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Research Article

Evaluation of Mechanical Properties of Concrete Containing Silica Fume from a Local Source in Pakistan

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Abstract: Concrete is one of the most commonly used construction materials with cement being its main ingredient. Since the construction industry is expanding rapidly, the cost of cement used in concrete is also increasing. In order to meet its growing demand and address the adverse effects on account of its production process, alternate cheap materials are needed to be developed. Silica Fume is a well-known pozzolanic material which when partially replaced with cement, enhances the mechanical and chemical properties of concrete and mortar. In present experimental research, compressive strength and modulus of rupture of concrete containing silica fume as secondary cementitious material have been evaluated. Silica fume was obtained from a local source in Pakistan. The incorporation of silica fume resulted in higher water demand in comparison with control concrete mixture. Replacement of cement with silica fume was by weight of cement in ratios of 0%, 10%, 15% and 20%. The incorporation of silica fume improved the later-age strength as compared to early-age strength. It was also noted that the highest compressive strength and flexural tensile strength have been achieved by 15% replacement of silica fume with cement at all ages.

Keywords: Silica fume, concrete compressive strength, modulus of rupture, pozzolanic material, mechanical properties

1. INTRODUCTION

Silica fume (SF) is very fine amorphous silica formed in electric arc furnaces as a byproduct of production of elemental silicon or alloys containing silicon [1– 2]. Silica fume (SF) is usually grey colored powder also called condensed silica, volatized silica, micro silica or simply silica dust, which is somewhat similar to Type - 1 ASTM cement (OPC). Silica fume (SF) is a well-known pozzolanic material that exhibits cementitious properties by enhancing the mechanical properties of concrete mixtures. It also helps in improving the durability properties of concrete and also protects them from corrosion of embedded steel in adverse environment [3].

Numerous research studies have been conducted on silica fume incorporation in concrete mixes. Inclusion of silica fume has positive effects on strength properties of concrete. Aitcin and Laplante [4] studied the effect of using silica fume in concrete on long term compressive strength of concrete. They found out that silica fume concrete is vulnerable to variation in temperature during the hydration process which leads to the hardening of concrete paste. The rate of strength gain is reduced when temperature falls below the optimum and increases with increase in temperature. They also found that the optimum silica fume content to achieve higher strength seems to range between 15 – 20% [4 - 5]. Katkhuda et al. [6] and Bhanja et al. [7] reported that modulus of rupture/flexural tensile strength, splitting tensile strength and compressive strength of concrete specimens increased by adding silica fume, while increase in strength depends upon the water to cementitious ratio of concrete mix. However, the effectiveness depends on the quantity of silica fume present in concrete mix [8]. The

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replacement of silica fume in range of 10–20 wt.% of cement enhanced the compressive strength by 11.56 – 18.89% in comparison to control concrete specimen at 28 days of age [9 – 11].

Moreover, some other research studies indicates that highest flexural tensile strength, splitting tensile strength and compressive strength have been obtained at 7 and 28 days age with 10 – 15 wt.% of cement replacement with silica fume [12 –14]. Pawade et al. [15] reported that highest rate of compressive strength gain was up to approximately 8.0%, 11.9% and 12.6% at 7, 28 and 90 days of age, respectively, for 12% replacement of silica fume in comparison to control concrete mixture. The pozzolanic materials are source of amorphous silica in concrete mixtures. The increase in strength is result of pozzolanic reaction of free calcium hydroxide with amorphous silica. The fine pozzolan particles present in the mixture act as nucleation sites for precipitation of hydration products thus generating homogeneous pastes. During cement hydration reaction tricalcium silicate (C_3S) reacts with water to form calcium silicate hydrate gel (C-S-H gel) and calcium hydroxide ($Ca(OH)_2$). The unreacted week phase of calcium hydroxide produced from the hydration of cement reacts with the amorphous silica from pozzolanic materials to generate extra amount of calcium silicate hydrate gel (C-S-H gel) which is the major strength contributing phase thus improving the mechanical and durability characteristics of concrete [12].

In a research study reported by Gonen and Yazicioglu [16] performance of mineral admixtures and their effect on properties of concrete was studied. The experimental test results indicated that normally the performance of concrete is improved with incorporation of mineral admixtures like fly ash and silica fume but it was noted that silica fume is beneficial in contributing both short term and long term properties of concrete. Use of silica fume also enhances the durability of concrete as it helps in improvement of resistance to chemical attacks and alkali silica reaction [17]. To maintain the workability of concrete mixtures, super plasticizers are added in the concrete mixtures. Bayasi and Zhou [18] studied the relationship of amount of silica fume and quantity of super plasticizers in concrete mixture. It was noted that amount of superplasticizer increases with the increase in silica fume content, so that the adverse effects on workability can be minimized.

Some other advantages of using silica fume include positive influence on properties of mortar and cement paste like standard consistency, specific gravity and air entrainment [19]. Creep and shrinkage, young modulus and moisture movement of high strength concrete improves by adding silica fume [20].

The present research study focused on investigation of mechanical properties of concrete mixtures containing silica fume obtained from local source in Pakistan as supplementary cementitious material. The mechanical properties include compressive strength and flexural tensile strength.

2. EXPERIMENTAL WORK

2.1 Material Properties

Materials used in this experimental research study were cement, silica fume, coarse aggregates, fine aggregates, super plasticizer and water.

Ordinary Portland cement (OPC) conforming ASTM C 150 Type – I [21] was used and its physical properties are given in Table 1. Fine aggregates (sand) conforming ASTM C 33 [22] from Lawrencepur was used in this research study with fineness modulus (FM) and specific gravity of 2.65 and 2.65 respectively. Table 2 presents physical properties of fine aggregates. Fig. 1 shows the gradation curve for fine aggregates used in concrete mixtures. Crushed granite stone with maximum size passing through 19 mm sieve size and specific gravity of 2.68, from Margalla conforming ASTM C 33 [22] was used as coarse aggregate. Physical properties of coarse aggregates are given in Table 2. Silica fume was obtained from Imporient Chemicals Pakistan. The gravimetric chemical analysis on silica fume reported that more than 90% of the silica was in amorphous state. Table 3 enlists the

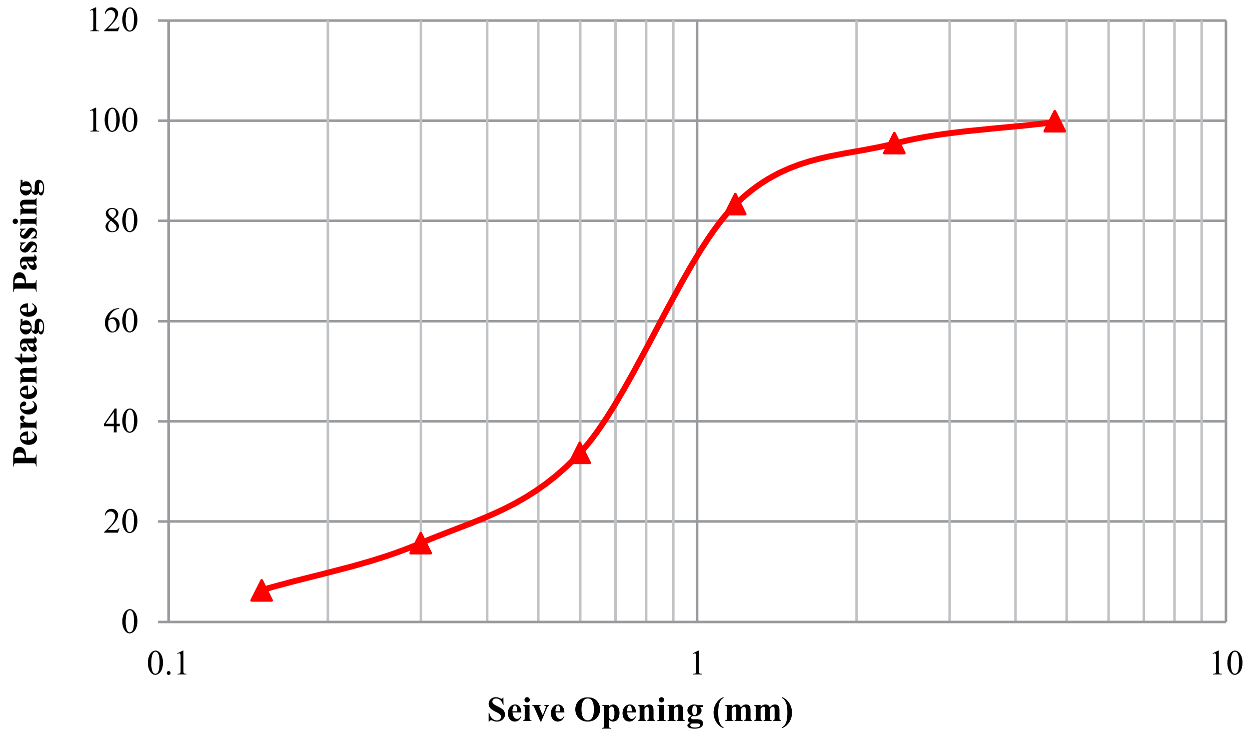

Fig. 1. Gradation curve for fine aggregates.

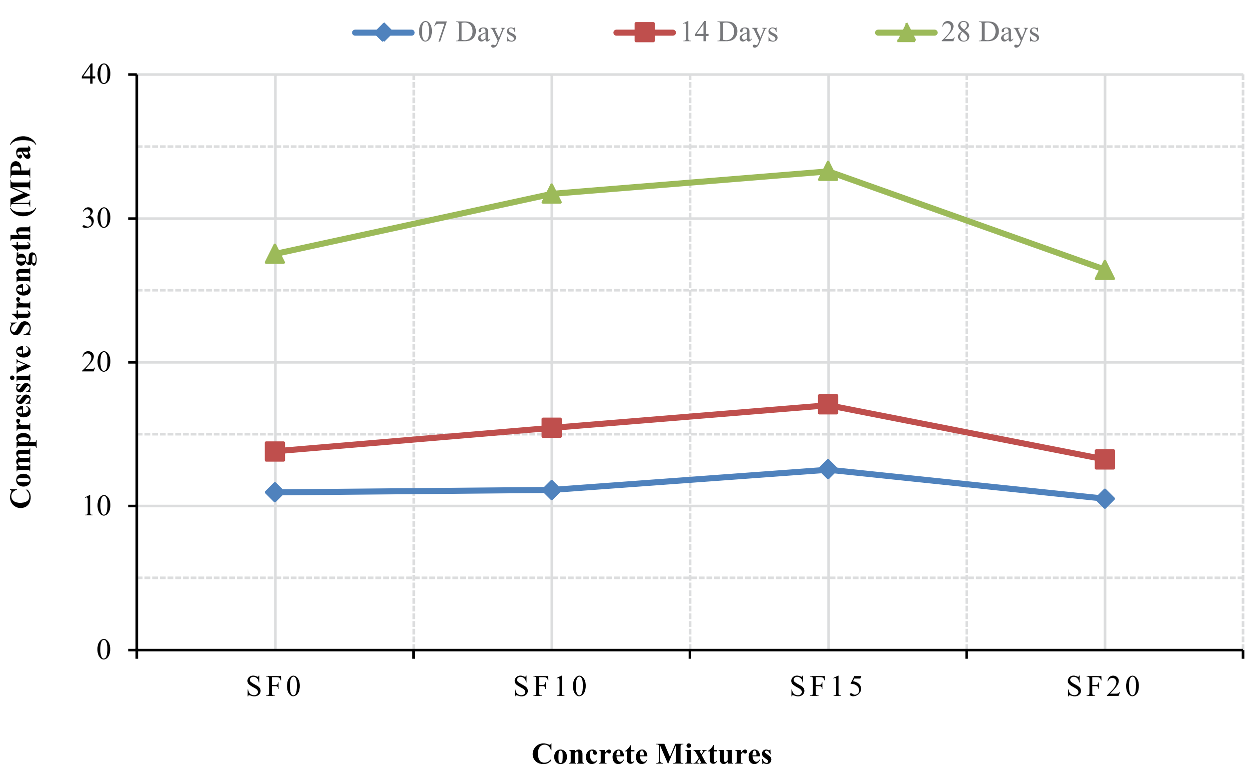

Fig. 2. Results of compressive strength test at 7, 14 and 28 days of age.

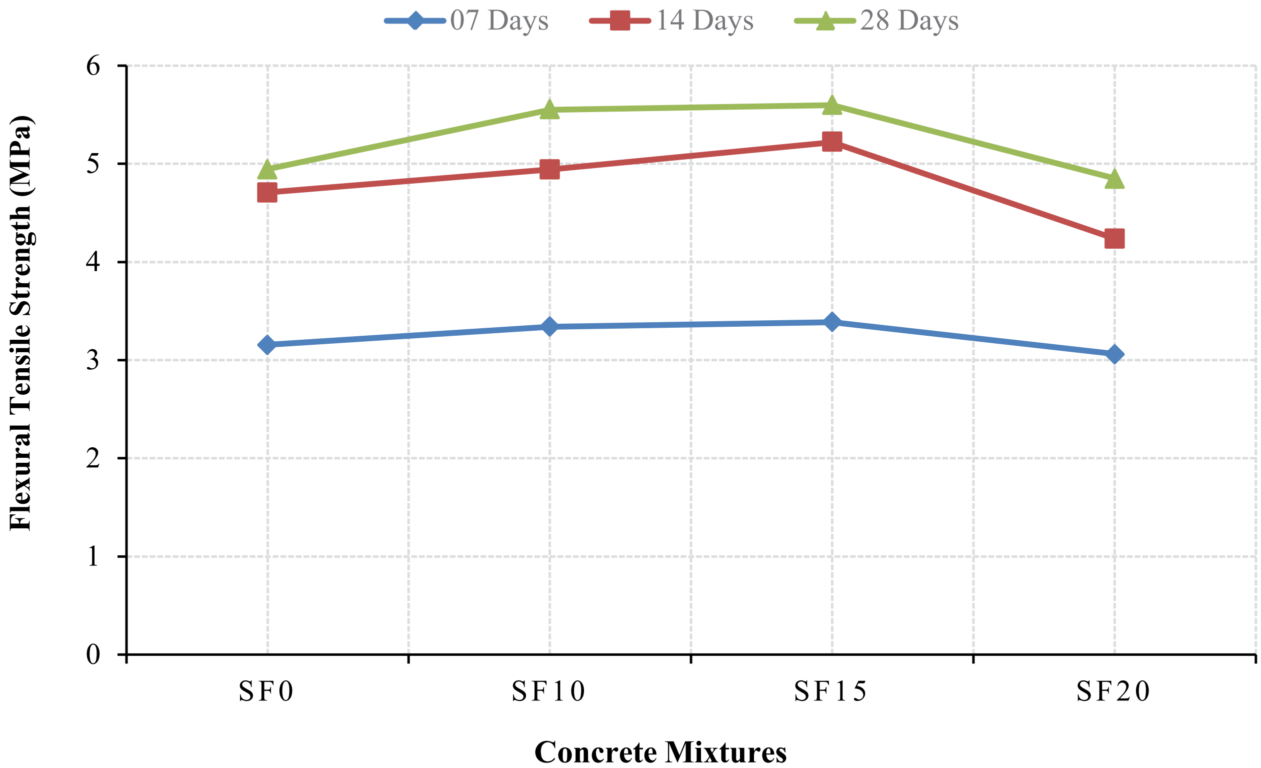

Fig. 3. Results of flexural tensile strength test at 7, 14 and 28 days of age.

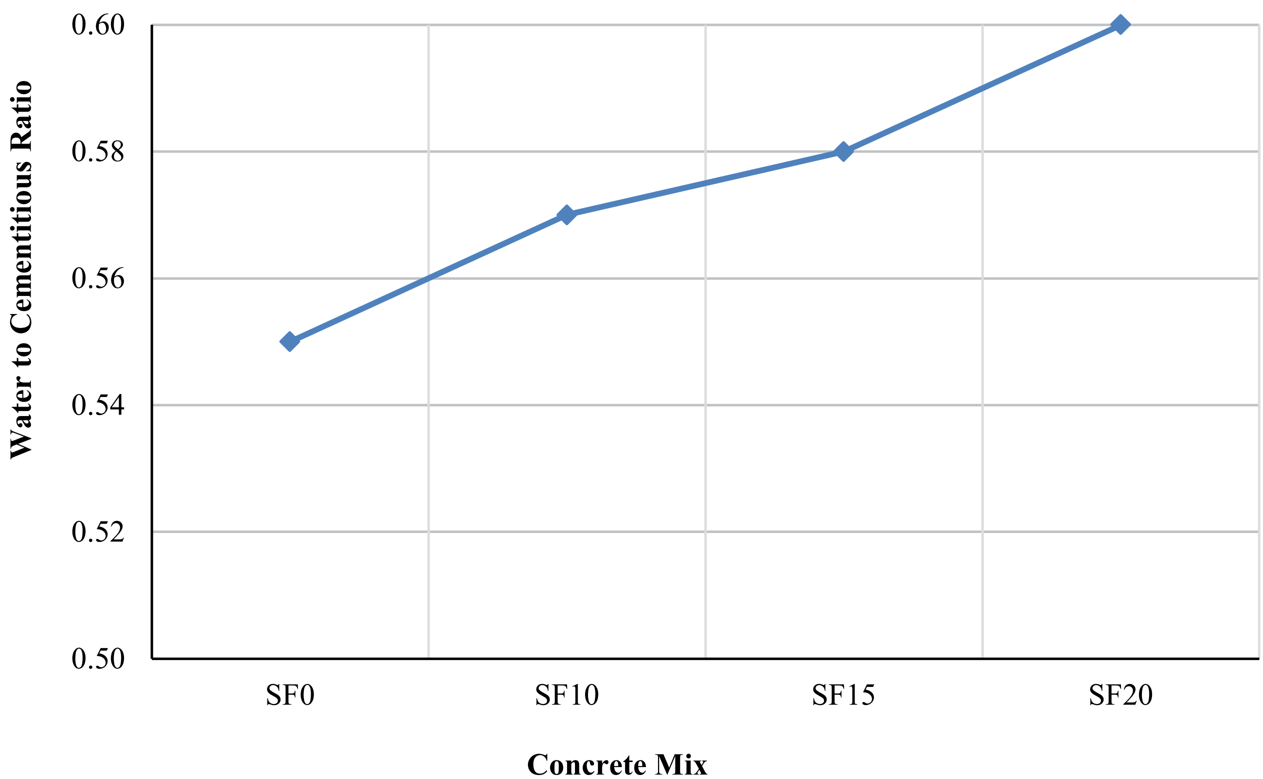

Fig. 4. Water to cementitious ratio of various concrete mixtures.

physical properties of silica fume. To maintain the workability of concrete, second generation water reducing admixture (Chemrite D-620) was added as super plasticizer.

Table 1. Physical properties of cement.

Property	Cement
Specific Gravity	3.15
Specific Surface Area (m^2/kg)	340
Normal Consistency (%)	29.3
Initial Setting Time (minute)	105
Final Setting Time (minute)	216

Table 2. Physical properties of fine aggregates and coarse aggregates.

Property	Fine Aggregate	Coarse Aggregate
Fineness modulus	2.65	2.83
Dry rodded unit weight (kg/m^3)	2512.98	1946.15
Specific gravity	2.65	2.68
Absorption (%)	1.57	0.63
Water content (%)	2.00	0.183

2.2 Specimens and Mixture Details

Concrete specimens were tested for determination of compressive strength and modulus of rupture. In each specimen, cement was replaced with 0, 10, 15 and 20% silica fume by weight of cement. Specimens were tested at age of 7, 14 and 28 days. 28 days target compressive strength of control concrete mix was taken as 30 MPa with the water to binder ratio of 0.55 and mix design ratio of 1: 1.6: 3.5 (cement: sand: gravel). The slump for the all samples were kept in range of 25 – 50 mm. Samples were cured in water and the curing of test specimens was conducted till the test day. Average of three samples was taken for each test. Cylindrical concrete specimens of size 150 ϕ x 300 mm (6 ϕ x 12 in.) were cast for determination of mean compressive strength. Standard ASTM C 39 [23] test procedure was adopted for determination of compressive strength. Prismatic concrete beams of size 100 × 100 × 510 mm (4 × 4 × 20 in.) were cast for determination of modulus of rupture in accordance with ASTM C 78 [24] standard under 3rd point loading test. Detail of concrete mixtures is given in Table 4. Concrete samples containing 0, 10, 15 and 20 wt % silica fume are abbreviated as SF0, SF10, SF15 and SF20 respectively.

Table 3. Physical properties of silica fume.

Property	Silica Fume
Specific Gravity	2.2
Specific Surface Area (m^2/g)	15-30
Dry Bulk Density (kg/m^3)	450
Mean Particle Size (µm)	0.5

3. RESULTS AND DISCUSSION

Results of compressive strength test and modulus of rupture/flexural tensile strength test are as discussed below.

3.1 Effect on Compressive Strength

Results of compressive strength test are shown graphically in Fig. 2. It is clearly indicated from Fig.2 that inclusion of 10% and 15% silica fume have positive effect on concrete compressive strength. However, concrete mixture containing 15 wt.% silica fume exhibited maximum compressive strength at all ages. Inclusion of 10% silica fume by

Table 4. Mixture proportion for various concrete mixes.

Mixture ID	Cement	Silica Fume	Sand	Coarse Aggregate	Water	Slump	W/C
	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(mm)	
SF0	352	0	576	1236	194	50	0.55
SF10	317	35	576	1236	194	41	0.57
SF15	299	53	576	1236	194	38	0.58
SF20	281	70	576	1236	194	38	0.60

weight of cement resulted in 1.5%, 12% and 15% strength improvement in comparison to control specimen at 7, 14 and 28 days of age respectively. While addition of 15% silica fume resulted in 14.7%, 23.7% and 20.9% strength improvement in comparison to control specimen at 7, 14 and 28 days of age respectively. Compressive strength of concrete specimens was reduced when more amount of silica fume was added i.e. beyond 15% at all ages.

Addition of silica fume helps in increasing the compressive strength of concrete by production of extra amount of C-S-H gel. Silica fume being rich in amorphous silica helps to prolong the hydration reaction of cement by reacting with free calcium hydroxide present in the mixture produced as a result of hydration of cement. Thus the reaction of silica from silica fume and calcium hydroxide generates extra amount of C-S-H gel, which is the major contributor of strength in concrete. However, there is certain limited quantity of calcium hydroxide present in the mixture to react with silica and additional amount of silica fume beyond certain limit acts as filler material, as there is not enough calcium hydroxide present in the mixture to continue the reaction and therefore the effectiveness of addition of silica fume reduces and its presence only marginally improves the packing density. Ajileye [12] also reported that when 15% silica fume is added by weight of cement in concrete mixtures, it exhibits higher compressive strength in comparison to mixture containing no silica fume.

3.2 Effect on Flexural Tensile Strength

Results of flexural tensile strength/modulus of rupture test correlate with the results of compressive strength, as modulus of rupture is directly related to the compressive strength. Fig. 3 indicates the results of flexural tensile strength test. Specimen containing 15% silica fume exhibited maximum flexural tensile strength at all ages. Addition of 10% silica fume aided in increasing flexural tensile strength by 6%, 5% and 12% at 7, 14 and 28 days of age in comparison to control specimen. While addition of 15% silica fume improved flexural tensile strength by 7.5%, 11% and 13% at 7, 14 and 28 days of age in comparison to control specimen. However, inclusion of 20% silica fume resulted in loss of modulus of rupture.

3.3 Effect on Water to Cementitious Ratio

Inclusion of silica fume resulted in increased demand of water in the concrete mixture in comparison to control specimen. To main the required slump range extra amount of water reducing agent was added as per the demand of silica fume. Fig. 4 presents the graphical relation of W/C ratio, clearly indicating the increased water demand.

4. CONCLUSIONS

Following conclusions are drawn from this experimental research study;

1. Compressive strength and flexure tensile strength of concrete improves by addition of silica fume the at all the ages.
2. Incorporation of 15% silica fume resulted in highest compressive strength and flexural tensile strength at all ages, however, with addition of 20% silica fume compressive strength and flexural tensile strength decreased at all ages because there was not enough calcium hydroxide present in the mixture to continue the pozzolanic reaction.
3. Inclusion of silica fume helped in later age strength gain as compared to early age strength development.
4. Specimens containing silica fume have higher water demand in comparison with control concrete mixture.

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