Silica Fume: Its Role in Cement and Concrete Technology

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ABSTRACT

The role of silica fume as a cementitious by-product is reported, in terms of its historical and experimental aspects. Silica fume is found to be ≈100nm in size and therefore is the finest component ever to be used to make cements or concrete so far. Its average particle size when compared to that of Portland cement (≈10–15μm) is almost 100 times smaller in terms of the diameter size of the particle. Evidently, enhanced compressive strength from the use of silica fume was found. This is thought to be due to improved densification of the cement matrix.

Key words: Silica fume, By-products, Strength

INTRODUCTION

Since the development of Portland cement by Joseph Aspdin in 1824, there have been a number of developments through out the 20th century from the use of pozzolanic by-products in order to cut down the fuel cost and CO_2 emission in the manufacturing process. At the same time, turning waste to by-products, reusing of materials help reduce waste from industries, thus moving towards sustainable construction. The particle size of Portland cement (PC) itself is ≈10–15 μm where fly ash and ground granulated blast-furnace slag, two common by-products used through out the world, are also of around 10 μm (Neville, 1995; Malhotra and Mehta, 1996). Silica fume is a by-product from the ferrosilicon industry. It was first used in concrete in the early 1950’s at the Norwegian Institute of Technology but its beneficial effects on concrete properties were not realized until early 1980’s where silica fume was started to be used in concrete structures such as in the New Tjorn cable-stayed bridge in Sweden and in Kinzua dam in the USA (Federation International de la Precontriant, 1988; Khayat and Aitcin, 1993). Although its technical advantages is now being recognized more so than ever before, only a small percentage of the current supply of silica fume is being used as a mineral admixture in the cement and concrete industries (Malhotra and Mehta, 1996). One of the attractive characteristics of silica fume is its particle size which was reported to be approximately 100–500nm (Malhotra and Mehta, 1996; Federation International de la Precontriant, 1988).

Furthermore, it is known that cement improvement (also enhance the performance of concrete) depends on both physical and chemical properties, improved physical characteristics such as the use of finer particles (higher surface area) nonetheless has advantages in its own right in terms of filling the cement matrix, densifying the structure, resulting in higher strength and at the same time allowing faster chemical reactions to occur. In this work, physical characterization such as particle size and morphology of silica fume were carried out, using a Scanning Electron Microscope. Furthermore, the effect of silica fume on the compressive strength was also investigated.

MATERIALS AND METHODS

Powder characteristics such as particle size, morphology and elements were determined, using a Scanning Electron Microscope (SEM; JEOL JSM-840A) and Energy Dispersive X-ray spectrometer. For compressive strength test, concrete of 100x100x100 mm cubes were cast, using a water to binder ratio of 0.45 (cement content = 410kg/m^3). Silica fume was used to replace Portland cement by direct weight at 5, 10, 15 and 20%. Natural sand and crushed coarse aggregates (20 mm maximum) were used for all mixes. A superplastizing admixture to BS 5075: part 3 was used to maintain a nominal slump of 75 mm. The samples were demoulded and cured in water at 20°C for a specified period (1 to 28 days). After curing, concrete specimens were tested for compressive strength in accordance with BS 1881: part 116.

RESULTS AND DISCUSSION

Silica fume was found to consist of essentially SiO_2 at 95.3% (Table 1). When tested using EDS technique, it can also be seen that the main elements were Si and O (Figure 1). The Si-O structure is said to be a disordered structure resulting as the product of solidification or consolidation from a fused material (Malhotra and Mehta, 1996). From Figure 2, it can be seen that silica fume is round in shape with its typical particle size of ≈ 100nm.

Table 1. Chemical characteristic of silica fume.

Oxide	%
SiO_2	95.3
Al_2O_3	0.65
Fe_2O_3	0.28
CaO	0.27
MgO	0.41
K_2O	0.77
Na_2O	0.26

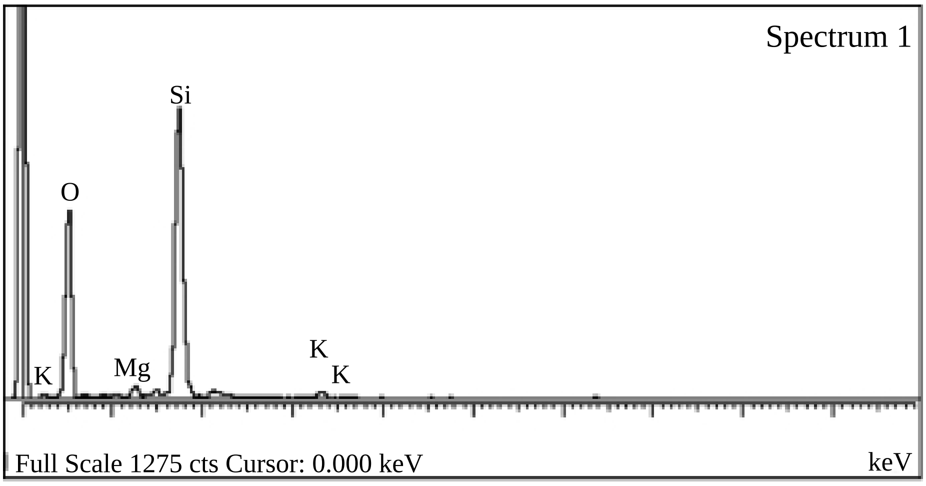

Figure 1. Energy Dispersive X-ray of silica fume.

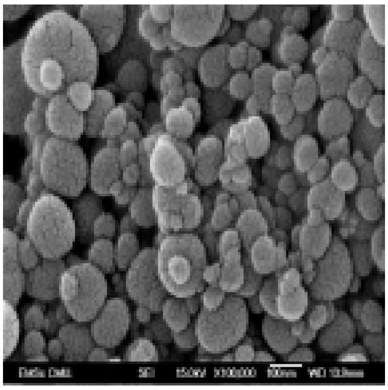

Figure 2. Scanning Electron Micrograph of silica fume particles.

The effect of silica fume on compressive strength of concrete can be seen in Figures 3 and 4, where Figure 3 shows the compressive strength development up to 28 days and Figure 4 shows the relative strength results compared to Portland cement concrete. It was found that at very early strength (1–2 days), the strength of silica fume concrete was slightly less than that of PC concrete. However, at later strength (from 7 days on), the compressive strength was found to increase significantly and with increasing level of silica fume used in the mixes. Greatest increase in strength can be seen in the concrete mix with silica fume at 20% and approximately 35% increase was found at 28 days. The significant gain in strength is thought to be due to the very high pozzolanic reactivity of silica fume once calcium hydroxide became available from Portland cement hydration, thus resulting in a denser structure of the cement matrix. Enhanced concrete strength from the use of silica fume has also been reported to be due to stronger bonding in the inter-facial zone between the cement paste and aggregates (Sarkar, 1991).

Silica fume is also known as micro silica since its first being put on the market by Elkem, a Norwegian leading ferrosilicon producer, as the word ‘micro’ was more common then. Now moving on in the 21st century, perhaps being in the ‘nanotechnology’ era, silica fume may now be referred to as nanosilica. Regardless of the trade name, its submicron size has so far made silica fume the most superior in strength enhancement to concrete structures.

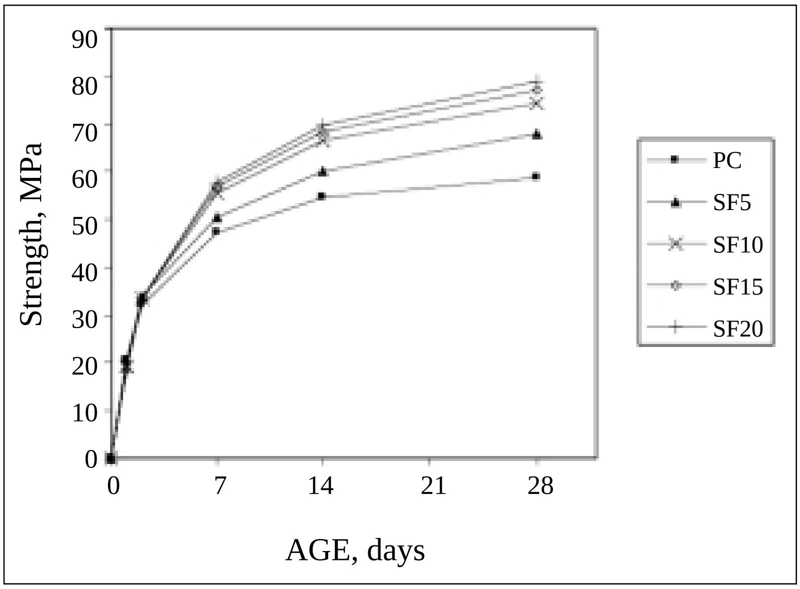

Figure 3. Compressive strength of silica fume concrete at w/c=0.45.

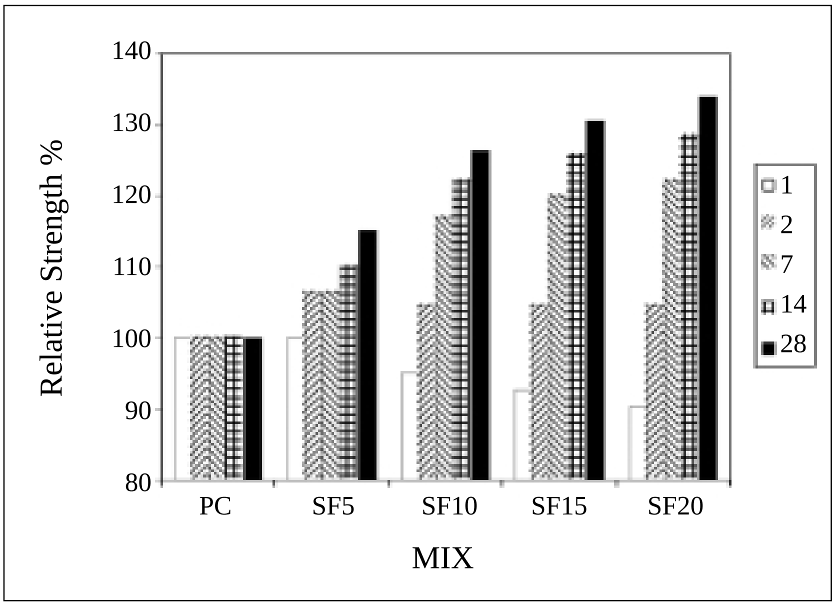

Figure 4. Relative strength of silica fume concrete to PC control concrete.

CONCLUSION

Silica fume is found to be ≈100nm in size and therefore is the finest component ever to be used to make cements or concrete so far. Its average particle size when compared to that of Portland cement (≈10–15 μm) is almost 100 times smaller in term of the diameter size of the particle. Enhanced compressive strength from the use of silica fume at 28 days was found. The compressive strength was found to increase significantly with increasing level of silica fume used in the mixes. Greatest increase in strength can be seen in the concrete mix with silica fume at 20%. This is thought to be due to improved densification of the cement matrix and also to stronger bonding in the inter-facial zone between the cement paste and aggregates.

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