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Research Article

Micro Filler Effects of Silica-Fume on the Setting and Hardened Properties of Concrete

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Abstract: The use of supplementary cementitious material is gaining much attention owing to its high pozzolanic property and further improvement in strength properties. Silica-fume is one among the widely used pozzolanic material which exhibits high cementing efficiency due to high silica content. This study presents comprehends a detailed insight on the hydration properties of silica fume with cement. Silica fume consists of very fine particle size and contains silica content more than 90%. The cement hydration results in the formation of calcium hydroxide and this is consumed with the addition of silica fume and results in additional calcium silicate hydrate. This compound primarily envisages the strength and improved microstructure of concrete. Addition of silica-fume fills in the spaces between cement grains. The test results showed that higher compressive strength of concrete is obtained by using 8.0% of silica-fume at 7 and 28 days was 48.25 and 55.83 MPa, respectively. This phenomenon is frequently referred to as particle packing or micro-filling. Even if silica fume did not react chemically, the micro-filler effect would lead to significant improvements in the microstructure of concrete. A comprehensive review has been carried out in this study to give a good understanding on the advantages of pozzolanic properties of silica fume in cement concrete.

Keywords: Microfillers, setting properties, silica-fume, strength and ultrasonic pulse velocity, superplasticizer

INTRODUCTION

Silica-fume is a highly reactive material which is used in relatively small amounts to enhance the properties of concrete. It is by-product of producing certain metals in electric furnaces. Silica-fume, also known by other names such as volatilized silica, microsilica, or condensed silica fume, is a by-product of the induction arc furnaces in the silicon metal and ferrosilicon alloy industries. Reduction of quartz to silicon at temperatures up to 2000ºC produces SiO_2 vapors, which oxidize and condensed in low-temperature zone of tiny spherical particles consisting non-crystalline silica. Compared to normal Portland cement and various classes of fly ash, silica-fume samples show particle size distributions finer than 0.1 microns. The material is highly pozzolanic and it increases the water requirement in concrete appreciably unless high range water-reducing admixtures are used.

Good number of research studies has been carried out in silica fume which showed the consistent properties in strength enhancement leading to high strength concrete. Owing to its chemical and physical properties, it is a very reactive pozzolan. Zhang *et al*. (2003) Concrete containing silica fume can have very high strength and can be very durable. During the last two decades concrete technology has undergone rapid development to produce high strength concrete of more than 100 MPa [ACI]. Apart from strength, durability properties have also been improved as a result of enhanced microstructure. High strength concrete has been widely used in many specialized civil engineering applications due to better rheological, mechanical and durability properties than those of conventional concretes (Behnood and Hasan, 2008; Dotto *et al*., 2004; Bhanja and Sengupta, 2002). High strength is made possible by reducing water content, porosity, in homogeneity and micro cracks in concrete and the transition zone (CEB-FIP committee). In addition to this the improved concrete properties are obtained by using super plasticizers and supplementary cementing materials such as silica fume, fly ash, granulated blast furnace slag and natural pozzolan. Fortunately, most of these supplementary materials help in reducing the amount of cement required to make concrete less costly, more environmental friendly and less energy intensive (Bhanja and Sengupta, 2003).Silica-fume is one among the widely used pozzolanic materials in concrete. It has been used either as a partial replacement for cement or as an additive when special properties are desired. The rapid increase in the use of silica-fume is attributed to its positive effects on the mechanical properties of cementitious composites. Though added strength and low permeability are the two reasons that silica-fume is added to concrete, there are other properties that are favorably improved which includes: high modulus of elasticity, higher strength at later ages, less sodium sulfate attack due to low

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permeability to water and chloride ions (Erhan *et al*., 2002; Fuat *et al*., 2008) It is well documented that the use of silica fume as a partial replacement for cement in combination with super plasticizers provides a significant increase in the strength of concrete. The water reduction of fresh concrete and the formation of a more densely compacted matrix at the inter-facial zone are believed to be the main causes for this improved durability and strength. The studies conclude that the strength improvement is as a result of the improved bond strength between the cement paste and the aggregate (Handong *et al*., 1999; Kayali and Zhu, 2005) while others concluded that it is mainly due to an increase in the strength of the cement paste matrix. It can be noted that both mechanical properties and ultrasonic pulse velocity for various mixture proportions of concrete was recorded due to increased level of silica fume. The experimental studies revealed that the optimum addition of silica-fume can be restricted upto 12% due to its high fineness and with the increased dosage the water demand increases. Mazloom *et al*. (2004), Ramazan *et al*. (2004) and Zain *et al*. (2000) Also, the increased performance levels of silica-fume can be achieved only with the addition of high range water reducers that can suitably compensate the workability. The present study is aimed at to evaluate the effect of partial replacement of cement by silica fume on strength properties of concrete for different water to binder ratio as well as various fines to aggregate ratio.

EXPERIMENTAL METHODOLOGY

Materials used: An ordinary Portland cement of 53 grade conforming to IS: 12269 (1987) was used which has a consistency of 30% and specific gravity of 3.12. Natural river sand conforming to IS 383-1979 having a fineness modulus of 2.7 and specific gravity of 2.68 and locally available blue granite metal passing through 16 mm sieve with a specific gravity 2.6 and fineness modulus of 6.56 was used. Silica-fume obtained from Elkem, containing fine amorphous particles of SiO_2 more than 90% of silica fume constituent. Chemical admixture was used as a Super plasticizer that is Conplast-Sp 430 (SNF) of specific gravity 1.2 and normal potable water was used throughout the experimental work.

Setting properties of binder: Initially the various level of setting time studied as per Indian standard method by vicat's apparatus (IS: 4031 (Part 5), 1988). The initial and final setting time of binder at different percentage (up to 8% by weight of cement) of silica-fume added.

Casting of specimen for mortar cubes: Mortar mixes were designed to study the compressive strength, at different ages, with different percentage of silica-fume. Silica-fume in various percentages ranging from 2, 4, 6 and 8% by weight of cement was replaced for the total binder content, respectively. The cementitious material-to sand ratio was kept at 1:3 by weight throughout the study. It seems that cement mortar decreases workability as the silica fume content increases. The compressive strength for mortar with different percentage of silica-fume with 0.30 w/b ratios has been studied at different curing ages, i.e., 7 and 28 days. A mortar mixer machine was used for mixing the dry as well as wet mortar for sufficient time till a uniform mix was achieved. The size of the metallic cube mould 70.6×70.6×70.6 mm was used for mortar cubes test. After 24 h the specimens were demoulded and were immersed in water tank for different curing ages at 7 and 28 days. After required curing, the specimens were air-dried with a relative humidity of 65±5% and an average temperature of 30±2ºC. The specimens were tested under loading control machine at a space rate of 1.5 KN/sec.

Casting of specimen for concrete: In this research study a total of 6 different concrete mixture proportions were prepared which consist of a reference mix without silica-fume was proportioned as per Indian standard

Table 1: Various mixture proportions of concrete

	Kg/m^3									
		Fine aggregate passing through IS sieve (mm)			Coarse aggregate passing through IS sieve (mm)					
Mix designation	Cement	4.75	2.36	1.18	12.5	10	Water	w/c ratio	F/C ratio	% replacement of cement by silica fume
F1	425	672	0	0	1113	0	128	0.3	0.6	0
F2	425	0	672	0	0	1113	128	0.3	0.6	0
F3	425	0	0	672	1113	0	128	0.3	0.6	0
F4	425	672	0	0	0	1113	128	0.3	0.6	0
F5	425	0	672	0	1113	0	128	0.3	0.6	0
F6	425	0	0	672	0	1113	128	0.3	0.6	0
SF1	400	672	0	0	1113	0	160	0.4	0.6	8
SF2	400	0	672	0	0	1113	160	0.4	0.6	8
SF3	400	0	0	672	1113	0	160	0.4	0.6	8
SF4	400	672	0	0	0	1113	160	0.4	0.6	8
SF5	400	0	672	0	1113	0	160	0.4	0.6	8
SF6	400	0	0	672	0	1113	160	0.4	0.6	8

specifications IS: 10262-1982 and the other 6 mixes contained with 8.0% of silica-fume throughout the experimental works for various compositions of mixtures are presented in Table 1. All mixtures were designed by conceptual mix was adopted. The water content for reference mix and various mix proportions was found to be 128 Kg/m^3 were established by keeping the fine aggregate to coarse aggregate ratio of 0.6 and w/c ratio of 0.3 and 0.4. The ingredients were mixed in a rotating mixer of capacity 30 Kg of container for a period of mixing the ingredients up to 3 min. The super plasticizer was added with 2% for fixed throughout experiments for various mixture proportions and then mixed thoroughly with the mixing water and added to the mixer and casted in steel cube moulds of standard size 100×100×100 mm were cast for each concrete mixture were compacted on a table vibrator. The surface finishing was done very carefully to obtain a uniform smooth surface. All the specimens were cured in the same curing tank to maintain the uniformity of the specimens. Tests were performed at 7, 28 and 90 days of curing period, respectively. At different curing ages the specimen is dried for 1 h depending on the room temperature.

EXPERIMENTAL TEST RESULTS AND DISCUSSION

Test results are presented graphically and in tabular forms and have been discussed under various categories.

Effect of silica fume on the fresh properties of concrete: Fresh concrete containing silica-fume is more cohesive and less prone to segregation. As the silica-fume normally does not segregate appreciably because of the fineness of the silica-fume and use of high range water reducing agent. The water cement increased in the various replacement levels of silica-fume and primarily to the high surface area of the silica-fume at the same time concrete containing silica fume showed significantly reduced bleeding. This leads to effect of primarily by the more surface area of the silica-fume normally to be wetted because of more amount of water left in the mixture for bleeding. With the addition of high range water reducers the consistency of silica-fume concrete mixes can be reinstated.

Setting time: From the setting time test results for different percentage addition of silica-fume given in Table 2 and it was concluded that normal cement paste (without silica-fume) the initial setting time was around 90 min and final setting time was 260 min. However, when 2% silica-fume is added with cement the initial and final setting time value was around 80 and 300 min, respectively. Similarly the setting time starts reducing

Table 2: Initial and final setting time for various level of silica-fume

Mix Id	Percentage of silica fume (by weight of cement)	Setting time (min) Initial	Setting time (min) Final	Time lagging (min)
N	0	95	260	165
S2	2	80	300	220
S4	4	75	180	105
S6	6	20	175	155
S8	8	10	135	125

Table 3: Average compressive strength of mortar cubes with various mixture proportions

Percentage of silica fume	Mix Id	Average compressive strength (MPa) 7 days	28 days	90 days
0% of silica fume	N	26.87	53.10	57.20
2% of silica fume	S2	27.31	49.55	53.90
4% of silica fume	S4	28.90	52.37	55.10
6% of silica fume	S6	31.78	55.10	58.41
8% of silica fume	S8	33.94	57.80	60.22

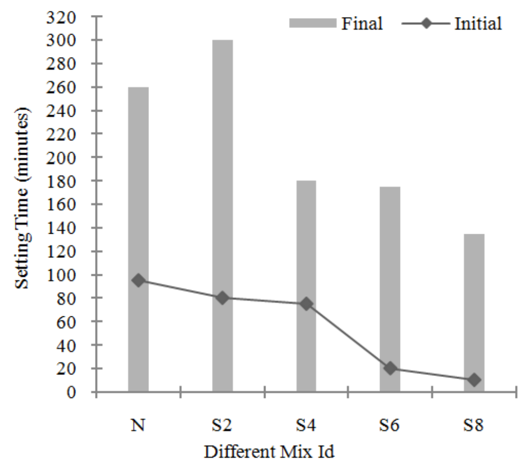

Fig. 1: Initial and final setting time for various percentage of silica fumes

with the increase in the silica-fume replacement. For 6 and 8% silica-fume replacement, the initial and final setting time was found to be still reduced to 20 and 135 min, respectively. Inclusion of silica fume up to 8% with addition of 2% super plasticizer the initial and final setting time was reduced further and the time lag was found to be 125 min of time lagging compare to other mixtures. The experimental values are represented graphically in Fig. 1.

Compressive strength of cement mortar: The experimental test results was carried out as per (IS: 4031 (Part 6), 1988) from that result for reference cement mortar cube was obtained at different curing ages 7, 28 and 90 days as shown in Table 3 and Fig. 2 and 3. The 7 days strength was 26.87 N/mm^2 for 28 days 53.10 N/mm^2 and for 90 days 57.20 N/mm^2. The compressive strength of 2% silica fume mortar cube at 7 days strength was found to be 27.31 N/mm^2 for 28 days 49.55 N/mm^2 for 90 days 53.90 N/mm^2. Same as for 4% the strengths are for 7 days 28.90 N/mm^2 for 28 days 52.37 N/mm^2 for 90 days 55.10 N/mm^2. For

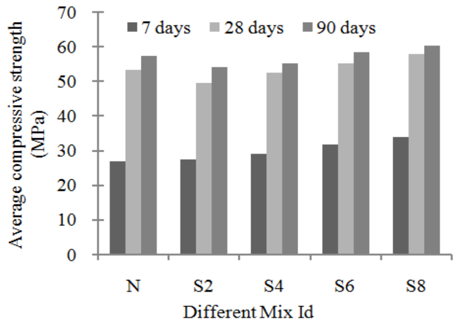

Fig. 2: Compressive strength of mortar cubes for various percentage of silica-fumes at 7, 28 and 90 days, respectively

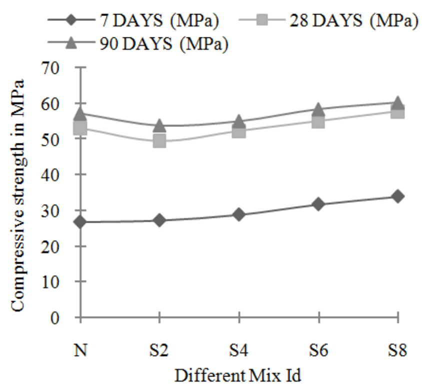

Fig. 3: Comparison of mortar cubes test for various percentage of silica-fumes at 7, 28 and 90 days, respectively

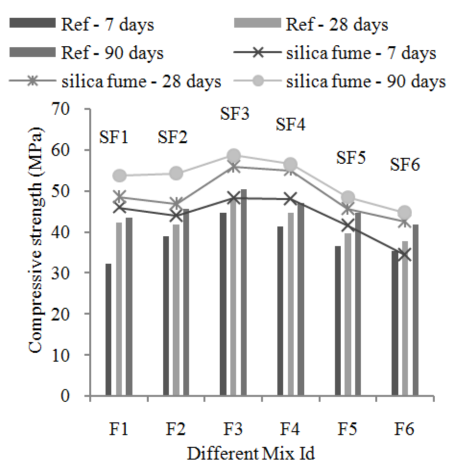

Fig. 4: Compressive strength for various mixture proportions of concrete at curing ages

inclusion of 6% silica fume increased the compressive strength compare to 7 days up to 57.6% the 7 days strength was found to be 31.78 N/mm^2 for 28 days strength was 55.10 N/mm^2 and for 90 days 58.41 N/mm^2. It can also concluded that from the test result compared to reference concrete the higher replacement level of silica fume with 8% was increased the compressive strength up to 19.68% at 28 days due to finer material acting as micro filler which makes reduces the crakes, voids and increased the density of cement mortar for 33.94, 57.8 and 60.22 N/mm^2 for 7, 28 and 90 days, respectively.

Table 4: Compressive strength of concrete cubes with various mixture proportions

Mix Id	Average compressive strength N/mm^2 7 days	28 days	90 days	Split tensile strength (N/mm^2) 28 days
F1	32.36	42.23	43.60	3.78
F2	38.90	41.72	45.71	4.01
F3	44.56	48.21	50.33	4.13
F4	41.30	44.65	46.98	3.21
F5	36.50	39.71	44.67	3.76
F6	35.42	37.86	41.80	4.11
FS1	45.93	48.37	53.60	3.95
FS2	43.93	46.75	54.17	4.01
FS3	48.25	55.83	58.60	4.63
FS4	48.00	54.91	56.34	4.41
FS5	41.52	45.60	48.30	4.47
FS6	34.40	42.61	44.56	3.38

Table 5: Ultrasonic pulse velocity for various mixture proportions of concrete

Mix Id	Ultrasonic pulse velocity (m/sec) Curing days 7 days	14 days	28 days
F1	3400	3590	3960
F2	3580	3690	3810
F3	3600	3730	3980
F4	3310	3590	4000
F5	3530	3690	3950
F6	3540	3810	4100
FS1	3480	3610	3950
FS2	3560	3680	3970
FS3	3460	3680	4130
FS4	3530	3600	4020
FS5	3480	3520	3980
FS6	3390	3650	3870

Compressive strength of concrete: The various test results for compressive strength of concrete with and without silica-fume are summarized in Table 4 and Fig. 4. A maximum increase in compressive strength of concrete is obtained for higher substitution of silica-fume at 8%. Also the increase in strength was reported for a fine aggregate passing through 1.18 mm, coarse aggregate passing through 12.5 mm and fine to coarse aggregate ratio of 0.6, which attained a 15.80% increase in compressive strength of 55.83 MPa at 28 days compared to controlled concrete which was around 48.21 MPa at 28 days. However, it can be observed from the test results that the steady increase in strength was achieved for higher replacements of silica-fume and optimum F/C ratio of 0.6.

Split tensile strength: A similar trend was observed for split tensile strength wherein the higher addition of silica-fume exhibited higher split tensile value of 4.63 MPa at 28 days and the increased was 23% compared to controlled concrete.

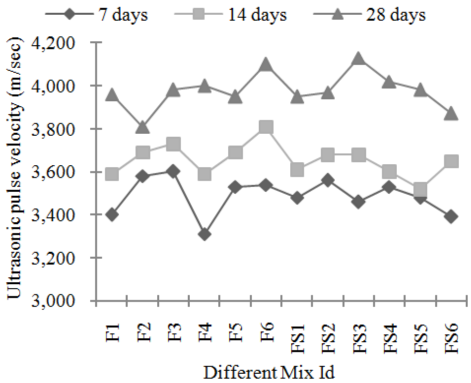

Fig. 5: Ultrasonic pulse velocity values at different curing days

Ultrasonic pulse velocity test: The ultrasonic pulse velocity values for all silica fume based concrete with respect to different curing ages are given in the Table 5. The experimental test results showed that higher enhancement of the strength for the ultrasonic pulse velocity as shown in Fig. 5. The UPV values revealed an increasing trend for different concrete mixes with the pulse velocity values in the range of 3300 to 4200 m/sec. However, the higher value of ultrasonic pulse velocity value (4130 m/sec) was obtained at 28 days, when silica-fume up to 8.0% and F/C ratio of 0.6 with w/c 0.4 was recorded at same mixes that gives the good improvement and satisfies the codal provision as per (IS: 13311 (Part 1), 1992). This is very essential part of important conclusion based on the pulse velocity techniques and predicts the quality of concrete by non destructive methods.

CONCLUSION

Based on the experimental investigation the following conclusions are drawn within the limitations of the test results:

- A higher strength was reported for silica-fume cement mortar at low w/b ratio and the increase was significant at higher substitution due to increased reactivity.
- The higher rate of strength gain was noticed at curing ages of 7, 28 and 90 days, respectively with w/c ratio 0.30 due to pour filling effect of silica-fume particles and further enhancement of micro structural properties.
- The careful selection of different ingredients such as water to binder ratio (0.3) and fine to coarse aggregate ratio of 0.6 has significant effect on the micro structural alterations in concrete, which results in improvements in the mechanical properties.
- Strength gain in concrete is a function of low water cement ratio, F/C ratio and super plasticizer dosage. Cement replacement up to 8.0% of silica-fume showed considerable strength gain than controlled concrete. Therefore, concrete mixes containing silica-fume can be used up to 8.0% can be safely used to produce high strength concrete.
- It was observed from the test results that the higher strength of silica-fume can be obtained with large replacements; however restricted due to high fineness which can adversely affect the workability due to increased water demand.

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