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Effect of Silica Fume in Concrete

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ABSTRACT: Since advent of civilization various types of cementitous materials have been used for constructiuon practices. The arrival of Ordinary Portland Cement (OPC) changed the construction activities completely. However, because of several drawbacks associated with properties of cement and manufactured building materials usinf OPC as well as the cost factor attempts one mode to utilize other materials for economical constructions and improved mortar and concrete characteristics. Also, several waste materials are generated in huge quantities by different industrial activities. Now attempts were made to utilize these waste materials or industrial byproducts in construction activities to solve the environmental pollution problems, and safer and economical construction. Silica fume is one such industrial by product which is being used and experimented upon to obtain a stronger and durable concrete. It is one of the pozzolonas having very large surface area which results in better and uniform utilization of calcium hydroxide released during hydration of OPC. Also, because of its very fine size it act as filler material between the cement gell grains. This paper presents a review of silica fume utilization in concrete production and its effect on the concrete.

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

I. INTRODUCTION

The use of pozzolanas in concrete and mortar was started with a view to reduce the cost, overcome the adverse effects of OPC and utilize waste materials and by products of industrial activities which were providing harmful to environment, natural resources etc. Also, the use of pozzolonas improves/modifies several properties of mortar and concrete viz. workability, strength, resistance to cracks, permeability and durability. Further, the use of pozzalonas has resulted in the production of high performance concrete. Now a days, the properties of concrete are modified with the use of several additives like plasticizers/super plasticizers and pozzolonas improve the microstructure of the concrete matrix resulting in more stronger and durable concrete. The pozzolonas contribute to the strength development by utilizing the whole or part of the calcium hydroxide generated during hydration process of OPC. This action improves the several undesirable properties associated with OPC used. Also, the pozzolonic materials act as a filler in the microstructures of the concrete. A more homogeneous matrix is obtained as the pozzolanas because of their very small size provide very large number of nucleation sites for the precipitation of hydrated products. 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 and calcium hydroxide, produced during the cement hydration reactions.(1-3)

Silica fume is a by product resulting from the reduction of high – purity quartz with coal or coke and

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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 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 or the cement grains fill the space between the 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 pozzolana reacts more quickly than ordinary pozzolans. The use of silica fume in concrete has both engineering potential and economic advantage.

This paper presents a review of silica fume and its effect on fresh and hardened concrete.

II. PROPERTIES OF SILICA FUME

The physical and chemical properties of silica fume vis-a-vis, OPC are presented in table 1.[4-6]

Table – 1

Properties	OPC	Silica fume
Physical		
Specific gravity	3.1	2.2
Mean grain size (µm)	22.5	0.1
Specific area cm^2/gm	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

Fig. 1. Silica fume

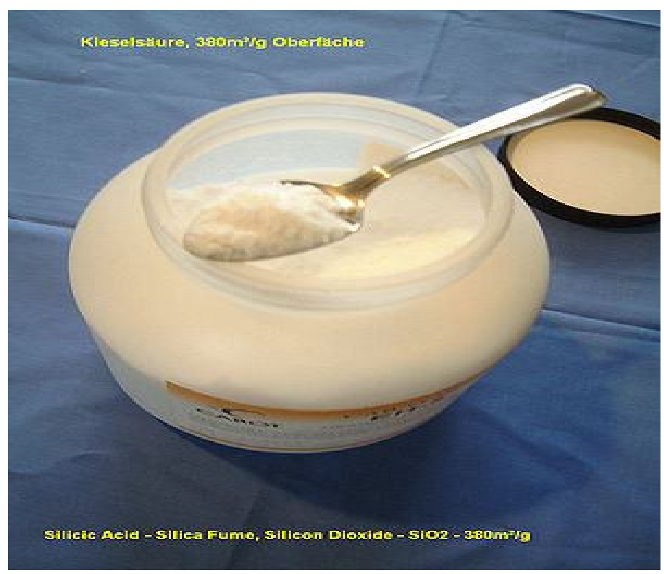

Fig. 2. Silica fume

III. PROPERTIES OF SILICA FUME CONCRETE (SFC)

The important properties of Silica Fume Concrete (SFC) in green and hardened states are presented below

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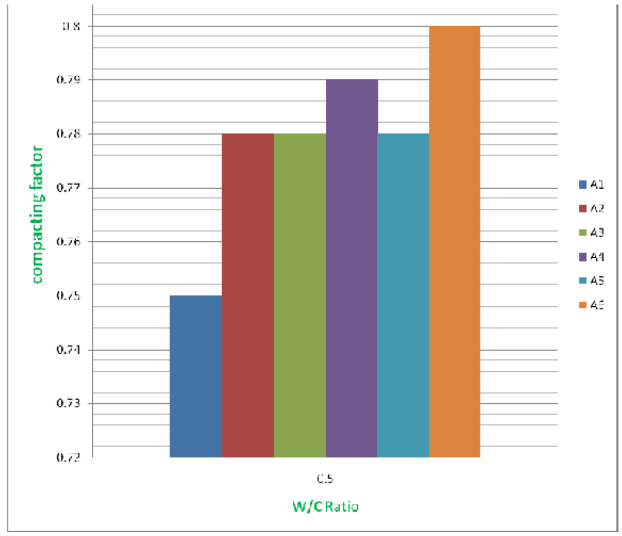
Workability

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 [7] reported that the general practice of researchers and designers is to alter the mixture proportion of conventional concrete (without silica fume) upon the incorporation of silica fume. This is done to overcome the adverse effect of silica fume on fresh mixture workability. Dual and Kadri [8] concluded that at 10% replacement of cement by silica fume, the workability increased in the range of 5-6.25% even after the reduction of super plasticizer's dose . However, Khayat et al [9] reported 15 -20 mm slump loss at 7.5% silica fume content as compared to conventional concrete. Yogendran et al [10] reported that on increasing the cement replacement with silica fume the workability decreases linearly. Ramakrishnan and Srinivasan [11] reported that addition of silica fume reduced the workability considerably in all the mixes. Also, the Silica fume mixes were sticky and cohesive. In general finishibility was improved with the addition of silica fume. Gafoori and Diaware [4] reported that workability of fresh concrete decrease on inclusion of silica fume. Pawade reported that workability of steel fiber reinforced concrete decreased with increase in silica fume and steel replacement so; however, the addition of super plasticizer might improve the workability [12]. Atul [13] reported increase in workability while using silica fume upto 10% as cement replacement. The variation of compacting factor at different replacement levels of cement by silica fume is shown in Fig. 3. The replacement levels are 0, 6 ,7 ,8 ,9 and 10% which are designated by A_1, A_2, A_3, A_4, A_5 and A_6 respectively.



*Note - A_1, A_2, A_3, A_4, A_5 and A6 are designated as 0, 6 ,7 ,8 ,9 and 10% replacement levels respectively

Fig. 3 Variation of compacting factor at different replacement level 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 between about 3 to 28 days. The contribution of silica fume to strength development after 28 days is minimal.[6] Bhanja and Sengupta [14] reported that inclusion of silica fume in the range of 5 - 25% increases compressive strength by about 6 – 30% for water cement ratio in the range of 0.26 - 0.42. Sakr [15] reported that at 15% silica fume content the gravel concrete, barite concrete and ilmenite concrete increased by : 23.33, 23.07 and 23.52% respectively at 7 days; 21.34, 20.00 and 22.58% respectively at 28 days; 16.50, 18.70 and 22.0% respectively at 56 days; and 18.00, 7.14 and 22.80 respectively at 90 days. Dual and Kadri [13] reported that at 10% replacement level the compressive strength increased in the range of about 10 – 17 % at different water cement ratios (0.25-0.45). Khayat et al [8] reported that at 7.5% replacement level the compressive strength increased in the range of about 10 – 17 % at different

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water cement ratios. Babu and Prakash [16] reported that concrete with silica fume even upto 40% replacement level shows strength higher than that of the conventional concrete. The improvements in strength at the different percentages of replacement level at any water cement ratio was also variable over a wide range. Khan and Ayers [17] reported 67% increase in compressive strength at 10% replacement level and 0.38 water cement ratio (w/c). Cong et. al[18] 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 [19] reported that at different replacement level of cement by silica fume (3.75 – 10.25%) increase in the compressive strength was in the range of about 12 - 57%. Detwiler and Mehta [5] reported that silica fume concrete showed improved compressive strength in the range of 11.56 - 18.89% over the conventional concrete at different water cement ratios. Yogendran et al [9] reported that at 0.34 w/c ratio, the compressive strength of concrete at 7, 28 and 56 days with 5 and 10% replacement levels is slightly higher than the coventional mix. Ramakrishnan and Srinivasan [11] reprted that high strength fibre reinforced concretes can be produced by addition of silica fume. Compressive strength as high as 58 MPa was achieved with locally available lime stone aggregate. Gafoori and Diaware [4] reported that at 28 days the concrete with 5, 10, 15 and 20% silica fume (as partial replacement of fine aggregate) showed gain in compressive strength by 25, 64, 42 and 25% respectively compared with the conventional concrete (referral). Atul [13] reported increase in compressive strength while using silica fume upto 10% as cement replacement. The variation of compressive strength at different replacement levels of cement by silica fume is shown in Fig. 4.

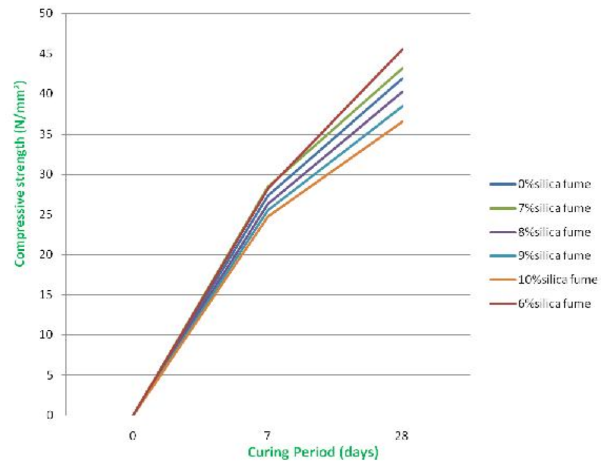

Fig. 4 Variation of Compressive Strength at different replacement level of Silica fume

Tensile Strength

The splitting tensile strength of concrete incorporating silica fume is similar to that observed in referral concrete. As the compressive strength increases, the tensile strength also increases, but at a gradually decreasing rate [20]. Several studies showed that the splitting tensile strength at various ages ranged between 5.8 – 15% of the compressive strength. Paillere et al [21] reported that at 15% silica fume content the tensile strength of concrete is in the range of 4.79 – 5.34 % of its compressive strength. Sakr [15] reported that at 15% replacement level the tensile strength of silica fume concrete increased in the range of 27 – 34% as compared to the referral concrete. Katkhuda et al. [22] reported that the split tensile strength of concrete is increased in the range of about 22 – 39% on addition of silica fume as SCM.

Flexural Strength

The flexural strength of concrete incorporating silica fume is similar to that observed in concretes without silica fume (referral concrete). Wolsiefer (1984) [23] reported that for the 98 MPa concrete containing 593 Kg/m^3 of cement and 20% silica fume, the flexural strength varies between 13 – 15% of the compressive strength. Yogendran et al [9] reported that at 0.34 w/c ratio the flexural strength of concrete at 7, 28 and 56

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days with 5 and 10% replacement level is slightly higher than the referral mix. However, at 15% replacement level the loss in strength is observed due to improper compaction, since the voids could not be removed even after using the vibrating table. Ramakrishnan and Srinivasan [11] reported that the flexural strength of silica fume concrete was higher by 10 - 15% as compared that of ordinary fibre concrete. Sakr [15] reported that at 15% replacement level flexural strength of silica fume concrete increased in the range of 52 - 65% as compared to the referral concrete. Roy and Sil [24] reported a marked improvement (about 21%) in flexural strength on addition of silica fume upto 10%, as cement replacement material. Katkhuda et al. [22] reported that the flexural strength of concrete is increased in the range of 23 – 47% on addition of silica fume as SCM.

Bond Strength

The inclusion of silica fume in concrete has improved the bond strength also. Sakr [15] reported that at 15% replacement level, the bond strength of silica fume concrete increased in the range of 37 - 43% as compared to the referral concrete.

Modulus of Elasticity

The static modulus of elasticity of silica fume concrete is apparently similar to referral concrete. Detwiler and Mehta [5] reported that at 0.25 and 0.34 w/c ratio, the modulus of elasticity of silica fume concrete decreasde by 2.34 and 3.76% respectively; whereas, at 0.50 w/c ratio it was found to increase by 3.59% as compared to the referral concrete.

IV. CONCLUSIONS

From the above review the following may be concluded.

1. The addition of silica fume reduces workability. However, in some cases it improves the workability.
2. Silica fume inclusion increases the compressive strength of concrete significantly (6-57%). The increase depends upon the replacement level.
3. The tensile and flexural strength of silica fume concrete is almost similar to the referral concrete.
4. The addition of silica fume improves the bond strength of concrete.
5. The modulus of elasticity of silica fume concrete is almost similar to the referral concrete.

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