J. Environ. Nanotechnol.
Volume 2 (2013) 53-58 pp.
ISSN (Print) : 2279-0748
ISSN (Online) : 2319-5541
doi:10.13074/jent.2013.02.nciset310

Silica Fume – An Admixture for High Quality Concrete

Vikas Srivastava [1], V. C. Agarwal[2], Atul[3], Rakesh Kumar[4], P. K. Mehta[4]

1. *Assistant Professor, Civil Engg. Department, SHIATS (Formerly AAI-DU), Allahabad.*
2. *Professor, Civil Engg. Department, SHIATS (Formerly AAI-DU), Allahabad.*
3. *Assistant Professor, Civil Engg. Department, Dev Prayag Institute of Technical Studies, Allahabad.*
4. *Assistant Professor, Civil Engg. Department, MNNIT, Allahabad*

Abstract

By addition of some pozzolanic materials, the various properties of concrerte viz, workability, durability, strength, resistance to cracks and permeability can be improved. Silica fume is one such pozzolanic material. Silica fume is a by product obtained 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. The use of Silica fume as admixture in concrete has opened up one more chapter on the advancement in concrete technology. More sticky mix can be obtained by addition of Silica fume in concrete. Using Silica fume in concrete increases its compressive, tensile, flexural and impact strengths and decreases permeability and bleeding. In this paper, an attempt is made to describe the suitability of silica fume in concrete.

Keywords : *compressive strength, flexural strength, pozzolan, silica fume, workability*

1. INTRODUCTION

Concrete is the widely used and versatile material, generally used to resist compressive forces in the structures . 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 theprecipitation of the hydration products.

Vikas Srivastava
E-mail : vikas_mes@rediffmail.com

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; Rojas and Cabrea, 2002; Antinovich and Goberis, 2003**)**.

Also, 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 concretemicrostructure 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.

One of the most widely used supplementary cementitious materials (SCMs) in the production of high-performance concrete (HPC) is silica fume which is also known as microsilica. As an admixture in HPC, it makes concrete stronger and more durable. Silicon metal and alloys are produced in electric furnaces as shown in (fig. 1). The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than being used in landfilling. Perhaps the most important use of this material is as a mineral admixture in concrete.

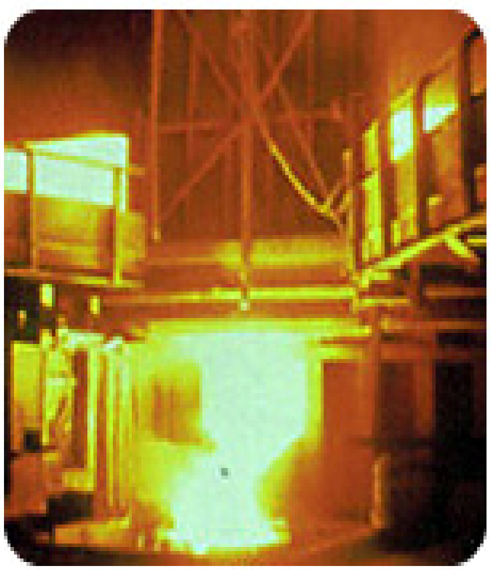

Fig.1:Electric furnace for silicon & alloys production

Silica fume consists of very fine particles about 100 times smaller than the average cement particles. The extreme fineness of the silica fume particles allows it to fill the microscopic voids between cement particles. Silica fume is a key component of high strength concrete as it contributes to strength at early and later ages.

2.1 Properties of Silica Fume

Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a very reactive pozzolan when used in concrete. The physical and chemical properties of silica fume are given in table 1.

Table - 1

Physical Properties	
Specific gravity	2.2
Mean grain size (μm)	0.15
Specific area cm^2/gm	150000-300000
Colour	Dark to Light Grey
Chemical Properties (%)	
SiO_2	85
CaO	0.2-0.8
MgO	0.2-0.8
Na_2O K_2O	0.5
LOI	<6.0

2.2 Properties of Silica Fume Concrete

Incorporation of silica fume is known to improve both the mechanical characteristics and durability of concrete. The important properties of Silica Fume Concrete (SFC) in green and hardened states are presented hereinafter.

2.3 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 materials, mix proportion and environmental conditions. Fresh concretecontaining silica fume is more cohesive and lessprone to segregation than concrete without silica fume. As the silica fume content is increased, the concrete may appear to become sticky. In general the workability of SFC decreases with increase in silica fume content (Bayasi and Zhou, 1993; Yogendran et al., 1987; Khayat et al. 1997; Ramakrishnan and Srinivasan, 1982) however, marginal increase in workability is also reported in several research (Kadri and Duval, 1998; Srivastava et al., 2011).

2.4 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 days (ACI, 234R-96, 1996). In general, inclusion of silica fume in the range of 5-25% increases the compressive strength by about 6-30% for water cement ratio in the range of 0.26-0.42 (Sengupta and Bhanja, 2003; Sakr, 2006; Kadri and Duval, 1998; Khayat et al. 1997; Yogendran et al., 1987). However, in a study 67% increase in compressive strength is reported at 10% replacement level and 0.38 w/c ratio (Khan and Ayers, 1995). Concrete with silica fume even up to 40% replacement showed strength higher than that of the referral concrete. The improvements in strength at the different percentages of replacement and at any water cement ratios are also reported over a wide range of these parameters.

2.5 Tensile strength

Splitting tensile strength of concrete 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. Several studies revealed that splitting tensile strength at various ages ranged between 5.8-15% of the compressive strength. However, it is reported that at 15% replacement level, tensile strength of silica fume concrete increased in the range of 27-34% as compared to referral concrete (Sakr, 2006).

2.6 Flexural Strength

Flexural strength of concrete incorporating silica fume is similar to that observed in concretes without silica fume. For normal weight concrete, the flexural strength is usually 15% of its compressive strength. It is concluded in several studies that flexural strength of silica fume concrete is higher than that of conventional concrete (Yogendran et al., 1987, Ramakrishnan and Srinivasan, 1982).

2.7 Bond Strength

Using silica fume as an admixture in concreteimproved the bond strength. It is reported that at 15% replacement level the bond strength of silica fume concrete increased in the range of 37 - 43% as compared to referral concrete (Sakr, 2006).

2.8 Permeability

Permeability is ability to transport different fluids like water, chloride, sulphate etc. The permeability dictates the rate at which aggressive agents can penetrate to attack the concrete and the steel reinforcement. Inclusion of silica fume in concrete reduces the permeability of concrete considerably.

2.9 Modulus of Elasticity

The static modulus of elasticity of silica fume concrete is almost similar to that of Portland cement concrete.

2.10 Alkali - Silica Reaction (ASR)

ASR is a process by which alkali silicate gel forms and afterwards expands on absorption of water. This expansion may cause cracks in concrete. Silica fume bind free alkalis present in fresh or plastic concrete; reduce cement content thereby reducing free alkalis; and reducing permeability of concrete which subsequently preventing entry of moisture and alkalis thus suppressing ASR.

2.11 Chloride Attack

Silica fume is very useful in concrete exposed to chloride environment. Silica fume reduces the chloride penetration in concrete due to pore refinement and thus delay the onset of corrosion.

2.12 Sulphate Attack

Sulphates reacts with $Ca(OH)_2$, forming gypsum. The gypsum may then react with C_3A in concrete to produce ettringite and mono-sulphoaluminate. These reactions result in increase in volume which subsequently cause in cracks and peeling. Silica fume reduces the amount of $Ca(OH)_2$ on the one hand and reduces the permeability which subsequently reduces the ingress of sulphates on the other hand.

The reaction between silica fume and the calcium hydroxide, released as the cement hydrates, provides a dense impermeable pore structure. Although the total porosity of the silica fume concrete is similar to the referral concrete the average pore size is much finer, conducting to a large reduction of permeability. The Silica fume reacts with the cement paste to form additional strong Calcium Silicate Hydrate (CSH) providing higher strength. Silica fume reduces bleeding and enhances the cement paste bond to the aggregates. The pozzolanic reaction with $Ca(OH)_2$ improves the strength. Thus Silica fume can be used to reduce to the cement content of the mix. Besides being economical, it also reduces the total heat of hydration and improves the performances of the concrete in terms of chemical resistance. Curing can start earlier as there is no need to wait for bleed water to dissipate. Bleeding is a form of segregation where the solid components of the concrete settle downwards, leaving water on the top surface. It continues until the cement paste has stiffened enough to end the settling process. Compressive strengths in excess of 60 N/mm^2 are easily achieved. Higher flexural strength and modulus of elasticity than conventional concretes of equal compressive strength can be achieved.

3. ADVANTAGES OF SILICA FUME CONCRETE

The following are the additional benefits obtained in case of concrete made using silica fume as a mixture:

- It reduces bleeding of the concrete mix..
- It reduces segregation of the concrete mix.
- It can be sticky and improve the finishability of mix.
- It aids the pumpability of the concrete.
- It may exhibit an increase in plastic shrinkage cracking.
- It reduces the permeability of the concrete.
- It increases density.
- Improves the sulfate resistance of concrete.
- Improves the protection of reinforcement against corrosion.

- Increases the cohesiveness of the fresh concrete, which can lead to improved handling characteristics.
- High early strength (in excess of 25 N/ mm2 at 24 hours).
- Lower permeability and improved durability (due to the fine particle size and reactivity of silica fume is obtained.
- Greater resistance to abrasion and impact than conventional concretes of similar strength grade fume is obtained.
- Lesser curing period is required.
- High strength concrete can be economically and easily made.

4. CONCLUSIONS

From the above study the following may be concluded.

1. The addition of silica fume reduces workability. However in some cases marginal increase in workability is also reported.
2. Substantial increase in compressive strength (6-57%) can be achieved by addition of Silica fume as partial cement replacement. Increase in compressive strength depends upon replacement level.
3. Tensile strength of silica fume concrete is similar to that of conventional concrete. Tensile strength of silica fume concrete is 5.8 – 15% of its compressive strength.
4. Flexural strength of silica fume concrete is higher than that of conventional concrete.
5. Addition of silica fume improves bond strength of concrete.
6. Modulus of elasticity of silica fume concrete is almost similar to that of conventional concrete.
7. Inclusion of silica fume in concrete reduces the permeability of concrete considerably.
8. ASR is reduced in silica fume concrete.
9. Silica fume reduces the chloride penetration in concrete due to pore refinement.
10. Silica fume reduces bleeding and enhances the cement paste bond to the aggregates.
11. Silica fume improves the performances of the concrete in terms of chemical resistance.
12. Sulphate resistance of silica fume concrete is better than that of referral concrete.

REFERENCES

ACI, 234R-96. “Guide for the use of silica fume in concrete” Reported by ACI, Committee, 234, pp.1-51, (1996).

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

Bayasi, Z. and Zhou, J. “Properties of silica fume concrete and mortar” *ACI Mater. J*. 90(4), 349-356. (1993).

Kadri, E.H. and Duval, R. “Influence of silica fume on the workability and compressive strength of high performance concrete” *Cement Concr. Res*. 28(4): 533-547, (1998).

Khan, S.M. and Ayers, M.E. “Minimum length of curing of silica fume concrete” *J. Mater. Civil Engg*. 7(3): 134-139, (1995).

Khayat, K.H., Vachon, M. and Lanctot, M.C. “Use of blended silica fume cement in commercial concrete mixtures” *ACI Mater. J*. 94(3): 183-192, (1997).

Ramakrishnan, V. and Srinivasan, V. “Silica fume in fibre reinforced concrete” *Ind. Concr. J*. 56(12): 326-334, (1982).

Rojas, M.F. and Cabrea J. “The effect of temperature on the hydration phase of metakaolinlime-water system” *Cem. Concr. Res*. 32: 133-138, (2002).

Sabir, B.B., Wild S. and Bai, J. “ Metakaolin and calcined clay as pozzola for concrete: A review” *Cem. Concr. Composites*. 23: 441-454.

Sakr, K. 2006. Effects of silica fume and rice husk ash on the properties of heavy weight concrete. *J. Mater. Civil Engg*. 18(3): 367-376, (2001).

Sengupta, B. and Bhanja, S. “Optimum silica fume content and its mode of action on concrete” *ACI Mater. J*. 100(5): 407-412, (2003).

Srivastava, V. Kumar, R. Agarwal, V. C. and Mehta, P. K., "Effect of Silica Fume and Metakaolin on Workability and Compressive Strength of Concrete. *NICMAR Journal of Construction Management*. XXVI(IV): 19-27, (2011).

Yogendran, Y., Langan, B.W., HaqueM.N. and Ward, M.A., "Silioca Fume in High Strength Concrete" ACI Materials Journal, Vol. 84, No. 2, March-April, pp. 124-129, (1982).