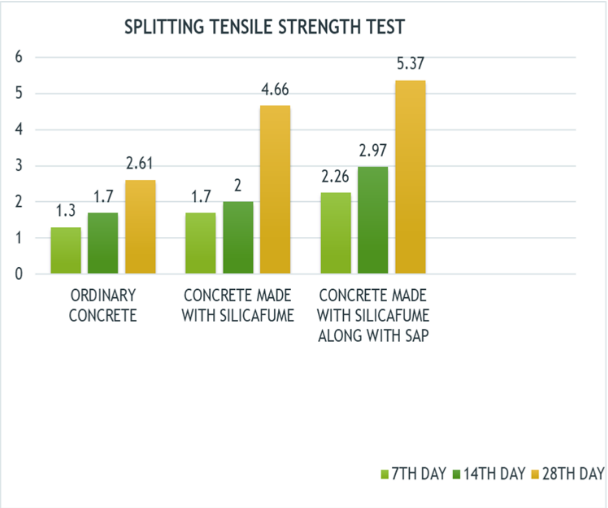
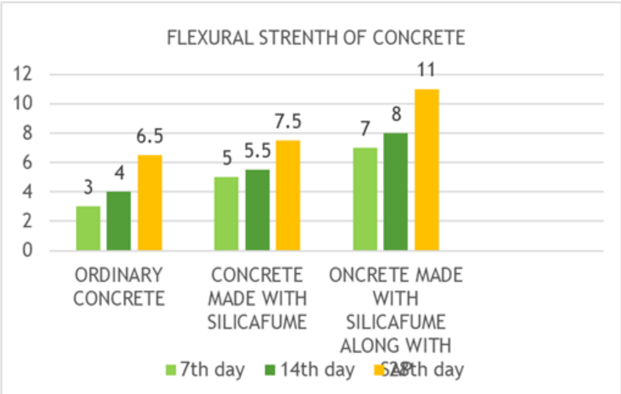


[Fig.3: Splitting Tensile Strength Tests]

Flexural Strength: The concrete mix with silica fume and SAP demonstrated a significant increase in flexural strength, suggesting improved resistance to bending and cracking



[Fig.4: Flexural Strength Test]

VII. SELF-HEALING

The self-healing process in concrete is a complex and ongoing area of research. By understanding the mechanisms involved, scientists and engineers can develop new technologies to improve the durability and sustainability of concrete structures. This innovative approach can significantly reduce maintenance and repair costs while also minimising the environmental impact associated with concrete production. Furthermore, self-healing concrete can enhance the resilience of infrastructure, ensuring the safety and well-being of communities worldwide. As research advances, we can expect to see the development of more efficient, cost-effective, and sustainable self-healing concrete solutions, which will transform the construction industry and shape the future of urban development.

Cracks were observed in the concrete specimens at various stages, and the healing behavior was monitored over different periods. The cracks on ordinary concrete, concrete made with silica fume, and concrete made with silica fume and SAP were observed before and after specific curing periods

A. Cracks on Ordinary Concrete

The cracks on ordinary concrete were observed before and after 35 days.

[Fig.5: Cracks on Ordinary Concrete Before and After 35 Days]

B. Cracks on Concrete Made with Silica Fume

Cracks were observed on concrete made with silica fume before and after 37 days.

[Fig.6: Cracks on Concrete Made with Silica Fume Before and After 37 Days]

C. Cracks on Concrete Made with Silica Fume and SAP

The healing of cracks was observed in concrete made with silica fume and SAP before and after 21 days.

[Fig.7. Cracks on Concrete Made with Silica Fume, Along with Sap Before and After 21 days]

Self-healing property was faster in concrete made with silica fume along with sap compared to concrete made with silica fume alone. The healing property was observed within 21 days in concrete with SF and SAP, whereas concrete with SF alone shows healing properties within 37 days.

VIII. CONCLUSION

The results of our study revealed that concrete made with silica fume and superabsorbent polymer (SAP) exhibited higher strength compared to concrete made with silica fume alone. Furthermore, concrete made with silica fume demonstrated greater strength than ordinary concrete, highlighting the

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benefits of incorporating silica fume into concrete mixtures. The addition of SAP to silica fume concrete appears to have a synergistic effect, leading to enhanced strength and improved durability. These findings suggest that the combination of silica fume and SAP can be a highly effective strategy for developing high-performance concrete. Overall, our results demonstrate a clear hierarchy of strength, with silica fume-SAP concrete > silica fume concrete > ordinary concrete.

The study also revealed that concrete made with silica fume and superabsorbent polymer (SAP) exhibited enhanced self-healing ability compared to concrete made with silica fume alone and ordinary concrete. The combination of silica fume and SAP was found to promote more effective crack closure and healing, leading to improved durability and sustainability. In contrast, concrete made with silica fume alone showed moderate self-healing ability, while ordinary concrete exhibited limited self-healing capacity.

These findings suggest that the addition of SAP to silica fume concrete can significantly enhance its self-healing properties, resulting in improved long-term performance and reduced maintenance requirements.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it was conducted without any external influence.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
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