World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

A study on hardened parameters of self-compacting concrete using silica fume

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World Journal of Advanced Engineering Technology and Sciences, 2025, 15(03), 1360-1368

Publication history: Received on 02 May 2025; revised on 08 June 2025; accepted on 11 June 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.15.3.1048

Abstract

The main focus of this study is to examine how silica fume, a by-product from industrial processes, performs when used in concrete with varying mix proportions. As the demand for cement continues to grow, its large-scale production has triggered environmental issues, overuse of natural resources, and rising costs. To help overcome these challenges, the study looks into the use of alternative materials like industrial waste. Silica fume was selected for partial replacement of both cement and sand in several concrete mixes. Due to its high pozzolanic activity and fine, non-crystalline silica content, it has the ability to enhance the mechanical strength of concrete. To assess its influence, concrete cubes and cylinders were prepared with replacement levels of 0%, 8%, 12%, and 16%. Testing showed that compressive strength improved as the silica fume percentage increased, with the best results at 12%. Beyond this point, strength gains began to reduce, suggesting that 12% is the optimal level for improving concrete performance using silica fume.

Keywords: Concrete; Self-compacting; Silica fume; Compressive strength; Split tensile strength

1. Introduction

Concrete is a composite material made by blending aggregates, cement, and water. It is one of the most widely used materials in construction due to its adaptability. Its composition can be adjusted for different purposes by modifying its components or incorporating additives, and it can be shaped into moulds to form various structural elements used in projects like bridges, dams, and tunnels. Silica fume, also called micro silica, is a by-product generated during the production of silicon metal or ferrosilicon alloys. It consists mainly of extremely fine silicon dioxide (SiO_2) particles in a non-crystalline form. These particles are typically less than 1 micron in size—around 0.1 micron—which makes them about 100 times smaller than regular cement particles. Silica fume also includes small amounts of other oxides like aluminium and iron oxides. Its ultra-fine nature allows it to fill the spaces between cement grains, leading to denser and stronger concrete. Additionally, it improves the strength, durability, and bonding in mortar. It helps reduce permeability and strengthens the bond between the cement paste and aggregates. Concrete made with silica fume is especially effective in applications where high durability, low permeability, and resistance to erosion or bleeding are required.

Objective

This study focuses on the partial replacement of cement with silica fume and examines both the short- term and long-term strength development of silica fume-based mortar. Silica fume was used to replace cement at varying levels—8%, 12%, and 16%. The base concrete mix was of M20 grade without any initial replacement, but in this case, silica fume was introduced in place of a portion of the cement. The primary aim of the research was to determine the optimal percentage of silica fume that delivers better performance, is cost-effective, environmentally friendly, and enhances strength and durability. This investigation was conducted to understand how silica fume influences these key aspects.

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Special attention was given to the compressive strength of mortar at 7 and 28 days, observing how different replacement levels affected the overall performance when cement was partially substituted with silica fume.

2. Material used

2.1. Cement

Cement is a fine, grey powder that, when mixed with water and other components, forms concrete or mortar. It plays a crucial role in construction, being widely used in both residential and commercial structures. Among the many types of cement available, Portland cement is the most commonly used. It belongs to the category of hydraulic cements, which harden when mixed with water, creating a durable and water-resistant material. The resulting hydration compounds act as a binder, holding the aggregates together to form solid concrete. In this study, Ordinary Portland Cement of 43 Grade from the JK brand was used, which complies with the BIS standard IS 269:2015.

Table 1 Physical parameters of Cement

Sr. No	Property	Results
1	Normal Consistency	29%
2	Initial Setting Time	30 min
3	Specific Gravity	9.93
4	Fineness of cement	5%
5	Specific Area	3250cm2/gm
6	Soundness of cement	1 mm

2.2. Fine Aggregate

Fine aggregate consists of small, granular particles that help fill the voids between coarse aggregates in concrete. It forms a significant portion of the mix and contributes to making mortar more economical. Typically, its particle size ranges from 0.075 mm to 4.75 mm in diameter. The most commonly used sizes in concrete mixtures include 2.36 mm, 1.18 mm, and 0.6 mm. Common sources of fine aggregates include natural sand, manufactured sand, crushed stone sand, and recycled materials processed into fine aggregate form.

Table 2 Physical properties of Sand

Sr. No	Property	Results
1	Specific gravity	2.63
2	Fineness of sand	2.16

2.3. Coarse Aggregate

Coarse aggregates are made up of larger particles compared to fine aggregates. Their size is typically measured in millimeters and generally ranges from 4.75 mm to several inches in diameter. The most commonly used sizes in concrete mixes are 20 mm, 16 mm, and 12.5 mm. Coarse aggregates are usually found in various shapes, with rounded, angular, and cubical forms being the most widely used.

Table 3 Physical properties of coarse aggregate

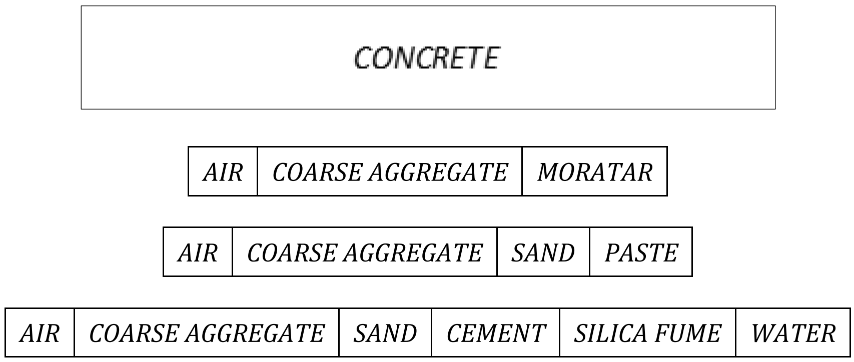
Sr. No	Property	Results
1	Specific gravity	2.73
2	Fitness Modulus	1.33

2.4. Water

Cement and aggregates are the primary components of concrete, with water being the essential third element. The water used must be clean and suitable for drinking. It should be free from impurities like high levels of salts, acids, alkalis, oils, organic matter, or any other substances that might interfere with the hydration process and overall quality of the concrete.

2.5. Silica Fume

Silica fume is produced as a by-product during the reduction of high-purity quartz with coal in electric arc furnaces used for manufacturing silicon, ferrosilicon, and other silicon-based alloys. It contains a high percentage of amorphous silicon dioxide, typically ranging from 85% to 98%. It can be used in mortar either on its own or combined with Ordinary Portland Cement. Due to its ultra-fine particles, silica fume improves particle packing and triggers a strong pozzolanic reaction in concrete. This reaction involves silicon dioxide interacting with calcium hydroxide, which leads to better strength, durability, and overall performance of cement-based materials.



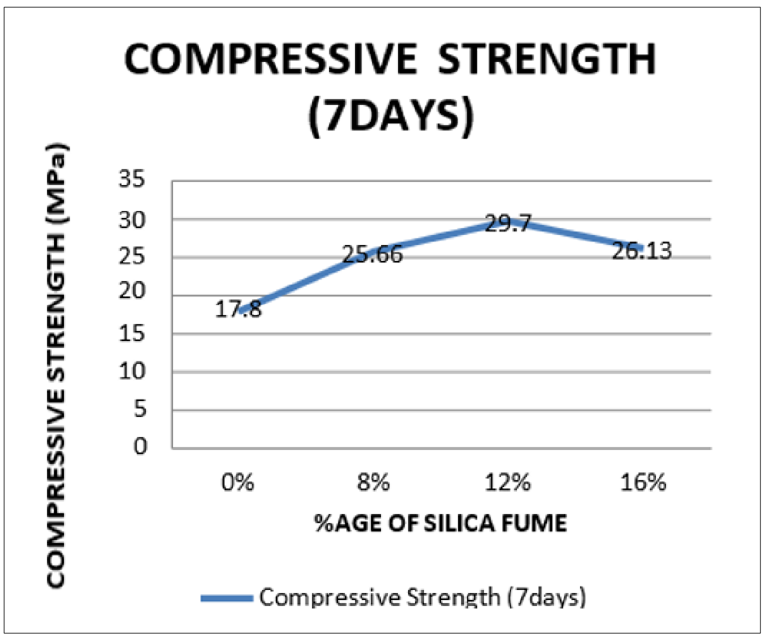


Figure 1 Compressive strength at 7 days

3. Casting of specimen

- Mix Proportion: In this study, the concrete mix was prepared using aggregate proportions by weight, following the recommended guidelines provided in EFNARC-2002.
- Casting of Specimen: The following moulds were used for preparing the test specimens.
- Cubes measuring 150 mm × 150 mm × 150 mm were used for testing the compressive strength.
- Cylinders of size 300 mm × 100 mm were used to test both compressive and split tensile strength.

A total 9 cubes and 9 cylinders were intended to assess the strength parameters and each cube is of 8kg. The components were weighed and the materials were mixed by hand. The concrete was filled in different moulds. After 24 hours, they were demoulded and cured in water for 7 and 28 days. Afterwards, they were tested for compressive and split tensile strength Pursuant to Indian Standards.

3.1. Mix Proportion for 3 cubes

Table 4 Mix Proportion

Mix	Percentage of silica fume	Water litre	Cement kg	Coarse aggregate kg	Fine aggregate kg	Weight Silica fume gm
MIX0	0%	1	3.71	11.55	6.58	0
MIX1	8%	1.70	3.414	11.55	6.58	296
MIX2	12%	1.70	3.265	11.55	6.58	445
MIX3	16%	1.70	3.117	11.55	6.58	593

4. Observation and results

The Compressive strength is the capability of structure to carry the loads on its surface without cracking and deforming. Under Compression, a material tends to reduce the size, whereas, in under tension it's elongates. The compressive strength test of a mortar cubes provides an overall indication of the concrete's characteristics. This test enables one to identify the performance of the concrete whether it is correct. The test was performed in accordance with IS 516-1959 to find out the compressive strength for 7 and 28 days. The cubes and cylinders were tested using Compression Testing Machine (CTM).

Table 5 Test Results for 7 Days Curing

Sr. No	Mix Description	Peak Load (KN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	0	401.1	17.82	17.80
		395.6	17.71	
		413.5	18.37	
2	8	541.4	24.06	25.66
		524.6	23.31	
		654.3	29.08	
3	12	654.3	29.8	29.7
		613.1	29.2	
		693.7	30.1	
4	16	546.6	24.73	26.13

5. Test Results for 7 days Curing

After removing the specimen from the mould and curing it in water for the specified time, any surface moisture should be wiped off before testing. The testing machine must have a clean and level bearing surface. The specimen should be placed so that the load is applied to the opposite faces of the cube, as originally cast. Load is applied gradually until failure or the maximum load is reached. Compressive strength is then calculated by dividing the load by the cross-sectional area. This procedure ensures reliable assessment of concrete quality and helps verify its structural performance. Regular testing helps maintain consistency across batches and ensures long-term durability.

$$\text{Compressive strength} = \text{Load} / \text{Cross-sectional Area}$$

Table 6 Test Results for 28 Days Curing

Sr. No	Mix Description	Peak Load (KN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	0%	441.9	29.64	23.22
		473.7	20.31	
		485.4	19.71	
2	8%	592.6	26.33	26.16
		553.9	24.59	
		610.6	27.56	
3	12%	817.8	36.34	38.9
		890.8	39.75	
		913.7	40.61	
4	16	717.9	33.90	34.72
		761.9	34.86	
		774.5	35.40	

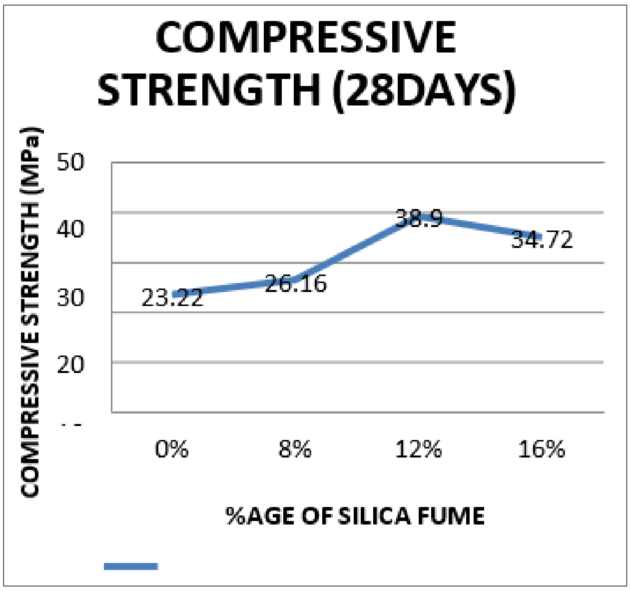


Figure 2 Compressive strength at 28 days

5.1. Test Results for 28 days curing

The compressive strength was compared for both 7- day and 28-day curing periods. In both cases, an increase in strength was observed up to 12% silica fume replacement. This improvement is likely due to enhanced pozzolanic reaction and better particle packing. Beyond 12%, the compressive strength started to decrease gradually. This decline may be attributed to the dilution of cementitious material at higher replacement levels. Therefore, 12% silica fume replacement is identified as the optimum for strength development. This trend was consistently reflected in the experimental data and graphical analysis.

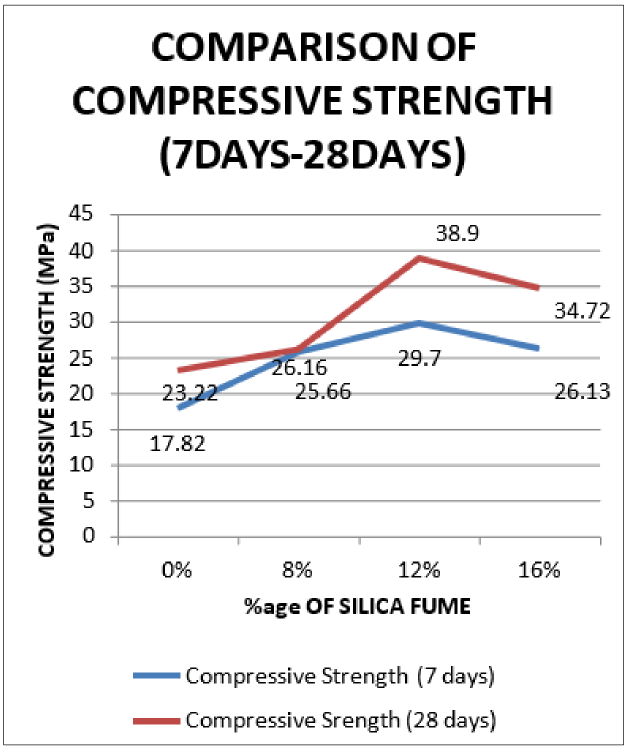


Figure 3 Comparison of 7 days and 28 days

The split tensile strength test helps determine the tensile capacity of concrete or similar materials. It is an indirect method used to assess how the material performs under tensile stress. A cylindrical concrete specimen is placed horizontally between the machine's loading surfaces. A steady load is applied until the specimen splits along its length. The tensile strength is then calculated using a standard formula based on the applied load and specimen dimensions.

$T = 2P/\pi DL$, P= Maximum load applied, D= diameter of the specimen, L= Length of the specimen

Table 7 Tests results for 7 and 28 days curing for split tensile strength

Sr. No	Mix Description	7-day scoring (MPa)	28-day scoring (MPa)
1	0%	1.86	3.04
2	8%	2.01	3.37
3	12%	2.26	3.85
4	16%	2.07	3.41

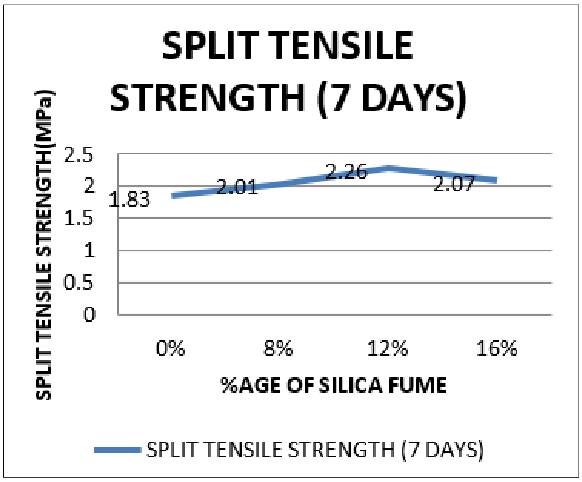


Figure 4 Test Results for 7 days curing

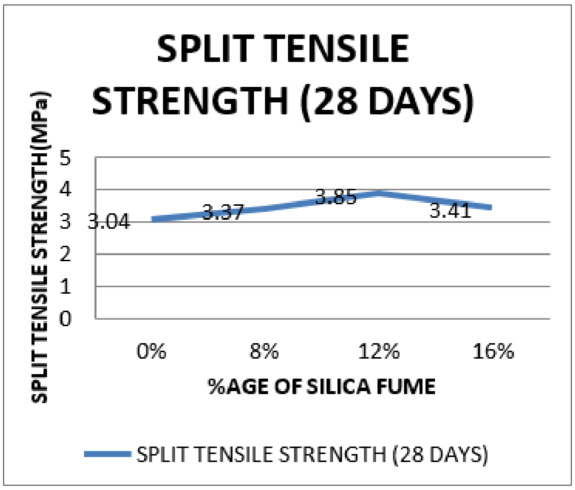


Figure 5 Test Results for 28 days curing

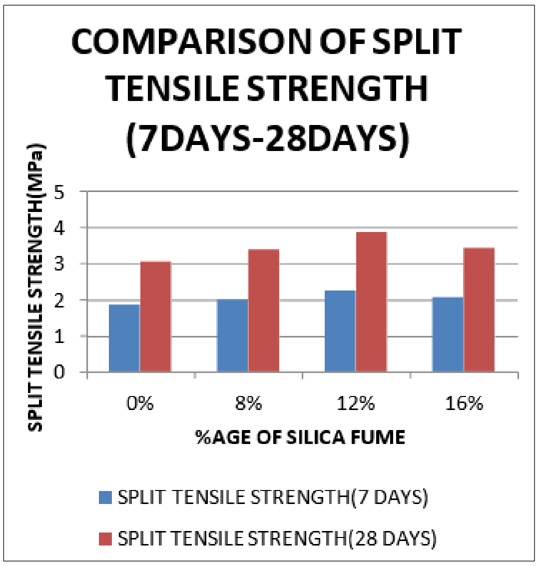


Figure 6 Test Results for comparison of Split Tensile Strength for 7 and 28 days

6. Conclusion

Experiments were carried out using varying amounts of silica fume—0%, 8%, 12%, and 16%. The findings indicated that compressive strength peaked at 12% replacement before showing a decline. Likewise, split tensile strength also increased up to 12% silica fume. Beyond this point, a steady reduction in strength was observed with higher replacement levels.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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