Effect of Silica Fume on Concrete Properties and Advantages for Kurdistan Region, Iraq

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Abstract— This research describes the importance of the effect of silica fume on concrete properties and the advantages of its use in the Kurdistan region, Silica fume can either be 'addition' (added separately at the concrete mixer) or incorporated into a factory-produced composite cement. This paper explores the merits and practical considerations of using both methods and how each is governed by Standards. As with conventional concretes, silica fume can generally be used with chemical admixtures, and it is usually used with a super-plasticiser. The performance of admixtures may depend upon the properties of the individual source of the cementations material (as with OPC cements), and tests should be carried out to establish the appropriate dosage levels. The conventional compressive strength-w/c relationship is followed in concrete made with silica fume, but strength is increased at a given w/c ratio. Silica fume is not universally available or practical for use, particularly where conventional raw materials used in concrete are more economical, but in some specific areas of the world the production and application of silica fume have been investigated. Its effectiveness in Kurdistan has not been investigated, thus this is a pioneering study concerning increasing the compressiveness of concrete in reinforced concrete structures.

Index Terms— Silica fume, effects, cementations materials, concrete properties, Advantages.

1 Introduction

Silica fume (SF) results from smelting in the silicon and ferro-silicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2,000°C produces SiO vapors, which oxidize and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica. By-products of the production of silicone metal and the ferrosilicon alloys having silicon content of 75% or more contain 85–95% non-crystalline silica. The by-product of the production of ferrosilicon alloy with 50% silicon has much lower silica content and is less pozzolanic. SF is also known as micro silica, condensed silica fume, volatilized silica or silica dust (Siddique and Khan, 2011).

SF has been recognized as a material of pozzolanic admixture that is highly effective in enhancing mechanical properties. By using silica fume along with super plasticizers, it is relatively easier to obtain compressive strengths of order of 100–150 MPa in laboratory. Addition of silica fume to concrete improves its durability through reduction in the permeability and refined pore structure, leading to a reduction in the diffusion of harmful ions, reducing calcium hydroxide content, which results in a higher resistance to sulfate attack. Improvement in durability will also improve the ability of silica fume concrete in protecting the embedded steel from corrosion (King, 2012). With regard to handling and availability, SF is available in dry and wet conditions. The former can be provided as produced or densified, with or without dry admixtures, and it can be stored in silos and hoppers. SF slurry with low or high dosages of chemical admixtures is available. Slurried products are stored in tanks. Adding silica fume to concrete significantly reduces bleeding, blocking the pores of fresh concrete and high early compressive strength while not significantly increasing the unit weight of concrete (Siddique and Khan, 2011) as shown in fig.(1-1).

Fig. (1-1) Silica Fume.

2 Materials and Methods

2.1 Sampling

SF contains the raw materials of silicon metal and cemintouse materilas used in concrete (King, 2012). SF is a by-product of silicon metal manufacturing and ferro-silicon alloys. Therefore, SiO content of the silica fume is related to the type of alloy being produced (Table 2-1). The process embraces the reduction of high purity quartz (SiO) in electric arc furnaces at temperature in overflow of 2,000°C. SF is a very fine powder consisting mainly of spherical particles or micro-

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International Journal of Scientific & Engineering Research, Volume 6, Issue 1, January-2015
ISSN 2229-5518

spheres ,with a mean diameter of about 0.15 microns, with a very high specific surface area (15,000–25,000 m^2/kg). Each microsphere is on average 100 times smaller than an average cement grain. At a typical dosage of 10% by mass of cement, there will be 50,000–100,000 silica fume particles per cement grain (Jahren, 1983).

Table (2-1): SiO content of the silica fume produced from different alloy sources.

Alloys types	*SiO Content of SF (%)*
50% ferrosilicon	61–84
75% ferrosilicon	84–91
Silicon metal	87–98

2.2 Physical and Chemical Properties of SF

SF particles are very small and more than 95% of them are softer than l µm. It is either premium white or grey in color, as explained in (Table 2-3). SF is organized primarily of fresh silica in non-crystalline form. X-ray diffraction analysis of different silica fumes discovered that material is basically vitreous silica, mainly of cristobalite form. It has a very high content of amorphous silicon dioxide and is composed of very fine spherical particles. Silica fume generally contains more than 90% SiO. Small amounts of iron, magnesium, and alkali oxides are also found in SF (Bentur and Goldman, 1989).

Silica fume is a highly reactive pozzolana that converts all or most of the liberated calcium hydroxide to C-S-H. Due to their varying levels of chemical reactivity and fineness, materials differ in the proportion of the cementitious content at which they can be used, with indicative proportions being:
GGBS - typically 50% but can be up to 70% or more
Fly ash - typically 30% but can be up to 50% or more
Limestone fines - typically 15% but can be up to 20% or mor
Silica fume - typically <8% but can be up to 12.5% or more.

2.3 Effect of Silica Fume on the Fresh Properties of Cement/Mortar/Concrete

Rheological properties of a fresh cement paste play an important role in determining the workability of concrete.

Table (2-3): Typical physical and chemical properties

	Fly ash	GGBS	Silica fume
Fineness (m /kg)	450	350 to 550	15,000 to 35,000
Bulk density (kg/m)	1300	1200	1350-1510
Specific gravity	2.2	2.9	2.2
Main elements (% as)			
Silicon (SiO_2)	38 to 55	30 to 40	> 85
Aluminum (Al_2O_3	20 to 40	5 to 20	< 2
Iron (Fe_2O_3)	6 to 16	< 2	< 1
Calcium (CaO)	1.8 to 10	35 to 40	< 1
Magnesium (MgO)	1.0 to 3.5	5 to 18	< 1
Sodium (NaO_2)	0.8 to 1.8	< 1	< 1
Potassium (K_2O)	2.3 to 4.5	< 1	< 1
Titanium (TiO_2)	0.9 to 1.1		-
Chloride (Cl)	< 0.01	< 0.1	< 0.3
Loss on ignition (%)	3 to 20	< 3	< 4
Sulfate (SO_4)	0.42 to 3.0	< 2.5	< 0.3
Free calcium oxide (%)	< 0.01 to1.0	< 1	< 1

The water requirement for flow, hydration behavior, and properties of the hardened state largely depends upon the degree of dispersion of cement in water. Properties such as fineness, particle size distribution, and mixing intensity are important in determining the rheological properties of cement paste. Due to the charges that develop on the surface, cement particles tend to agglomerate in the paste and form flocs that trap some of the mixing water. Factors such as water content, early hydration, water reducing admixtures and mineral admixtures like silica fume determine the degree of flocculation in a cement paste. Fresh concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. Concrete containing silica fume shows substantial reduced bleeding. Additionally, silica fume reduces bleeding by physically blocking the pores in the fresh concrete. Use of silica fume does not significantly change the unit weight of concrete.

2.4 Effect of Silica Fume on the Hardened Properties of Cement/Mortar/Concrete

When silica fume is added to concrete, it results in a significant change in the compressive strength of the mix. This is mainly due to the aggregate-paste bond improvement and enhanced microstructure. Huang and Feldman found that mortar without silica fume has lower strength than cement paste with the same water–cement ratio, while mortar with 30% of cement replaced with silica fume has a higher strength than cement- silica fume paste with the same water-cementitious ratio.

They concluded that the addition of silica fume to mortar resulted in an improved bond between the hydrated cement matrix and sand in the mix, hence increasing strength. This improved bond is due to the conversion of the calcium hydroxide, which tends to form on the surface of aggregate particles, into calcium silicate hydrate due to the presence of reactive silica, as clarified in (Table 2-4).

Table (2-4): Mortar compressive strength

Age (days)	0% Silica fume	10% Silica fume
7	3.26 ± 0.12	3.96 ± 0.13

International Journal of Scientific & Engineering Research, Volume 6, Issue 1, January-2015
ISSN 2229-5518

28	6.58 ± 0.19	7.11 ± 0.25

3 Use in Concrete

Silica fume can either be added separately at the concrete mixer, where they are referred to as ‘additions’ or else be incorporated into factory-produced composite cement. The following sections describe the way in which Standards deal with these two alternative approaches and the relative merits and practicalities.

The European standard for cements BS EN 197-1 covers a wide range of cements other than CEM I.
These include:

- CEM II-S Portland-slag cement (6-35% blastfurnace slag)
- CEM II-D Portland- silica fume cement(6-10% silica fume)
- CEM II-V Portland-fly ash cement (6-35% fly ash)
- CEM II-L(LL) Portland-limestone cement (6-35% limeston
- CEM III Blastfurnace cement (36-95% blastfurnace slag)
- CEM IV Pozzolanic cement (11-55% pozzolan (including fly ash)

Concrete made with silica fume follows the conventional relationship between compressive strength and w/c but strength is increased at a given w/c ratio when silica fume is used. High early compressive strength (in excess of 25N/mm at 24 hours) can be achieved. With proper concrete design, very high 28-day strengths can be produced, using normal ready-mixed concrete plants and in the USA and Asia 100–130N/mm concretes are used in tall buildings. Cementitious contents are generally > 400 kg/m and w/c in the range 0.30 to 0.40. An example in South East Asia is the new 79 floor East Island Centre in Hong Kong where the volume of concrete was reduced by 15% through the use of Grade 100 MPa self-compacting concrete. Not only were there significant sustainability benefits but also the client benefited commercially through the additional floor space opened up for rental in this expensive part of Hong Kong.

4 Current Availability and Use of Silica Fume

Global consumption of silica fume exceeds 1 million tonnes per annum. Silica fume is generally dark grey to black or off-white in colour and can be supplied as a densified powder or slurry depending on the application and the available handling facilities. For use in the UK, it is normally supplied as slurry, consisting of 50% powder and 50% water. In powder form silica fume is available in bulk, large bags and small bags. If required in bags, these can be tailored to suit the customers’ needs for handling and batch weight per cubic metre of concrete. Other applications include fibre cement, gypsum cement, refractory mortars and castables and in the use of specialised ultra high strength precast sections where strengths of over 200 N/mm can be designed.

5 Applications of Silica Fume

High Performance Concrete (HPC) containing silica fume; for bridges, parking decks, marine structures and bridge deck overlays which are subjected to constant deterioration caused by rebar corrosion current, abrasion and chemical attack problems. Silica fume will protect concrete against deicing salts, seawater, and road traffic and freeze/thaw cycles. Rebar corrosion activity and concrete deterioration are virtually eliminated, which minimizes maintenance expense.

• High-strength concrete enhanced with silica fume; provides architects and engineers with greater design flexibility. Traditionally used in high-rise buildings for the benefit of smaller columns (increasing the usable space) high strength concrete containing silica fume is often used in precast and prestressed girders allowing longer spans in structural bridge designs as shown in fig.(1-2).

• Silica-fume Shotcrete; delivers greater economy with low costs, greater time savings and more efficient use of sprayed concrete. Silica fume produces superior shotcrete for use in rock stabilization; mine tunnel linings, and rehabilitation of deteriorating bridge and marine columns and piles. Greater bonding strength assures ou standing performance of both wet and dry process shotcreting with less rebound loss and thicker applications with each pass of the shotcrete nozzle.

• Repair Products; silica fume is used in a variety of cementitious repair products. Mortars or grouts modified with silica fume can be tailored to perform in many different applications—overhead and vertical mortars benefit from silica fume’s ability to increase surface adhesion. Silica fume significantly improves cohesiveness making it ideal for use in underwater grouts, decreases permeability in grouts used for post-tensioning applications and increases the resistanc to aggressive chemicals.

•Refractory and Ceramics; the use of silica fume in refractory castables provides better particle packing. It allows for less water to be used while maintaining the same flow characteristics. It also promotes low temperature sintering and the formation of mullite in the matrix of the castable. This produces a castable that has a low permeability to avoid gas, slag and metal penetration. Castables incorporating silica fume are stronger than non-silica fume containing castables especially at high temperatures with higher density they attain lower porosity and are more volume stable.

• Oil Well Grouting—whether used for primary (placement of grout as a hydraulic seal in the well-bore) or secondary applications (remedial operations including leak repairs, splits, closing of depleted zones); the addition of silica fume enables

International Journal of Scientific & Engineering Research, Volume 6, Issue 1, January-2015
ISSN 2229-5518

a well to achieve full production potential. Besides producing a blocking
effect in the oil well grout that prevents gas migration, it provides these advantages such as (i) Improved flow, for easier, more effective application; (ii) dramatically decrease permeability, for better control of gas leakage; and (iii) lightweight.

Fig. (1-2) Silica Fume used in Viaduc de Tulle Bridge, France.

6 Results and Discussions

Silica fume increases the strength of concrete. Silica fume is much cheaper than cement therefore it very important form economical point of view. Silica fume is a material which may be a reason of Air Pollution this is a byproduct of some silica fume Industries use of micro silica with concrete decrease the air pollution. Silica fume also decrease the voids in concrete. Addition of silica fume reduces capillary. Absorption and porosity because fine particles of silica fume reacts with lime present in cement.

Advantages of Using Silica Fume in Kurdistan Region for future studying and concrete skills;

- High early compressive strength.
- High tensile, flexural strength and modulus of elasticity.
- Very low permeability to chloride and water intrusion.
- Enhanced durability.
- Increased toughness.
- Increased abrasion resistance on decks, floor, overlays and marine structures.
- Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates and life-cycle cost efficiencies.
- Higher bond strength.
- High electrical resistivity and low permeability.

7 Conclusion

Using of Silica fume is important in infrastructure sectors in whole of the world, but especially in Kurdistan Region we found that our improvement in building and new technologies used in this area need to improve concrete admixtures with silica fume to get required details of stable buildings that are high early compressive strength, enhanced durability, toughness, protecting structure members and reinforcement from corrosion and increasing abrasion.

8 Acknolwdgment

I would like to thank Duhok Polytechnic University and Kurdistan Regional Government for them helps always in researching and improving research innovation in Kurdistan Region, Iraq.

Also I would like to thank my family to them continue support to get all goals that I have in scientific world.

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