

# Effect of Silica Fume on Steel Slag Concrete

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**Abstract**— Concrete is the most versatile construction material because it can be designed to withstand the harshest environments while taking on the most inspirational forms. Engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixtures and supplementary cementations materials. Nowadays, most concrete mixture contains supplementary cementitious material which forms part of the cementitious component. These materials are majority by-products from other processes. The main benefits of SCMs are their ability to replace certain amount of cement and still able to display cementitious property, thus reducing the cost of using Portland cement. The fast growth in internalisation has resulted in tons and tons of by product or waste materials, which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag, steel slag etc. The use of these by-products not only helps to utilize these waste materials but also enhances the properties of concrete in fresh and hydrated states. Slag cement and fly ash are the two most common SCMs used in concrete. Most concrete produced today includes one or both of these materials. For this reason their properties are frequently compared to each other by mix designers seeking to optimize concrete mixtures. Perhaps the most successful SCM is silica fume because it improves both strength and durability of concrete to such extent that modern design rules call for the addition of silica fume for design of high strength concrete. To design high strength concrete good quality aggregates is also required. Steel slag is an industrial by product obtained from the steel manufacturing industry. This can be used as aggregate in concrete. It is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial by product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides hence steel slag aggregates are not used in concrete making. Proper weathering treatment and use of pozzolanic materials like silica fume with steel slag is reported to reduce the expansion of the concrete. However, all these materials have certain shortfalls but a proper combination of them can compensate each other's drawbacks which may result in a good matrix product with enhance overall quality.

**Key words:** Silica Fume, Steel Slag Concrete

## I. INTRODUCTION

Concrete is a mixture of cement, sand, coarse aggregate and water. Its success lies in its versatility as can be designed to withstand harshest environments while taking on the most inspirational forms. Engineers and scientists are further trying to increase its limits with the help of innovative chemical

admixtures and various supplementary cementations materials SCMs.

Early SCMs consisted of natural, readily available materials like volcanic ash or diatomaceous earth. The engineering marvels like Roman aqueducts, the Coliseum are examples of this technique used by Greeks and Romans. Nowadays, most concrete mixture contains SCMs which are mainly byproducts or waste materials from other industrial processes.

### A. Supplementary Cementitious Material

More recently, strict environmental – pollution controls and regulations have produced an increase in the industrial wastes and sub graded byproducts which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag etc. The use of SCMs in concrete constructions not only prevent these materials to check the pollution but also to enhance the properties of concrete in fresh and hydrated states.

The SCMs can be divided in two categories based on their type of reaction: hydraulic and pozzolanic. Hydraulic materials react directly with water to form cementitious compound like GGBS. Pozzolanic materials do not have any cementitious property but when used with cement or lime react with calcium hydroxide to form products possessing cementitious prosperities.

#### 1) Ground Granulated Blast Furnace Slag: It is Hydraulic type of SCM.

Ground granulated blast furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag, a by-product of iron and steel making from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder.

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of coal-fired power plants, and is one of two types of ash that jointly are known as coal ash; the other, bottom ash, is removed from the bottom of coal furnaces. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO<sub>2</sub>) (both amorphous and crystalline) and calcium oxide (CaO). Fly ash is classified as Class F and Class C types.

The replacement of Portland cement with fly ash is considered to reduce the greenhouse gas "footprint" of concrete, as the production of one ton of Portland cement produces approximately one ton of CO<sub>2</sub> as compared to zero CO<sub>2</sub> being produced using existing fly ash. New fly ash production, i.e., the burning of coal, produces approximately twenty to thirty tons of CO<sub>2</sub> per ton of fly ash. Since the worldwide production of Portland cement is expected to reach nearly 2 billion tons by 2010, replacement of any large portion of this cement by fly ash could significantly reduce carbon emissions associated with construction.

It has been used successfully to replace Portland cement up to 30% by mass, without adversely affecting the

strength and durability of concrete. Several laboratory and field investigations involving concrete containing fly ash had reported to exhibit excellent mechanical and durability properties. However, the pozzolanic reaction of fly ash being a slow process, its contribution

Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 ft<sup>2</sup>/lb (20,000 m<sup>2</sup>/kg) when measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement. Because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material particle.

Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stem from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the reaction, sulphate attack. L. Lam, Y.L. Wong, and C.S. Poon<sup>4</sup> in their studied entitled Effect of fly ash and silica fume on compressive and fracture behaviors of concrete had concluded enhancement in strength properties of concrete by adding different percentage of fly ash and silica fume. Tahir Gonen and Salih Yazicioglu<sup>5</sup> studied the influence of binary and ternary blend of mineral admixtures on the short and long term performances of concrete and concluded many improved concrete properties in fresh and hardened states. Mateusz Radlinski, Jan Olek and Tommy Nantung<sup>6</sup> in their experimental work entitled Effect of mixture composition and Initial curing conditions on the scaling resistance of ternary concrete have find out effect of different proportions of ingredients of ternary blend of binder mix on scaling resistance of concrete in low temperatures. S.A. Barbhuiya, J.K. Gbagbo, M.I. Russeli, P.A.M. Basheer<sup>7</sup> studied the properties of fly ash concrete modified with hydrated lime and silica fume concluded that addition of lime and silica fume improve the early days compressive strength and long term strength development and durability of concrete. Susan Bernal, Ruby De Gutierrez, Silvio Delvasto<sup>8</sup>, Erich Rodriguez carried out Research work in Performance of an alkali-activated slag concrete reinforced with steel fibers. Their conclusion is that the developed AASC present higher compressive strengths than the OPC reference concretes. Splitting tensile strengths increase in both OPCC and the AASC concretes with the incorporation of fibers at 28 curing days. Hisham Qasrawi, Faisal Shalabi, Ibrahim Asi<sup>9</sup> carried out Research work in Use of low CaO unprocessed steel slag in concrete as fine aggregate. Their conclusion is that regarding the compressive and tensile strengths of concrete steel slag is more advantageous for concretes of lower strengths. O. Boukendakdji, S. Kenai, E.H. Kadri, F. Rouis<sup>10</sup> carried out Research work in Effect of slag on pozzolanic reactions between the silica fume and free

### B. Steel Slag

The Steel slag, a byproduct of steel making, is produced during the separation of molten steel from impurities in steel making furnaces. This can be used as aggregate in concrete. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides

that have not reacted with the silicate structure and that can hydrated and expand in humid environments. This potentially expansive nature (volume changes up to 10 percent or more attributable to the hydration of calcium and magnesium oxides) could cause difficulties with products containing steel slag, and is one reason why steel slag aggregate are not used in concrete construction. Steel slag is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Most of the volume of concrete is aggregates. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag has high specific gravity, high abrasion value than naturally available aggregate apart from the drawbacks like more water absorption, high alkalis. Therefore with proper treatments it can be used as coarse aggregate in concrete.

The production of a HSC may be hampered if the aggregates are weak. Weak and marginal aggregates are widespread in many parts of the world and there is a concern as to the production of HSC in those regions. Incorporation of silica fume is one of the methods of enhancing the strength of concrete, particularly when the aggregates are of low quality.

## II. LITERATURE SURVEY

Many works have been done to explore the benefits of using pozzolanic materials in making and enhancing the properties of concrete. M.D.A. Thomas, M.H. Shehata<sup>1</sup> et al. have studied the ternary cementitious blends of Portland cement, silica fume, and fly ash offer significant advantages over binary blends and even greater enhancements over plain Portland cement. Sandor Popovics<sup>2</sup> have studied the Portland cement-fly ash – silica fume systems in concrete and concluded several beneficial effects of addition of silica fume to the fly ash cement mortar in terms of strength, workability and ultra-sonic velocity test results. Jan Bijen<sup>3</sup> have studied the benefits of slag and fly ash added to concrete made with OPC in terms of alkali-silica calcium hydroxide in the paste. Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions. When silica fume is incorporated, the rate of cement hydration increases at the early hours due to the release of OH<sup>-</sup> ions and alkalis into the pore fluid. The increased rate of hydration may be attributable to the ability of silica fume to provide nucleating sites to precipitating hydration products like lime, C<sub>2</sub>S±H, and ettringite. It has been reported that the pozzolanic reaction of silica fume is very significant and the non-evaporable water content decreases between 90 and 550 days at low water /binder ratios with the addition of silica fume.

During the last decade, considerable attention has been given to the use of silica fume as a partial replacement of cement to produce high-strength concrete.

Tahir Gonen, Salih Yazicioglu<sup>12</sup> carried out research work in the influence of mineral admixtures on the short and long term performance of concrete, hence concluded that

silica fume contributed to both short and long term properties of concrete, whereas fly ash shows its beneficial effect in relatively longer time. As far as the compressive strength is concerned, adding of both silica fume and fly ash slightly increased compressive strength, but contributed more to the improvement of transport properties of concrete. M. Maslehuddin, Alfarabi M. Sharif, M.

Shameem, M. Ibrahim and M.S Barry<sup>12</sup> carried out experimental work on comparison of properties of steel slag and crushed limestone aggregate concretes, finally concluded that durability characteristics of steel slag cement concrete were better than those of crushed limestones aggregate concrete. Some of physical properties were better than of crushed lime stones concrete. J. G. Cabrera and P. A. Claisse<sup>13</sup> carried out experimental work on Oxygen and water vapour transport in cement pastes, hence concluded that the flow of oxygen is described by the Darcy equation, but the flow of water vapour is not. The different mechanisms of transmission cause the transmission rates for oxygen to be spread over a far greater range than those for water vapour with some of the SF samples almost impermeable to oxygen. Houssam A.

Toutanji and Tahar El-Korchi<sup>14</sup> carried out experimental work on Oxygen and water vapour transport in cement pastes, hence concluded that the increase in compressive strength of mortar containing silica fume as a partial replacement for cement, greatly contributes to strengthening the bond between the cement paste and aggregate. It was also demonstrated that super plasticizer in combination with silica fume plays a more effective role in mortar mixes than in paste mixes. This can be attributed to a more efficient utilization of super plasticizer in the mortar mixes due Ground granulated blast furnace slag (GGBFS) has been utilized for many years as an additional cementitious material in Portland cement concretes, either as a mineral admixture or as a component of blended cement. Granulated blast furnace slag typically replaces 35–65% Portland cement in concrete. The use of GGBFS as a partial replacement of ordinary Portland cement improves strength and durability of concrete concrete. Micheline Moranville-Regourd<sup>16</sup> carried out experimental work on the Cements Made from Blastfurnace Slag, hence concluded that Slag has found a considerable use in the road and building industries, in the production of cementing materials, as an aggregate in concrete and tarmacdam, in the production of light weight aggregate, and in the manufacture of slag wool for thermal insulation. M. J. Shannag<sup>17</sup> carried out experimental work on the high strength concrete containing natural pozzolana and silica fume, hence concluded that use of natural pozzolana in combination with silica fume in the production of high strength concrete, and for providing technical and economic advantages in specific local uses in the concrete industry. Houssam A. Toutanji and Ziad Bayasi<sup>18</sup> carried out experimental work on the Effect of curing procedures on properties of silica fume concrete hence concluded that Steam curing was found to enhance the properties of silica fume whereas air curing exhibited adverse effects as compared to moist curing. Enhancement in the mechanical properties of silica fume concrete caused by steam curing was manifested by strength increase and permeability and permeable void volume decrease. A. M. Boddy, R. D. Hooton and M. D. A.

Thomas<sup>19</sup> carried out experimental work on the effect of product form of silica fume on its ability to control alkali-silica reaction, hence concluded that slurried Silica fumes are significantly better at controlling the expansion of a reactive siliceous limestone aggregate than are densified or pelletized silica fume. Ha-Won Song, Seung-Woo Pack, Sang-Hyeok Nam, Jong-Chul Jang and Velu Saraswathy<sup>20</sup> carried out experimental work on the Estimation of the permeability of silica fume cement concrete, hence concluded that higher permeability reductions with silica fume are due to pore size refinement and matrix densification, reduction in content of Ca(OH)<sub>2</sub> and cement paste-aggregate interfacial refinement. Finally, optimum silica fume replacement ratios that reduce the permeability of concrete reasonably are proposed for durable concrete.

| cement         | Consistency in % | Specific gravity | Initial setting time | Final setting time |
|----------------|------------------|------------------|----------------------|--------------------|
| Fly ash cement | 37.5             | 3                | 3 hour 50 min        | 11 hour 35 min     |
| FC10           | 47               |                  |                      |                    |
| FC20           | 55.5             |                  |                      |                    |

Table 1:

#### A. Materials

##### 1) Silica Fume

Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 ft<sup>2</sup>/lb (20,000 m<sup>2</sup>/kg) when measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement. Because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material particle.

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Cracking in concrete. The results proved that if up to 50 to 75 % of steel slag aggregates are incorporated in the traditional concrete, there would not be much change in the durability of

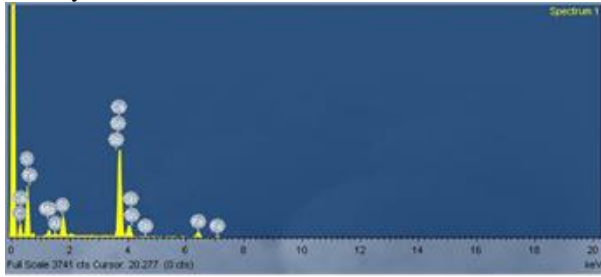


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Table 2:

### III. RESULTS & DISCUSSION

#### A. Experimental Study on Mortar

Here we prepared mortar with ratio 1:3 from different types of cement + silica fume replacement as binder mix and sand as fine aggregate. Then its physical properties like capillary absorption consistency, compressive strength and porosity was predicted. These test results both in tabular form and graphical presentation are given below.

##### 1) Normal Consistency for Mortar

Normal consistency of different binder mixes was determined using the following procedure referring to IS 4031: part 4 (1988):

- 1) 300 gm of sample coarser than 150 micron sieve is taken.
- 2) Approximate percentage of water was added to the sample and was mixed thoroughly for 2-3 minutes.
- 3) Paste was placed in the vicat's mould and was kept under the needle of vicat's apparatus.
- 4) Needle was released quickly after making it touch the surface of the sample.
- 5) Check was made whether the reading was coming in between 5-7 mm or not and same process was repeated if not
- 6) The percentage of water with which the above condition is satisfied is called normal consistency.

### IV. CONCLUSIONS

From the present study the following conclusions are drawn:

- V. Inclusion of silica fume improves the strength of different types of binder mix by making them denser.
- W. Addition of silica fume improves the early strength gain of fly ash cement whereas it increases the later age strength of slag cement.
- X. The equal blend of slag and fly ash cements improves overall strength development at any stage.
- Y. Addition of silica fume to any binder mix reduces capillary absorption and porosity because fine particles

of silica fume reacts with lime present in cement and form hydrates dencer and crystalline in composition.

- Z. The capillary absorption and porosity decreases with increase dose up to 20% replacement of silica fume for mortar.
- AA. Addition of silica fume to the concrete containing steel slag as coarse aggregate reduces the strength of concrete at any age.

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