Evaluation of Hardened Properties of Concrete with Silica Fume as Partial Replacement of Cement

Aditya Punia[1], Mohammad Faisal Bazaz[1]

[1]Department of Civil Engineering, National Institute of Technical Teachers Training & Research, Chandigarh, India

Abstract-The demand for supplementary cementitious materials will soon take over the world as the carbon emissions from cement plants is on the rise. The day is not far when the world will also start looking for waste materials which can be used as cementitious material like silica fume, steel slag, fly ash, blast furnace slag etc. Till date, silica fume and fly ash are the most successful cementitious materials because they improve strength of concrete to a good extent. An experimental analysis of the nature of SF and its effects on the characteristics of fresh and cured concrete is presented in this research. The goal of this study was to look at the strength properties of concrete built with SF as a partial replacement for cement. Compressive strength, flexural strength, and splitting tensile strength of hardened concrete have been determined for various mix combinations of materials, and these values have been compared to the equivalent values of conventional concrete. The purpose of this study was to raise awareness about the benefits of these novel concrete mixtures. For this purpose, silica fume is replaced by 0%, 5%, 10%, 15% and 20% by the weight of cement. Water binder ratio is taken 0.5 for M-25 grade of concrete. The use of Silica fume in concrete has increased the performance of concrete in the hardened stage, according to test results.

Keywords: Silica Fume, Supplementary Material, Compressive strength, Pozzolanic activity.

1. Introduction

Cement manufacturing has a negative impact on the environment and depletes numerous natural resources. As a result of the threat to the environment, researchers are looking at using a variety of industrial by-products as extra cementation ingredients in concrete production. When industrial by-products are utilised to partially replace cement, significant energy and cost savings can be realised. The use of silica fume improves compressive strength and durability to a significant amount, which is mostly due to refined pore structure and reduced permeability. [1].

When cement is hydrated, many compounds are formed, including Tri Calcium Aluminate, Tetra Calcium Aluminate, Tri Calcium Silicate, and Di Calcium Silicates, as well as Calcium Silicate Hydrates (CSH gel) and Calcium Hydroxide (Ca(OH)2). When silica fume is added to the concrete, it chemically reacts with the Calcium Hydroxide to form beneficial CSH gel that acts as a binder [2]. This reaction not only improves the binding between the paste and the coarse particles, but it also increases the compressive strength of the concrete.

Silica fume is a by-product of the manufacture of silicon alloys such as ferrochromium, ferromanganese, calcium silicon, and others, and it pollutes the environment and poses a health risk. When silica fume was added (5-12.5% with an increment of 2.5%) to a high slump concrete, compressive strength improved by roughly 21%, flexural strength increased by 35%, and split tensile strength increased by 10%, according to Ray et al. [3]. When silica fume was added as 10% by weight of cement content, Joshi et al. [4] found that reducing cement content at a given water cement ratio had no effect on fresh or cured concrete characteristics and may even increase performance. Perraton et al. [5] investigated the influence of silica fume on concrete permeability and found that the decrease in permeability was due to pore refinement caused by the addition of silica fume.

In light of the foregoing, an attempt has been made to substitute cement with SF in order to generate a cost-effective modified concrete, referred known as SF concrete. In light of this, the current work reports on a study of the effect of partial cement replacement with SF (from 5% to 20% with a 5% step) on M25 grade concrete. As a result, the current study attempted to employ SF as a cement replacement material in order to reach the needed concrete higher grade strength requirements.

2. Experimental Method

2.1 Materials

Cement: Ordinary Portland cement (OPC) of 43 grades satisfying the requirements of IS: 8112- 1989 was used. The specific gravity of cement was found to be 3.15.

Fine Aggregates: Locally available river sand with grading of zone-II confirming to IS: 383-1978 was used with specific gravity of 2.62 and water absorption of 1.8% at 24 hours.

Coarse Aggregates: Crushed aggregate confirming to IS: 383-1987 was used. Aggregates of size 20mm and 12.5 mm of specific gravity 2.74 and fineness modulus 7.20 were used.

Silica Fume: The silica fume used was supplied by "Hryn Cramx Silixa Fume, Ambala" having a specific gravity of 2.2 and size 0.1 micron.

Water: Tap water, free from any deleterious materials, was used for casting of concrete specimens confirming to IS 456:2000.

2.2 Sample Preparation

Aggregates, cement, and SF were all charged into the mixer machine in the proper quantities for a dry mix, then water was added and the machine was rotated enough to create a uniform and high workable mix. For this study, concrete of the M25 grade (W/C=0.5) was employed. IS:10262-1982 was used to design the mix. The concrete mix percentage (Kg/m3) is shown in Table 1. The compressive strength, split Tensile strength, and flexural strength of concrete were determined using specimens of standard cubes (150mm x 150mm x 150mm), standard cylinders (300mm x100mm), and prisms (150mm x150mm x 750mm). With each fraction of silica fume replacement, three specimens were examined for 7, 28, and 56 days. The concrete was poured in many levels, each of which was compressed. After being demoulded for 24 hours, the specimens were cured in water for 7, 28, and 56 days before being tested for compressive, split tensile, and flexural strength according to Indian Standards. The mix proportioning used is shown in Table 1 below.

Table 1: Mix Proportioning

S.No	Material	Quantity (Kg/m^3).
1	Cement	395
2	Coarse Aggregates	654
3	Fine Aggregates	1120
4	Water	197

3. Test Results and Discussion

3.1 Fresh State

Mix Character: Because of the superfine quality of SF particles, SF concrete has proved to be more cohesive than regular Portland cement concrete. In terms of segregation and bleeding, all of the combinations have shown to be adequate. However, as the proportion of SF increased, concrete became stickier.

Workability: As the proportion of SF in the mix is increased from 5% to 20%, the compacting factor, i.e., workability, increases somewhat. Table 2 summarises the findings.

Table 2: Variation of Compaction Factor of different Mixes

Replacement level (%)	Compaction Factor
0	0.81
5	0.82
10	0.83
15	0.83
20	0.84

3.2 Hardened State

Table 3 compares the results of fresh and hardened concrete with partial replacement of silica fume to those of regular concrete.

Table 3: Results of hardened properties of different Mixes

Mix	% Of Silica Fume added	Compressive Strength(N/mm^2)			Split Tensile Strength(N/mm^2)			Flexural Strength(N/mm^2)		
		7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
M1	0	21.3	32.8	34.6	2.1	3.2	3.5	3.2	4.0	4.2
M2	5	22.4	33.0	35.4	2.2	3.3	3.6	3.4	4.1	4.3
M3	10	28.6	37.8	38.1	2.6	3.8	3.8	3.5	4.3	4.4
M4	15	30.1	39.1	38.3	2.8	3.9	3.9	3.6	4.4	4.5
M5	20	28.2	36.7	37.8	2.9	4.0	4.1	3.5	4.2	4.2

Compressive Strength: Table 3 shows the results of compressive strength testing. The test was carried out in accordance with IS 516-1959 to determine the compressive strength of concrete at 7, 28, and 56 days of age. Compression Testing Machine was used to test the cubes (CTM). At 15% silica fume replacement, the greatest compressive strength is found.

Because of the strong pozzolanic nature of silica fume and its void filling capacity, concrete's compressive strength improves significantly [5]. Early strength growth on silica replacement is extremely spectacular, according to the findings. This is mostly due to pore refinement and transition zone change. Compressive strength testing results are shown in Fig. 1.

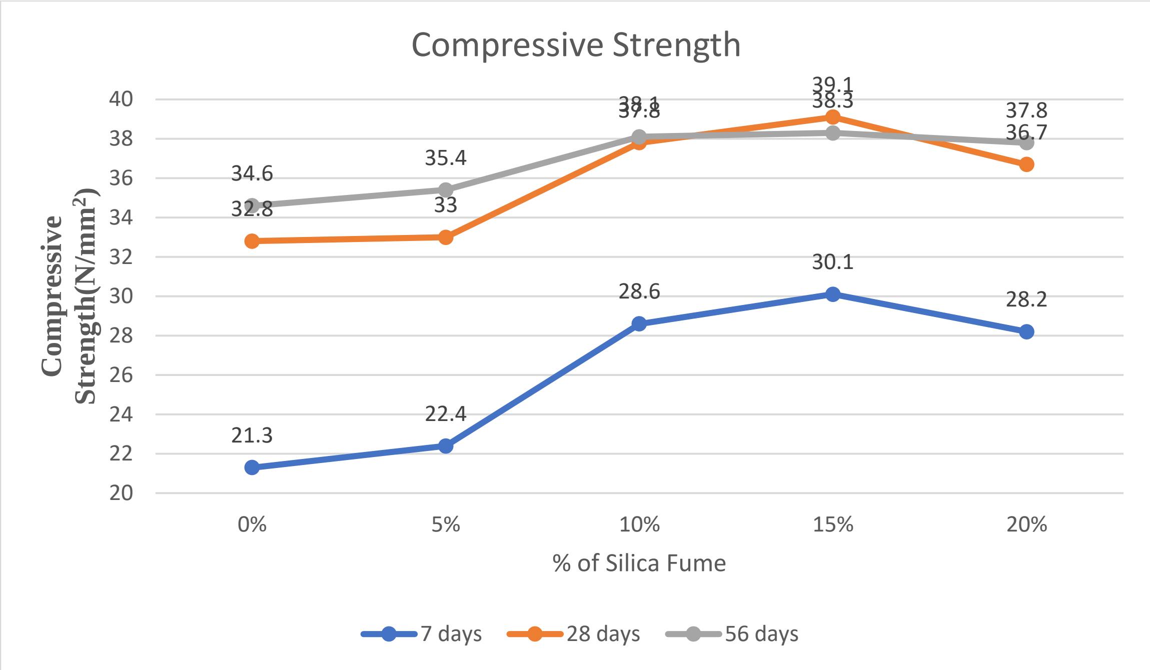

Fig. 1 Results of Compressive Strength Testing

Split Tensile Strength: Table 3 shows the results of split tensile strength testing. The test was performed in accordance with IS 5816-1999 to determine the split strength of concrete at 7, 28, and 56 days. The increase in split tensile strength is due to pore refinement and higher cohesion.

Fig. 2 shows the results of split tensile strength testing.

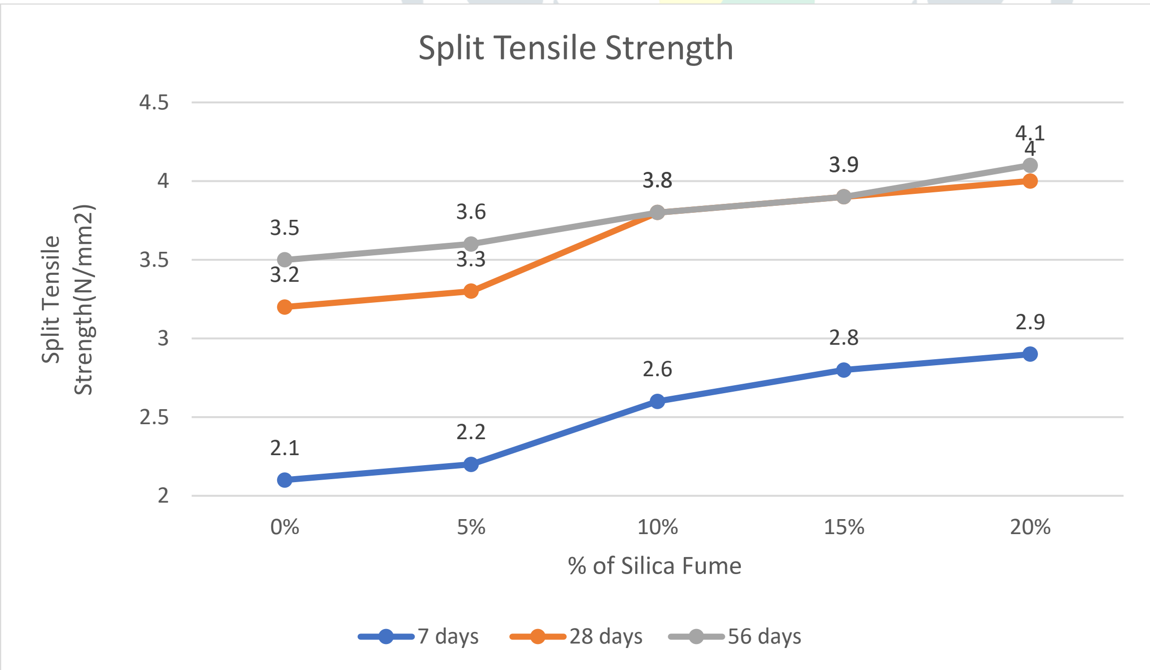

Fig. 2 Results of Split Tensile Strength Testing

Flexural Strength: Table 3 shows the results of the flexural strength test. The test was performed in accordance with IS 516-1959 to determine the flexural strength of concrete at 7, 28, and 56 days. Because we know that flexural strength is directly related to compressive strength, we may deduce from the data that the greatest flexural strength is reached at 15% silica fume inclusion. Furthermore, early strength improvement on silica replacement is fairly impressive, which is mostly due to pore refinement and transition zone change. Fig. 3 shows the results of flexural strength testing.

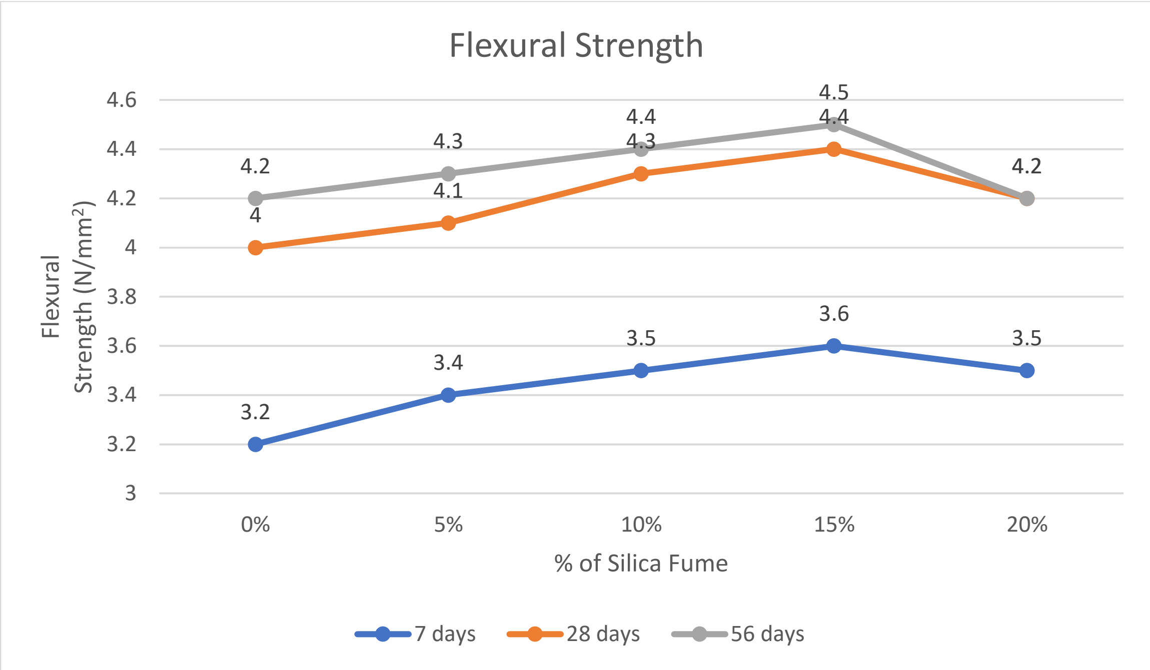

Fig. 3 Results of Flexural Strength Testing

4. Conclusion

It can be inferred that the usage of silica fume is required not only in the manufacturing of high-strength concrete but also in the creation of low- and medium-strength concrete. Following the completion of all testing and analysis of the results, the following findings were reached:

- The findings of the current investigation reveal that silica fumes have a lot of promise for use in concrete as a cement alternative.
- When silica fume replacement is around 15%, maximum compressive and flexural strength is seen.
- When silica fume replacement is around 20%, maximum split tensile strength is seen.
- As the quantity of silica fumes in concrete increases, the workability of the concrete increases.

5. References

[1] Siddique, R. (2011). Utilization of silica fume in concrete: Review of hardened properties. *Resources, Conservation and Recycling*, *55*(11), 923-932.

[2] Sensualle GR, Strength development of concrete with rice husk ash, Cement and Concrete Composites 2006.

[3] Ray, I, De, A and Chakraborty, Fifth Conference on Concrete Technology for High Slump Concrete, Vol 1, p.p 86-93

[4] Joshi, N. G. Bandra – Worli Sea Link: Evolution of HPC mixes containing Silica Fume, Indian Concrete Journal, (Oct. 2001), pp. 627-633

[5] V.Bhikshma, K.Nitturkar and Y.Venkatesham, "Investigations on mechanical properties of high strength silica fume concrete." Asian journal of civil engineering (building and housing) vol. 10, no. 3 (2009) pp.335-346.

[6] IS 516: 1959 (R2018), Methods of tests for strength of concrete.

[7] IS 5816: 1999 (R2004), Splitting Tensile Strength of Concrete Method of Test.

[8] IS 10262: 2009, Concrete Mix Proportioning – Guidelines.

[9] IS 383: 2016, Coarse and Fine Aggregate for Concrete – Specification.

[10] IS 8112: 2013, Ordinary Portland Cement, 43 Grade.

[11] IS 456: 2000 (R2016), Plain and reinforced concrete - Code of practice (Fourth Revision).