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REVIEW ARTICLE

Effect of Silica fume on mechanical properties of Concrete

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Abstract

The construction activities in last few decades have increased many folds in almost all the developing countries of the world. Cement is becoming a scarce commodity globally because of its growing demand day by day. It is the need of time to search such alternative materials that would partially or fully replace cement used in concretes and mortars without affecting its quality, strength and other characteristics. The use of supplementary cementitous materials (SCMs) or non-conventional material is vital in developing low cost construction. By addition of some pozzolanic materials, the various properties of concrete viz., workability, durability, strength, resistance to cracks and permeability can be improved. Silica fume is a byproduct resulting from the reduction carbothermic 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 both the mechanical properties and durability of concrete. The principle physical effect of silica fume in concrete is that of filler besides the pozzolanic activity, 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 will not significantly change the unit weight of concrete. Silica fume will produce a much less permeable and high strength concrete, but it will not produce a concrete with a higher mass per unit volume. Against these backdrops, this review is focused on the effect of silica fume on mechanical properties of concrete.

Keywords: Silica fume, pozzolan, workability, compressive strength, flexural strength.

Introduction

The construction activities in last few decades have increased many folds in almost all the developing countries of the world. Cement is becoming a scarce commodity globally because of its growing demands day by day. It is the need of time to search such alternative materials that would partially or fully replace cement used in concretes and mortars without affecting its quality, strength and other characteristics. The use of supplementary cementitous materials (SCMs) is fundamental in developing low cost construction materials for use in developing countries.

Concrete is the most widely used and versatile building material which is generally used to resist compressive forces. By addition of some pozzolanic materials, the various properties of concrete 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 material and calcium hydroxide, produced during the cement hydration reactions (Sabir *et al*., 2001; Rojas and Cabrea, 2002; Antonovich and Goberis, 2003). 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 an industrial by product of silicon metal or some ferrosilicon alloys. The fume which has a high content of amorphous silicon dioxide and consists of very fine spherical particle particles (0.1-0.2 µm) is collected from the effluent gases escaping from the furnace.

Silica fume which is commonly used in cement based systems, contain 85 to 98% silica. Silica fume, in itself, does not have any cementious properties but when reacts with Ca(OH)2 on hydration of cement produces the gel i.e. calcium-silicate-hydrate (C-S-H) which has good cementious properties. 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. The use of silica fume will not significantly change the unit weight of concrete. Silica fume will produce a much less permeable and high strength concrete, but it will not produce a concrete with a higher mass per unit volume. This paper presents a review of silica fume and its effect on fresh and hardened concrete.

Properties of silica fume: Silica fume is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles. It is an airborne material with spherical particles less than 1 μm in diameter, the average being about 0.1 μm. This makes it approximately 100 times smaller than the average cement particle. The physical and chemical properties of silica fume viz-a-viz, OPC are presented in Table 1 (ACI 234R-96, 1996; Detwiler and Mehta, 1989; Nader and Hamidou, 2007).

Table 1. Physical and chemical properties of silica fume and OPC.

Properties	OPC	Silica fume
Physical		
Specific gravity	3.1	2.2
Mean grain size (μm)	22.5	0.1
Specific area (cm^2/g)	3250	200000
Colour	Dark grey	Light to dark grey
Chemical compositions (%)		
Silicon dioxide (SiO_2)	22.03	96.0
Aluminium oxide (Al_2O_3)	4.03	0.1
Iron oxide (Fe_2O_3)	3.67	0.6
Calcium oxide (CaO)	65.19	0.1
Magnesium oxide (MgO)	0.88	0.2
Sulphite (SO_3)	2.86	-
Sodium oxide (Na_2O)	0.12	0.1
Potassium oxide (K_2O)	0.20	0.4
Loss on ignition	0.98	1.7

Source: Gafoori, and Diawareand, 2007; Detwiler and Mehta, 1989; ACI, 234R-96, 1996).

Properties of silica fume concrete (SFC): 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. The important properties of Silica Fume Concrete (SFC) in green and hardened states are presented below.

Workability: The property of concrete which determines the amount of useful internal work necessary to produce full compaction is known as workability. The workability of fresh concrete depends mainly on the material, mix proportion and environmental conditions. Fresh concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. As the silica fume content is increased, the concrete may appear to become sticky. Bayasi and zhou (1993) reported that it has been the general practice of researchers and designers to alter the mixture proportion of plain concrete (without silica fume) upon the incorporation of silica fume. This has been done to overcome the adverse effect of silica fume on fresh mixture workability. Kadri and Dual (1998) concluded that at 10% replacement of cement by silica fume, the workability increased in the range of 5-6.25% even after reduction of super plasticizer's dose. Khayat *et al.* (1997) reported that concrete with 7.5% silica fume content showed 15 to 20 mm slump loss as compared to conventional concrete. Yogendran *et al*. (1987) reported that for increase is cement replacement with silica fume the workability decreases linearly. Ramakrishnan and Srinivasan (1982) reported that addition of silica fume had reduced the workability considerably in all the mixes. Silica fume mixes were sticky and cohesive. In general finishibility was improved with the addition of silica fume. Nader and Hamidou (2007) reported that workability of fresh concrete decrease with the incorporation of silica fume.

Compressive strength: 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 d. The contribution of silica fume to strength development after 28 d is minimal (ACI, 234R-96, 1996). Sengupta and Bhanja (2003) reported that inclusion of silica fume in the range of 5-25% increases compressive strength about 6-30% for water cement ratio in the range of 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 d, 21.34%, 20% and 22.58% respectively at 28 d, 16.5%, 18.7% and 22% respectively at 56 d and 18%, 7.14% and 22.80% respectively at 90 d.

Kadri and Dual (1998) reported that at 10% replacement level, compressive strength increased in the range 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 Ganesh and Suryaprakash (1995) reported that concrete with silica fume even up to 40% replacement showed strength higher than that of the control concrete. The improvements in strength at the different percentages 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. Yogendran *et al.* (1987) reported that at 0.34 w/c, the compressive strength of concrete at 7, 28 and 56 d with 5 and 10% replacement level are slightly higher than the control mix. Ramakrishnan and Srinivasan (1982) reported that high strength fibre reinforced concretes can be produced by addition of silica fume. Compressive strength as high as 58 MPa have been obtained with locally available lime stone aggregate. Gafoori and Diaware (2007) reported that at 28 d concrete with 5, 10, 15 and 20% silica fume (as partial replacement of fine aggregate) showed gain in compressive strength of concrete by 25, 64, 42 and 25% respectively when compared with referral.

Tensile strength: Splitting tensile strength of concrete and incorporating silica fume is similar to that observed in concretes without silica fume. As the compressive strength increases the tensile strength also increases, but at a gradually decreasing rate (Goldman, 1987). Several study showed that splitting tensile strength at various ages ranged between 5.8-15% of the compressive strength. Paillere *et al.* (1989) reported that at 15% silica fume content and tensile strength of concrete found to be in the range of 4.79-5.34% of its compressive strength. Sakr (2006) reported that at 15% replacement level, tensile strength of silica fume concrete increased in the range of 27-34% as compared to concrete without silica fume.

Flexural strength: Flexural strength of concrete incorporating silica fume is similar to that observed in concretes without silica fume. Wolsiefer (1984) reported that for the 98 MPa concrete containing 593 Kg/m^3 of cement and 20% silica fume, the ratio of flexural to compressive strength varies between 0.13 to 0.15. Yogendran *et al.* (1987) reported that at 0.34 w/c, the flexural strength of concrete was at 7, 28 and 56 d with 5 and 10% replacement level which are slightly higher than the control mix. However at 15% replacement level, loss in strength is observed due to improper compaction since, the voids could not be removed even using vibrating table. Ramakrishnan and Srinivasan (1982) reported that flexural strength of silica fume concrete was higher by 10-15% as compared that of ordinary fibre concrete. Sakr (2006) reported that at 15% replacement level, flexural strength of silica fume concrete found to be increase in the range of 52-65% as compared to concrete without silica fume.

Bond strength: Using silica fume as a component of concrete has been shown to improve bond strength. Sakr (2006) reported that at 15% replacement level bond strength of silica fume concrete found to be increase in the range of 37-43% as compared to concrete without silica fume.

Modulus of elasticity: The static modulus of elasticity of silica fume concrete is apparently similar to that of Portland cement concrete. Detwiler and Mehta (1989) reported that at 0.25 and 0.34 w/c, modulus of elasticity of silica fume concrete found to be decrease by 2.34 and 3.76% respectively, whereas at 0.50 w/c it was found to be increase by 3.59% as compared to conventional concrete.

Conclusion

The addition of silica fume reduces workability. However, in some cases improved workability were also reported. Silica fume inclusion increases compressive strength significantly (6-57%) and increase in compressive strength depends upon replacement level. Tensile strength and flexural strength of silica fume concrete is similar to that of conventional concrete. Addition of silica fume improves bond strength of concrete. Modulus of elasticity of silica fume concrete is similar to that of conventional concrete.

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