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A REVIEW FOR CHARACTERIZATION OF SILICA FUME AND ITS EFFECTS ON CONCRETE PROPERTIES

Mohammad Panjehpour[1*], Abang Abdullah Abang Ali[1], Ramazan Demirboga[1,2]

[1]Housing Research Centre, University Putra Malaysia, 43400, Serdang, Selangor.
[2]Ataturk University, Engineering Faculty, Civil Engineering Dept., 25240, Erzumum, Turkey.

[*]Corresponding Email: mdpanjehpour2006@yahoo.com

ABSTRACT

Mineral additions which are also known as mineral admixtures have been used in Portland cement for many years. There are two types of additions which are commonly mixed into the Portland clinker or blended directly with cement these days. They are crystalline, also known as hydraulically inactive additions and pozzolanic, which are hydraulically active additions. Silica fume is very reactive pozzolan, while it is used in concrete because of its fine particles, large surface area and high SiO_2 content. Silica fume is much fined separated silica obtained as a by-product in industry. It is used as an admixture in the concrete mix and it has significant effects on the properties of the resulting material. Simultaneously, silica fume can be also utilized in production of refectory and porcelain, to increase intensity and durability. In addition, it can improve the overall performance of the material as filler used in coating resin, paint, rubber and other high molecular materials. This review paper discusses the effects of silica fume on the concrete properties such as strength, modulus, ductility, permeability, chemical attack resistance, corrosion, freeze-thaw durability, creep rate. Characterisation of silica fume as well as its physical and chemical properties will also be reviewed in this paper.

Keywords: *Silica fume, cement, Composite, physical properties, chemical properties, concrete properties*

1.0 INTRODUCTION

The terms of microsilica, condensed silica fume, and silica fume are often used to describe by-products extracted from the exhaust gases of ferrosilicon, silicon, and other metal alloy smelting furnaces. However, the terms of silica fume and microsilica are used for those condensed silica fumes that are of high quality for using in the cement and concrete industry. In the European standard, the term of silica fume has been used [2].

Silica fume was first discovered in Norway in 1947 when the environmental controls started the filtering of the exhaust gases from furnaces. The main portion of these fumes was a finely composed of a high percentage of silicon dioxide. As the pozzolanic reactivity for silicon dioxide was well known, many studies have been done on it [1].

There are over 3000 publications that have been published about silica fume and silica fume concrete. Conforming to AASHTO M 307 or ASTM C 1240, silica fume can be utilised as material for supplementary cementations to increase the strength and durability [7]. According to the Florida Department of Transportation (2004), the quantity of cement replacement with silica fume should be between 7% and 9% by mass of cementation materials.

Silica fume consists of the fine particles with specific surface about six times of cement because its particles are very finer than cement particles. Hence, it has been found that when silica fume mixes with concrete the minute pore spaces decreases. Silica fume is pozzolanic, because it is reactive, like volcanic ash. Its effects are related to the strength, modulus, ductility, sound absorption, vibration damping capacity, abrasion resistance, air void content, bonding strength with reinforcing steel, shrinkage, permeability, chemical attack resistance, alkali-silica reactivity reduction, creep rate, corrosion resistance of embedded steel reinforcement, freeze-thaw durability, coefficient of thermal expansion (CTE), specific heat, defect dynamics, thermal conductivity, dielectric constant, and degree of fibre dispersion in mixes containing short microfibers[3].

Also, addition of silica fume decreases the workability of the mix. Silica fume can solve problems, because of its very loose bulk density and fine particles [5]. However, it causes other problem such as stickiness, bridging in storage silos, and clogging of the pneumatic transport equipment. The Package of silica fume in factory is shown in the Figure 1.

Figure 1: Package of silica fume in factory

2.0 SILICA FUME SOURCE

It is very fine no crystalline silica manufactured by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. The raw materials are coal, quartz, and woodchips [16]. The smoke that produced from furnace operation is stored and sold as silica fume rather than being land filled.

As the silica fume powder particles are hundred times finer than ordinary Portland cement, there might be problems arise when deals with silica fume, such as dispensing consideration, transportation, and storage that must be taken into account. To overcome some of these difficulties, the material is commercially divided in various forms. The difference between these forms is the size of the particle which do not significantly affect the chemical make-up or reaction of material. This difference has effect on the different purposes of use. Thus, careful consideration is needed when choosing the type of silica fume for specific application.

3.0 PHYSICAL PROPERTIES

The properties of silica fume depend on the type of producing and the process used for its manufacture. It is in form of spherical particle shape. Referring to Table 1, it is a powder with particles having diameters 100 times smaller than Portland cement particles [12]. Silica fume comes in three forms of powder, condensed, and slurry. Its colour varies from light to dark grey which depends on the process in the manufacturing and is influenced by some parameters such as wood chip composition, furnace temperature, ratio of wood chip to the coal used, exhaust temperature, and type of metal produced [17].

Table 1: Physical properties of OPC, MK and SF (H. Abdul Razak, H.S. Wong, 2004)

	OPC	MK	SF
Specific gravity	3.11	2.52	2.22
Average particle size (μm)[a]	23	9.5	99.4
Specific surface area (m^2/kg)			
Blaine	340	–	–
Nitrogen adsorption (BET)	4200	9500	21,300
Standard consistency (%)	27.4	–	–
Setting time (min)			
Initial	110	–	–
Final	300	–	–

Scanning electron micros copies of condensed silica fume is shown in Figure 2. Like all fine powder, there are potential health risks; as an example, silicon dioxide can cause lung disease silicosis [5].

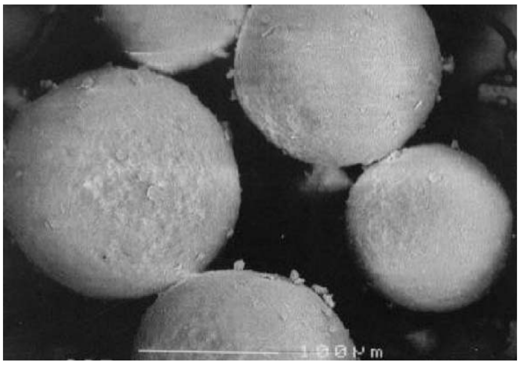

Figure 2: Scanning electron microscopy of condensed silica fume (Chai Jaturapitakkul, 2003)

For undensified silica fume, bulk density is in range of 200-350 kg/m^3. Due to the low bulk density, this form is considered impractical to be utilised in normal concrete production [16]. Undensified silica fume is commonly used in refractory products and formulated bagged material such as mortars, grouts, protective coatings, and concrete repairs system.

For this type of silica fume, bulk density is in range of 500 -650 kg/m^3.In the densification process the ultra fine particles become loosely agglomerated which makes the size of particles larger. Hence, the powder becomes easier to be used, with less dust compared to the intensified forms. This material is commonly used in those processes that utilise high shear mixing facilities such as concrete roof tile works, pre-cast works, and ready mixed concrete plants with wet mixing units [16], [3].

4.0 CHEMICAL PROPERTIES

Fuat K. et al [2] summarises properties of cement and silica fume which is shown in Table 2. Silica fume is produced during a high-temperature reduction of quartz in an electric arc furnace when the main product is silicon or ferrosilicon. Due to the large amount of electricity needed, theses arc furnaces are located in countries with well-provided electrical capacity including Scandinavia, Europe, Canada, USA, South Africa, and Australia [14].

The chemical process is complex and it depends on the temperature of the producing. The SiC formed, initially plays important intermediate roles.

At temperatures > 1520 □ C

$SiO_2 + 3C = SiC+2CO$

At temperatures > 1800 □ C

$3SiO_2+2SiC = Si+4SiO+2CO$

The unstable gas diffuses in the furnace where it reacts with oxygen to give the silicon dioxide

$4SiO+2O_2 = 4SiO_2$

Table 2: Properties of cement and silica fume (Fuat Ko¨ksal, Fatih Altun, et al, 2007)

Composition (%)	Cement	Silica fume
Chemical compositions		
SiO_2	19.12	81.35
Al_2O_3	5.63	4.48
Fe_2O_3	2.39	1.42
CaO	63.17	0.80
MgO	2.75	1.47
SO_3	2.74	1.34
Na_2O		
K_2O	1.00	
Insoluble material	0.49	
Loss on ignition	2.33	3.4
Physical properties		
Specific gravity	3.09	2.23
Specific surface (cm^2/g)	3114	

As the concrete hardens, the pozzolanic action of the silica fume starts from the physical effects. The silica fume reacts with the calcium hydroxide to produce calcium silicate and aluminates hydrates. Calcium silicate and aluminates hydrates, increase the strength and decrease the permeability by densifying the matrix of the concrete. Abdul Razak et al, point out the silica fume which has a higher surface area and higher silicon dioxide content is much more reactive than pfa or ggbs [10]. This increased reactivity causes an increase to the rate of hydration of C_3S fraction of the cement in the first instance [11].

5.0 EFFECT ON MECHANICAL PROPERTIES

With the addition of silica fume, the slump loss with time is proportionally increased in concrete mix. Due to the high surface area of silica fume particles in the concrete mix, workability and consistency of concrete decrease [9]. These are restraints against the suitable utilisation of silica fume concrete. However, the consistency of silica fume mortar is significantly increased by either using silane treated silica fume, i.e., silica fume which has been coated by a silane coupling agent prior to incorporation in the mix, or utilising silane as an additional admixture [11].

Vibration reduction is useful for structural stability, hazard mitigation, and structural performance improvement. Effective vibration reduction requires both stiffness and damping capacity. Silica fume is effective for increasing both damping capacity and stiffness [2]. Sound or noise absorption is helpful for numerous structures, such as noise barriers and pavement overlays. The addition of silica fume to the concrete increases the sound absorption ability [10].

5.1 STRENGTH

High compressive is normally the first property associated with silica fume concrete. Many experiments [14],[5],[16] have shown that the addition of silica fume to concrete mix increases the strength of mix by between 30% and 100% depending on the type of cement, type of mix, use of plasticizers, amount of silica fume, aggregates type, and curing regimes [16].

The relationship between tensile, flexural and compressive strengths in silica fume concrete is the same as those for ordinary strength concrete. Increase in compressive strength by using silica fume also results an increase in the tensile and flexural strength. This plays an important role when silica fume concrete is used in bridging, flooring, and roadway projects. Increased tensile strength causes a possible reduction in slab thickness while maintaining high compressive strengths. Hence, it reduces the overall slab weight and cost [13].

The stronger concrete is more brittle and silica fume concrete is no exception to this rule. Modulus of elasticity does not follow the pattern of tensile strength, but only displays slight increase compared to the compressive strength. Thus, high and ultra-high strength concrete can be used for tall structures without loss of ductility [17].

Silica fume concrete has a very finer phase and good bonding to substrates compared to the ordinary concrete. Studies have shown that the aggregate-cement interface changes in the presence of silica fume [18]. By using silica fume, the bonding to the steel fibres is significantly increased. This is particularly useful in the steel fibre-silica fume modified shotcrete which is commonly used in Scandinavia.

Short microfibers, such as glass, carbon, polypropylene, steel, and other fibres are used as an admixture in concrete to improve the tensile and flexural properties and reduce the drying shrinkage. Effective use of the fibres, which is consumed in very small quantities such as 0.5% by weight of cement in the case of carbon fibres, needs good dispersion of the fibres. The addition of untreated silica fume to microfibers reinforced cement enhances the degree of fibre dispersion, due to the fine silica fume particles which help the mixing of the microfibers. Silica fume also increases the structure of the fibre-matrix interface and decreases the weakness of the interfacial zone and also the number and size of cracks [7].

6.0 EFFECT ON CHEMICAL

The reaction of calcium hydroxide with carbon dioxide in the atmosphere results efflorescence, which is a whitish haze. Primary stage of efflorescence occurs while concrete becomes hard. Secondary efflorescence is resulted from the weathering of the hardened concrete. It does not only increase the aesthetic quality of the structures but it can also give an increase in permeability, porosity, and ultimately weaker and less durable concrete [4]. Research has shown that addition of silica fume decreases efflorescence due to the refined pore structure and increased consumption of the calcium hydroxide.

The addition of untreated silica fume to steel reinforced concrete enhances the corrosion resistance of the reinforcing steel. Besides that, it also increases the concrete chemical attack resistance, whether the chemical is acid, chloride, and sulphate. These cause reduction in the permeability [16].

According to the literature review [1], for equal strengths and any concrete strength below 40 MPa, carbonation is higher in silica fume concretes. Concrete above 40 MPa gives a reduction in carbonation rate, but this concrete can be affected by corrosive damage due to the reinforcement. Silica fume concrete is normally utilised when the compressive strength is above 40 MPa .It is an issue as to whether carbonation is a serious risk. Concrete curing procedures are necessary to ensure the optimum performance of the silica fume concrete [1].

Silica fume decreases bleeding significantly, because free water is used in wetting of the large surface area of the silica fume. In addition, silica fume blocks the pores in the fresh concrete and stops water from permeate the surface of the concrete. [14].

7.0 EFFECT ON DURABILITY

The durability of silica fume concrete to freeze thaw is normally satisfactory at silica fume content of less than 20%. Freeze-thaw durability is related to the ability to withstand changes between temperatures above 0◦C and those below 0 ◦C [11]. Due to the presence of water, which undergoes freezing and thawing and also in turn causes changes in volume, concrete shows a tendency to decrease upon such temperature cycling. Air voids which are called air entrainment are utilised as cushions to accommodate the changes in volume, thereby improving the freeze-thaw durability. The addition of silica fume to mortar enhances the freeze-thaw durability in spite of the poor air void system. Hence, the use of air entrainment is still recommended.

The permeability of chloride ions in concrete reduces by the addition of untreated silica fume. In this regard, there is reduction in the water absorbance. These effects are the cause of the microscopic pore structure which produces calcium silicate hydrate from the pozzolanic reaction of silica fume with free lime within the hydration of concrete [6]. The addition of untreated silica fume to the cement paste reduces the compressive creep rate at 200◦C from 1.3×10^{-5} to 2.4×10^{-6} min^{-1}. Shrinkage in cement paste increase when silica fume is used [1].

8.0 EFFECT ON TEMPERATURE

Concrete with low thermal conductivity is useful for the thermal insulation of buildings. On the other hand, concrete with high thermal conductivity is useful for decreasing temperature gradients in structures. The thermal stress that is resulted from temperature gradients may cause mechanical property reduction in the structure. Bridges are among the structures that tend to encounter temperature differentials between their top and bottom surfaces. In contrast to buildings which encounter temperature differentials; bridges do not require thermal insulation [4], [16]. Hence, concrete of high thermal conductivity is in demand for bridges and related structures. The thermal conductivity can be reduced by the addition of untreated or silane treated silica fume due to the interface between silica fume particles and cement which act as an obstacle against heat conduction.

9.0 CONCLUSION

The application of silica fume in concrete mixture has significantly increased and enhanced the properties of the concrete whether it is in wet stage or in harden condition. The overall effects of silica fume on the concrete properties are as summarised in Table 3.

Table 3: Effects of silica fume on the concrete properties

Concrete properties	Increase	decrease	enhancement
Tensile strength	×		
Compressive strength	×		
Compressive modulus	×		
Flexural modulus	×		
Tensile ductility	×		
Air void content	×		
Freeze-thaw durability			×
Vibration damping capacity			×
Abrasion resistance			×
Bond strength with steel bars			×
Chemical attack resistance			×
Corrosion resistance of reinforcement steel			×
Dispersion of micro fibres			×
Alkali-silica reactivity		×	
During shrinkage		×	
Permeability		×	
Creep rate		×	
Coefficient of thermal expansion		×	
Dielectric constant		×	
Thermal conductivity		×	
Density		×	
Workability		×	
Bleeding		×	

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