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# Experimental Study on the Effect of Silica Fume on Steel Slag Concrete

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***Abstract---The most versatile construction material is concrete because it can be considered to withstand the harshest environments while taking on the most inspirational forms. Limits are continually pushed to expand its act with the support of pioneering chemical admixtures and supplementary cementitious materials. Nowadays, most concrete mixture contains supplementary cementitious material which forms part of the cementitious component. These materials are majority byproducts 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 initialization has resulted in tons and tons of byproduct 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 byproducts 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 purpose, their properties are normally associated to each other by mix designers seeking to improve concrete mixtures. Possibly the most effective SCM is silica fume because it advances 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. For designing high strength concrete good quality aggregates is also mandatory. Steel slag is an industrial byproduct attained from the steel manufacturing industry. It 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 supplementary work to regulate the feasibility of exploiting this industrial byproduct more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Swapping all or some share of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag aggregate generally exhibit a propensity to increase because of the existence of free lime and magnesium oxides hence steel slag aggregates are not used in concrete making. Good weathering treatment and use of pozzolanic materials like silica fume with steel slag is described to decrease the development of the concrete. However, all these materials have sure losses but a proper combination of them can reimburse each other's drawbacks which may result in a good matrix product with improve complete quality.***

***Keywords – Steel Slag, Aggregates, flexural strength, compressive strength, SCM***

## 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 cementitious 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.

### 1.1 Silica Fume: It is also a type of pozzolanic material

Silica fume, also known as microsilica, is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

It is sometimes confused with fumed silica). However, the production process, particle characteristics and fields of application of fumed silica are all different from those of silica fume

The first testing of silica fume in Portland-cement-based concretes was carried out in 1952. The biggest drawback to exploring the properties of silica fume was a lack of material with which to experiment. Early research used an expensive additive called fumed silica, an amorphous form of silica made by combustion of silicon tetrachloride in a hydrogen-oxygen flame. Silica fume on the other hand, is a very fine pozzolanic, amorphous material, a by-product of the production of elemental silicon or ferrosilicon alloys in electric arc furnaces. Before the late 1960s in Europe and the mid-1970s in the United States, silica fumes were simply vented into the atmosphere. With the implementation of tougher environmental laws during the mid-1970s, silicon smelters began to collect the silica fume and search for its applications. The early work done in Norway received most of the attention, since it had shown that Portland cement-based-concretes containing silica fumes had very high strengths and low porosities. Since then the research and development of silica fume made it one of the world's most valuable and versatile admixtures for concrete and cementitious products.

### 1.2 Steel Slag

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process or in specialty steel plants (mini-mills) using an electric arc furnace process. The open-hearth furnace process is no longer used. In the basic oxygen process, hot liquid blast furnace metal, scrap, and fluxes, which consist of lime (CaO) and dolomitic lime (CaO.MgO or "dolime"), are charged to a converter (furnace). A lance is lowered into the converter and high-pressure oxygen is injected. The oxygen combines with and removes the impurities in the charge. These impurities consist of carbon as gaseous carbon monoxide, and silicon, manganese, phosphorus and some iron as liquid oxides, which combine with lime and dolime to form the steel slag. At the end of the refining operation, the liquid steel is tapped (poured) into a ladle while the steel slag is retained in the vessel and subsequently tapped into a separate slag pot. There are many grades of steel that can be produced, and the properties of the steel slag can change significantly with each grade. Grades of steel can be classified as high, medium, and low, depending on the carbon content of the steel. High-grade steels have high carbon content. To reduce the amount of carbon in the steel, greater oxygen levels are required in the steel-making process. This also requires the addition of increased levels of lime and dolime (flux) for the removal of impurities from the steel and increased slag formation

## II. LITERATURE REVIEW

Y.L. Wong, and C.S. Poon[4] 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[5] 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[6] 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.

AASC concretes with the incorporation of fibers at 28 curing days. Hisham Qasrawi, Faisal Shalabi, Ibrahim Asi [9] 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 [10] carried out Research work in Effect of slag on the rheology of fresh self-compacted concrete. Their conclusion is that slag can produce good self-compacting concrete. Shaopeng Wu, Yongjie Xue, Qunshan Ye, Yongchun Chen[11] carried out Research work in Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. Their conclusion is that the test roads shows excellent performances after 2-years' service, with abrasion and friction coefficient of 55BPN and surface texture depth of 0.8 mm.

A. M. Boddy, R. D. Hooton and M. D. A. Thomas[19] 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[20] 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 $Ca(OH)_2$ and cement paste-aggregate interfacial refinement. Finally, optimum silica fume replacement ratios that reduce the permeability of concrete reasonably are proposed for durable concrete.

## III. MATERIALS AND METHOD

### 3.1 Fly Ash cement

Fly ash is a fine powder that is a byproduct of burning pulverized coal in electric generation power plants. Fly ash is a pozzolan, a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, fly ash forms a compound similar to Portland cement. This makes fly ash suitable as a prime material in blended cement, mosaic tiles, and hollow blocks, among other building materials. When used in concrete mixes, fly ash improves the strength and segregation of the concrete and makes it easier to pump.

**3.2 Slag Cement**

Slag cement is a hydraulic cement formed when granulated blast furnace slag (GGBFS) is ground to suitable fineness and is used to replace a portion of portland cement. It is a recovered industrial by-product of an iron blast furnace. Molten slag diverted from the iron blast furnace is rapidly chilled, producing glassy granules that yield desired reactive cementitious characteristics when ground into cement fineness. Once the slag has been cooled and ground to a usable fineness it is stored and shipped to suppliers throughout the united states. Slag cement is commonly found in ready-mixed concrete, precast concrete, masonry, soil cement and high temperature resistant building products. While there are many applications and benefits of slag cement, a few are highlighted below and detailed information sheets are located here

**3.3 Sand**

Sand is a granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e., a soil containing more than 85 percent sand-sized particles by mass.The composition of sand varies, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or $SiO_2$), usually in the form of quartz. The second most common type of sand is calcium carbonate, for example, aragonite, which has mostly been created, over the past half billion years, by various forms of life, like coral and shellfish. For example, it is the primary form of sand apparent in areas where reefs have dominated the ecosystem for millions of years like the Caribbean.

**3.4 Coarse aggregate**

Coarse aggregates are an integral part of many construction applications, sometimes used on their own, such as a granular base placed under a slab or pavement, or as a component in a mixture, such as asphalt or concrete mixtures. Coarse aggregates are generally categorized as rock larger than a standard No. 4 sieve (3/16 inches) and less than 2 inches.

## IV. EXPERIMENTAL SETUP

**4.1 Compressive Strength**

Each set six standard cubes were cast to determine 7-days,28 day and 56 days compressive strength after curing. Also, nine no. of cube was casted to know the compressive strength of concrete. The size of the cube is as per the IS 10086 1982.

**4.2. Capillary Absorption Test**

Two cube specimens were cast for both (Mortar and concrete cube) to determine capillary absorption coefficients after 7days, 28 days and 56 days curing. This test is conducted to check the capillary absorption of different binder mix mortar matrices which indirectly measure the durability of the different mortar matrices

**4.3. Porosity Test**

Two cylindrical specimens of size 65 mm dia and 100 mm height for each mix were cast for porosity test after 7 days and 28 day of curing. This indirectly measures the durability of the mortar matrices.

**4.4 Wet and Dry Test**

Concrete cube was dipped inside a sea water for 4 hours and then exposed to dry for 20 hours. Sea water is prepared by dissolved 35 g of salt (Nacl) in one-liter water. Here cubes were dipped inside the Sea water for 56 days and its compressive strength were determined by compressive testing machine.

Table 1
Compressive Strength of different concrete cubes after 7 days, 28 days and 56 days

| Type of cement | % of SF replaced | 7 days | 28 days | 56 days |
|---|---|---|---|---|
| Fly ash cement | 0 | 25.56 | 29.51 | 37.4 |
| | 10 | 22.4 | 25.64 | 26.94 |
| | 20 | 23.4 | 23.9 | 30.2 |
| Slag cement | 0 | 18.3 | 23.6 | 27.35 |
| | 10 | 18.7 | 21.3 | 28.4 |
| | 20 | 18.4 | 22.4 | 27.5 |
| Slag and fly ash cement blend (1:1) | 0 | 21.9 | 26.4 | 32.45 |
| | 10 | 22.8 | 24 | 28.44 |
| | 20 | 22.4 | 21.9 | 29.23 |

Table 2
flexural strength of steel slag concrete at 28 days and 56 days

| Type of cement | % of SF replaced | 28 days($N/mm^2$) | 56 days ($N/mm^2$) |
|---|---|---|---|
| Fly ash cement (FC) | 0 | 7.875 | 5 |
| | 10 | 8 | 5.25 |
| | 20 | 7.875 | 5.5 |
| Slag cement (SC) | 0 | 8 | 6 |
| | 10 | 7.5 | 4.55 |
| | 20 | 7.125 | 4.975 |
| Slag and fly ash cement blend (1:1) (SFC) | 0 | 7 | 5.5 |
| | 10 | 7.725 | 4.23 |
| | 20 | 5.75 | 3.975 |

Table 3
Compressive Strength of different mortar after 7 days, 28 days and 56 days

| Type of cement | % of SF replaced | 7days | 28days | 56 days |
|---|---|---|---|---|
| **Fly ash cement** | 0 | 24.33 | 38.1 | 46.1 |
| | 10 | 22.61 | 28.77 | 31.44 |
| | 20 | 21.66 | 24.1 | 29 |
| **Slag cement** | 0 | 17.6 | 25.21 | 29.44 |
| | 10 | 19.44 | 26.33 | 26.55 |
| | 20 | 20.2 | 25.89 | 22.1 |
| **Slag and fly ash cement blend (1:1)** | 0 | 28.05 | 28.55 | 34.11 |
| | 10 | 23 | 24.77 | 29.77 |
| | 20 | 21 | 23.88 | 28.88 |

Table 4
28 days and 56 days wet and dry test of concrete cube.

| Type of cement | % of SF replaced | 28 days ($N/mm^2$) | 56 days ($N/mm^2$) |
|---|---|---|---|
| **Fly ash cement (FC)** | 0 | 36.5 | 36.0 |
| | 10 | 30.7 | 30.66 |
| | 20 | 26.8 | 28.44 |
| **Slag cement (SC)** | 0 | 23.8 | 27.55 |
| | 10 | 26.8 | 24.88 |
| | 20 | 25.3 | 20.88 |
| **Slag and fly ash cement blend (1:1) (SFC)** | 0 | 20.7 | 38.22 |
| | 10 | 36.5 | 24 |
| | 20 | 30.1 | 30.66 |

Table 5
28 days and 56 days porosity test

| Type of cement | % of SF replaced | 28 days (%) | 56 days (%) |
|---|---|---|---|
| Fly ash cement (FC) | 0 | 6.1 | 4.8 |
| | 10 | 8.3 | 6.7 |
| | 20 | 9.1 | 7.4 |
| Slag cement (SC) | 0 | 9.3 | 7.3 |
| | 10 | 16 | 11.11 |
| | 20 | 18 | 13.23 |
| Slag and fly ash cement blend (1:1) (SFC) | 0 | 5.7 | 3.79 |
| | 10 | 7.1 | 5.21 |
| | 20 | 12 | 9.83 |

## V. CONCLUSIONS

- Additions silica fume progresses the strength of different types of binder mix by making them denser.
- Accumulation of silica fume progresses the early strength gain of fly ash cement where it increases the later age strength of slag cement.
- Improves overall strength development at any stage.
- Accumulation of silica fume to any binder mix decreases capillary absorption and porosity because fine particles of silica fume reacts with lime present in cement and form hydrates dancer and crystalline in composition.
- The capillary absorption and porosity cut with rise dose up to 20% replacement of silica fume for mortar.
- Accumulation of silica fume to the concrete encompassing steel slag as coarse aggregate diminishes the strength of concrete at any age.
- The furthermost vital reason of decrease in strength is due to alkali aggregate reaction between binder matrix and the steel slag used as coarse aggregate. By nature, cement paste is alkaline. The existence of alkalis Na2O, K2O in the steel slag make the concrete extra alkaline. When silica fume is extra to the concrete, silica present in the silica fume react with the alkalis and lime and form a gel which harm the bond between aggregate and the binder matrix. This decrease is more prominent with higher dose of silica fume.
  - Grouping of fly ash cement and silica fume makes the concrete more consistent or sticky than the concrete holding slag cement and silica fume causing development of more voids with fly ash cement.

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