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Effect of Silica Fume on Workability and Compressive Strength of OPC Concrete

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Abstract

Silica fume is a by product resulting from the reduction of high – purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or silicon alloys. Silica fume is known to improve the mechanical characteristics of concrete. The principle physical effect of silica fume in concrete is that of filler, which because of its fineness can fit into space between cement grains in the same way that sand fills the space between particles of coarse aggregates and cement grains fill the space between sand grains. As for chemical reaction of silica fume, because of high surface area and high content of amorphous silica in silica fume, this highly active pozzolan reacts more quickly than ordinary pozzolans. The use of silica fume in concrete has engineering potential and economic advantage. This paper presents the results of an experimental investigations carried out to find the suitability of silica fume in production of concrete. It is observed that the optimum dose of silica fume is 5% (by weight), when used as part replacement of OPC. The silica fume inclusion increases the workability and strength of concrete considerably.

Keywords: *Silica fume; pozzolan; compressive strength; OPC.*

1. INTRODUCTION

By addition of some pozzolanic materials, the various properties of concrerte viz, workability, durability, strength, resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixtures, which improve the microstructure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the microstructure of cement composites improves the mechanical properties, durability and increases the service-life properties. When fine pozzolana particles are dissipated in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica of the pozzolanic and calcium hydroxide, produced during the cement hydration reactions (Sabir et al., 2001, Antonovich and Goberis, 2003, Rojas and Cabrea, 2002).

In addition, the physical effect of the fine grains allows dense packing within the cement and reduces the wall effect in the transition zone between the paste and aggregate. This weaker zone is strengthened due to the higher bond development between these two phases, improving the concrete microstructure and properties. In general, the pozzolanic effect depends not only on the pozzolanic reaction, but also on the physical or filler effect of the smaller particles in the mixture. Therefore, the addition of pozzolans to OPC increases its mechanical strength and durability as compared to the referral paste, because of the interface reinforcement. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste. Silica fume is a by product resulting from the reduction of high – purity quartz with coal or coke and wood chips in an

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electric arc furnace during the production of silicon metal or silicon alloys. Silica fume is known to improve both the mechanical characteristics and durability of concrete. The principle physical effect of silica fume in concrete is that of filler, which because of its fineness can fit into space between cement grains in the same way that sand fills the space between particles of coarse aggregates and cement grains fill the space between sand grains. As for chemical reaction of silica fume, because of high surface area and high content of amorphous silica in silica fume, this highly active pozzolan reacts more quickly than ordinary pozzolans.

The use of silica fume in concrete has engineering potential and economic advantage. It is reported by most researchers (Gafoori and Hamidou, 2007, Yogendran et al., 1987, Khayat et al., 1997, Ramakrishnan and Srinivasan, 1982, Bayasi, 1993) that workability is reduced on silica fume inclusion however Kadri and Dual reported increase in workability on replacement of cement by silica fume. It is also reported (Gafoori and Hamidou, 2007, Yogendran, 1987, Khayat, 1997, Ramakrishnan and Srinivasan, 1982, Kadri and Dual, 1998) that compressive strength is increased upto optimum replacement level of silica fume. Strength of silica fume concrete is affected by several factors viz. type of cement, quality and proportion of silica fume and curing temperature. The main contribution of silica fume to concrete strength development at normal curing temperature takes place from about 3 to 28 days. The contribution of silica fume to strength development after 28 days is minimal (Sakr, 2006).

Bhanja and Sengupta (2003) reported that inclusion of silica fume in the range of 5 – 25% increases compressive strength in the range of 6.25 – 29.85% for water cement ratio between 0.26 - 0.42. Sakr, 2006 reported that at 15% silica fume content gravel concrete, barite concrete and ilmenite concrete showed increased compressive strength by 23.33%, 23.07% and 23.52% respectively at 7 days, 21.34%, 20% and 22.58% respectively at 28 days, 16.5%, 18.7% and 22% respectively at 56 days and 18%, 7.14% and 22.80% respectively at 90 days.Dual and Kadri (1998) reported that at 10% replacement level compressive strength increased in the range of about 10 – 17 % at different water cement ratio(0.25-0.45). Khayat et al (1997) reported that at 7.5% replacement level compressive strength increased in the range of about 10 – 17 % at different water cement ratio (w/c). Babu and Prakash (1995) reported that concrete with silica fume even upto 40% replacement show strength higher than that of the control concrete. The improvements in strength at the different percentages of replacement of replacement at any water cement ratio were also varying over a wide range. Khan and Ayers (1995) reported 67% increase in compressive strength at 10% replacement level and 0.38 w/c.

Cong et. al(1992) reported that concrete containing silica fume as a partial replacement of cement exhibits an increased compressive strength in large part because of the improved strength of its cement paste constituent. Slaniska and Lamacska (1991) reported that at different replacement level of cement by silica fume (3.75 – 10.25%) increase in compressive strength in the range of about 12% - 57% is observed. Detwiler and Mehta (1989) reported that silica fume concrete showed improved compressive strength in the range of 11.56% - 18.89%than the conventional concrete at different water cement ratio.

In the present study an experimental programme was conducted to investigate the suitability of silica fume as partial replacement of cement and its effect on the compressive strength and workability of concrete. The referral concrete M_{25} was made using 43 grade OPC (Birla) and the other mixes were prepared by replacing part of OPC with silica fume. The replacement levels were 5%, 10%, 15%, 20%, 25% and 30% (by weight). This paper presents the results of this investigation.

2. MATERIAL AND METHODS

For the present investigation, the coarse aggregate of size 12.5 mm and down from Bharatkup quarry was used. The sieve analysis of the aggregates was carried out and the same distribution / FM was maintained throughout the experiment. The important properties of the coarse aggregate were: Fineness Modulus = 6.29; Flakiness index = 20% (< 40% Ok BS 882-1992); Elongation Index = 7%; Moisture content = 0.52% (<2% Ok); Crushing value = 18.2% (<30 Ok); Specific gravity = 2.72 (2.6-2.8).

The fine aggregate used in the investigation was ‘Jamuna’ sand. The properties of fine aggregate found as per IS-383 were: Fineness Modulus = 2.5; Moisture content = 0.52% (<2% Ok); Specific gravity = 2.54. The gradation of fine aggregate (Zone III) was maintained throughout the experiment.

Silica fume for the present investigation was obtained from M/s ELCOM Enterprises, Mumbai. The silica fume was sieved and the fraction passing 100µ IS sieve was used in the experiments. The physical and chemical properties of silica fume viz-a-viz, OPC are presented in table 1. The binder used in the present investigation was 43 grade OPC (Birla). The properties of cement were determined in accordance with IS – 8112: 1989 were: Fineness = 6.8% (<10%

Ok); Consistency = 31%; Initial Setting Time = 60 minutes (>30 minutes Ok) ; Final Setting Time = 480 minute (<600 minutes Ok).

Table 1. Physical and Chemical Properties of Silica Fume

Properties	OPC	Silica Fume
Physical		
Specific gravity	3.1	2.2
Mean grain size (μm)	22.5	0.15
Specific area cm^2/gm	3250	150000-300000
Colour	Dark Grey	Light to Dark Grey
Chemical compositions (%)		
Silicon dioxide (SiO_2)	20.25	85
Aluminium oxide (Al_2O_3)	5.04	1.12
Iron oxide (Fe_2O_3)	3.16	1.46
Calcium oxide (CaO)	63.61	0.2-0.8
Magnesium oxide (MgO)	4.56	0.2-0.8
Sodium oxide (Na_2O)	0.08	0.5-1.2
Potassium oxide (K_2O)	0.51	
Loss on ignition	3.12	<6.0

For the present investigation, mix design for M_{25} grade of concrete (Target strength = 31.6 MPa) was carried out using the above coarse aggregate, fine aggregate, and the binder. The proportion of the materials by weight was 1:1.89:2.17:0.48 (Cement: Fine aggregate: Coarse aggregate: Water). To investigate the effect of silica fume inclusion (as part replacement of cement), 100 mm cubes were cast for referral and other mixes having variable silica fume content. The cement was replaced by silica fume at the rate of 5, 10, 15, 20, 25, 30 and 35% (by weight). The workability (Slump value) and the compressive strength of different mixes were tested at 7 and 28 days as per the procedure laid down in IS: 516 - 1981. The results obtained from the above investigation are presented below.

3. RESULTS

The compressive strength of the cubes at different ages and different silica fume content are presented in Fig - 1. The slump values and compaction factor of the different mixes are presented in table - 2.

Table 2. Variation of Slump and Compaction Factor of different Mixes

Replacement level (%)	Slump (mm)	Compaction Factor
0 (Referral)	25	0.81
5	28	0.82
10	30	0.83
15	30	0.83
20	32	0.84
25	34	0.85
30	37	0.86
35	42	0.87

Fig 1 reveals that optimum replacement level of cement by silica fume is 5%. At 5% replacement level the strength of silica fume concrete improved by 12.5% and 18.18% at 7 days and 28 days respectively as compared to the referral concrete. At all other replacement levels the strength of silica fume concrete is lower than the referral concrete, however, the workability is marginally improved at all replacement levels. It is reported in the literature that inclusion of silica fume (5 – 40%) increases the strength in the range of 6.25 – 67%. In our research work in which silica fume was included between 5 – 35%, the increase in strength is observed by 18.18%. The strength improvement due to silica fume incorporation in concrete occurs due to chemical and physical processes, the chemical effect due to the pozzolanic activity and the physical effect due to the microfiller action. However, decrease in strength is due to the reason that silica fume added in excess of that required for pozzolanic and filler actions results in replacement of primary binder, that is cement, and hence reduction in strength.

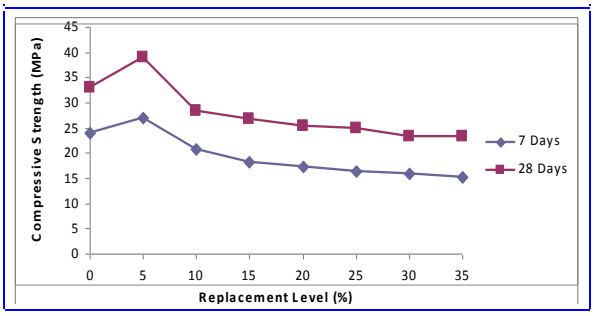

Fig. 1: Variation of compressive strength with replacement level of OPC by silica fume.

4. CONCLUSIONS

The following conclusions are derived on the use of silica fume in concrete making.

1. The optimum replacement level of cement by silica fume is found to be 5% by weight.
2. There is a significant improvement in the compressive strength of concrete using silica fume at both 7 and 28 days as compared to the referral concrete.
3. The workability in case of silica fume concrete is marginally improved.
4. Beyond optimum silica fume level the strength decreases but the workability increases.

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REFERENCES

ACI, 234R-96, Guide for the Use of Silica Fume in Concrete", Reported by ACI, Committee, 234, 1-51 (1996).

Antonovich V. and Goberis S., The effect of different admixtures on the properties of refractory concrete with Portland cement, Mater Sci, 9, 379-383(2003).

Bhanja, Shantanu, and Sengupta, Bratish "Optimum Silica Fume content and its Mod of Action on Concrete, ACI Materials Journal, 100(5), 407-412(2003).

Bayasi, Z. and Zhou, J., "Properties of Silica Fume Concrete and Mortar", ACI Materials Journal, 90,(4), 349 – 356 (1993).

Cong, X., Gong, S., Darwin, David and McCabe, S.L., "Roll of Silica Fume in Compressive Strength of Cement Paste, Mortar and Concrete." ACI Materials Journal, 89(4), 375-387(1992).

Detwiler, R. J. and Mehta, P. K., Chemical and Physical Effects of Silica Fume on the Mechanical Behaviour of Concrete, ACI Materials Journal, 86 (6), 609-614 (1989).

Gafoori, Nader and Diawareand, Hamidou, Strength and Wear Resistance of Sand -Replaced Silica Fume Concrete, ACI Materials Journal, 104(2), 206-214 (2007).

Ganeshbabu, K. and Suryaprakash, P. V., Efficiency of Silica Fume in Concrete Cement and Concrete Research, 25(6), 1273-1283 (1995).
doi:10.1016/0008-8846(95)00120-2

Kadri, E. H. and Duval, R., Influence of Silica Fume on the Workability and Compressive Strength of High Performance Concrete Cement and Concrete Research, 28(4), 533-547 (1998).
doi:10.1016/S0008-8846(98)00010-6

Khan, S. M. and Ayers, M. E., Minimum Length of Curing of Silica Fume Concrete, Journal of Materials in Civil Engineering, 7(3), 134-139 (1995).
doi:10.1061/(ASCE)0899-1561(1995)7:2(134)

Khayat, K. H., Vachon, M. and Lanctot, M. C., Use of Blended Silica Fume Cement in Commercial Concrete Mixtures, ACI Materials Journal, 94(3), 183-192 (1997).

Ramakrishnan, V and Srinivasan, V., Silica Fume in Fibre Reinforced Concrete, Indian Concrete Journal, 56(12), 326-334 (1982).

Rojas M. F., Cabrea J., The effect of temperature on the hydration phase of metakaolin – lime-water system, Cem. Concr. Res, 32, 132-138(2002).
doi:10.1016/S0008-8846(01)00642-1

Sabir B. B., Wild S. and Bai J., Metakaolin and calcined clays as pozzolona for concrete – A review, Cem. Concr. Composites, 23, 441 – 454 (2001).

Sakr K., Effects of silica fume and Rice husk Ash on the Properties of Heavy Weight Concrete" Journal of Materials in Civil Engineering, 18(3), 367 -376 (2006).

Slanicka, Stefan and Lamacska, B., The Influence of Condensed Silica Fume on the Concrete Strength Cement and Concrete Research 21(4), 462-470 (1991).
doi:10.1016/0008-8846(91)90094-X

Yogendran, Y., Langan, B. W., HaqueM. N. and Ward, M. A., Silioca Fume in High Strength Concrete, ACI Materials Journal, 84(2), 124-129 (1987).