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# An Experimental Study on the Properties of Steel Slag Concrete with Incorporation of Silica Fume

**G. Suryanarayana[1], A. B. S. Dadapeer[2], K. Mohammed Rasheed[2]**

*[1]M.Tech Student, Chiranjeevi Reddy Institute of Engineering & Technology, Anantapur, Andhra Pradesh, India

*[2]Assistant Professor, Civil Engineering Department, Chiranjeevi Reddy Institute of Engineering & Technology, Anantapur, Andhra Pradesh, India

## 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 cementitious 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 industrialisation 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. In the present work a series of tests were carried out to make comparative studies of various mechanical properties of concrete mixes prepared by using ACC brand Slag cement , Fly ash cement and their blend (in 1:1 proportion ). These binder mixes are modified by 10% and 20% of silica fume in replacement. The fine aggregate used is natural sand comply to zone II as per IS383-1982.The coarse aggregate used is steel making slag of 20 mm down size. The ingredients are mixed in 1:1.5:3 proportions. The properties studied are 7days, 28days and 56 days compressive strengths, flexural strength, porosity & capillary absorption.

**Keywords :** Compressive, Flexure, Compaction, Steel Slag, Silica fume, Weathering

# 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 by products or waste materials from other industrial processes.

# II. STEEL SLAG

The Steel slag, a by-product 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.

## 2.1 SILICA FUME:

Silica fume is a by-product 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 $ft^2/lb$ (20,000 $m^2/kg$) 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 stems from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Addition of silica fume also reduces the per meability 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 ÿ 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-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.

## 2.2 SLAG CEMENT

Slag cement has been used in concrete projects in the United States for over a century. Earlier usage of slag cement in Europe and elsewhere demonstrates that long-term concrete performance is enhanced in many ways. Based on these early experiences, modern designers have found that these improved durability characteristics help further reduce life-cycle costs, lower maintenance costs and makes concrete more sustainable. For more information on how slag cement is manufactured and it enhances the durability and sustainability of concrete.

# III. LABORATORY TESTS CONDUCTED

## 3.1 Compressive Strength Test

For 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.

## 3.2 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.

Procedure:

1) The specimen was dried in oven at about 105°C until constant mass was obtained.
2) Specimen was cool down to room temperature for 6hr.
3) The sides of the specimen was coated with paraffin to achieve unidirectional flow.
4) The specimen was exposed to water on one face by placing it on slightly raised seat (about 5 mm) on a pan filled with water.
5) The water on the pan was maintained about 5mm above the base of the specimen during the experiment as shown in the figure below.
6) The weight of the specimen was measured at 15 min and 30 min. intervals.
7) The capillary absorption coefficient (k) was calculated by using formula:

$$k=Q/\sqrt{A}$$

## 3.3 Porosity Test

Two cylindrical specimen of size 65mm dia and 100mm 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.

Procedure:

1) The specimen was dried in oven at about 100°C until constant mass $W_{dry}$ was obtained.
2) The specimens were placed in a desiccators filled with distilled water under vacuum for 3 hrs.
3) Weight of the saturated specimen $W_{sat}$ in distilled water is taken.
4) The specimens are taken out and its weight is taken in air i.e. $W_{wat}$
5) The vacuum saturated porosity is calculated by the formula:

$P = ((W_{sat} - W_{dry}) / (W_{sat} - W_{wat}))*100$

**3.4 Wet-dry Test:**

Concrete cube were 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.

**3.5 Compressive test by pulse velocity.**

The strength of concrete is generally governed by the strength of cement paste. If the strength of paste can be measured, then we can find reasonable indication for strength of concrete. This strength can be measured on site by rebound hammer method. The rebound hammer is an instrument which provides quick and simple non-destructive test for obtaining an immediate indication for concrete strength in every part of structure.

**3.6 Flexural Test:**

It is the ability of a beam or slab to resist failure in bending. The flexural strength of concrete is 12 to 20 percent of compressive strength. Flexural strength is useful for field control and acceptance for pavement .but now a days flexural strength is not used to determine field control, only compressive strength is easy to judge the quality of concrete. To determine the flexural strength of concrete four numbers of prism were casting. Then it was cured properly.

$$\text{Flexural strength} = PL/BD^2$$

## IV. RESULTS AND DISCUSSIONS

**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.

**Normal consistency for Mortar:**

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

- 300 gm of sample coarser than 150 micron sieve is taken.
- Approximate percentage of water was added to the sample and was mixed thoroughly for 2-3 minutes.
- Paste was placed in the vicat's mould and was kept under the needle of vicat's apparatus.
- Needle was released quickly after making it touch the surface of the sample.
- Check was made whether the reading was coming in between 5-7 mm or not and same process was repeated if not
- The percentage of water with which the above condition is satisfied is called normal consistency.
- Normal consistency of different binder mixes were tabulated below in Table No. 4.1.

Table No.4.1

| Mix | Description | Cement (grams) | Silica fume | Consistency (%) |
|---|---|---|---|---|
| SC0 | SC | 300 | 00 | 31.5 |
| SC10 | SC with 10% SF | 270 | 30 | 35 |
| SC20 | SC with 20% SF | 240 | 60 | 40.5 |
| FC0 | FC | 300 | 00 | 37.5 |
| FC10 | FC with 10% SF | 270 | 30 | 47 |
| FC20 | FC with 20% SF | 240 | 60 | 55.5 |
| SFC0 | SC:FC (1:1) | 150 each | 00 | 36.5 |

| | | | | |
|---|---|---|---|---|
| SFC10 | SC:FC (1:1) | 135 each | 30 | 41.5 |
| SFC20 | SC:FC (1:1) with | 120 each | 60 | 47.5 |

From the above table we can conclude that water requirement increases wit h increase in percentage of replacement by silica fume and fly ash cement consumes more water due to its fineness. Water requirement or normal consistency of a binder mix increases with increment in percentage of silica fume replacement. Water requirement in case of fly ash cement binder mix is more because it is finer when compared to slag cement.

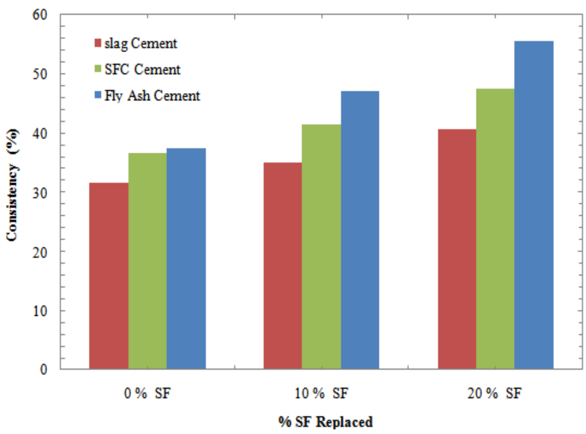

Figure.4.1 Consistency of Mortar.

From the above graph we can conclude that water requirement increases with increase in percentage of replacement by silica fume and fly ash cement consumes more water due to its fineness. Water requirement or normal consistency of a binder mix increases with increment in percentage of silica fume replacement.

**Compressive Strength of Mortar:**

Compressive Strength of different mortars after 7 days and 28 days are tabulated in table.

| Type of cement | % of SF replaced | 7 days | 28 days |
|---|---|---|---|
| Slag cement (SC) | 0 | 18.91 | 29.43 |
| | 10 | 25.97 | 35.09 |
| | 20 | 34.13 | 42.12 |
| Fly ash cement (FC) | 0 | 14.82 | 26.57 |
| | 10 | 27.07 | 31.74 |
| | 20 | 31.43 | 37.23 |
| Slag and fly ash Cementblend (1:1) (SFC) | 0 | 15.73 | 32.57 |
| | 10 | 22.58 | 37.69 |
| | 20 | 27.89 | 40.12 |

From the above table, we can conclude that early or 7 days strength and 28 days strength increases with increase in percentage of replacement by silica fume. Early gain of strength is more in case of fly ash cement and gain of strength at later stages is more in case of slag cement. the reason for early gain of strength in fly ash cement could be fast reaction between fly ash and silica fume particles due to fine nature. as slag particles are coarser than fly ash, reaction rate is relatively slow and hence gain of early strength is not that much but at later stages gain of strength is more.

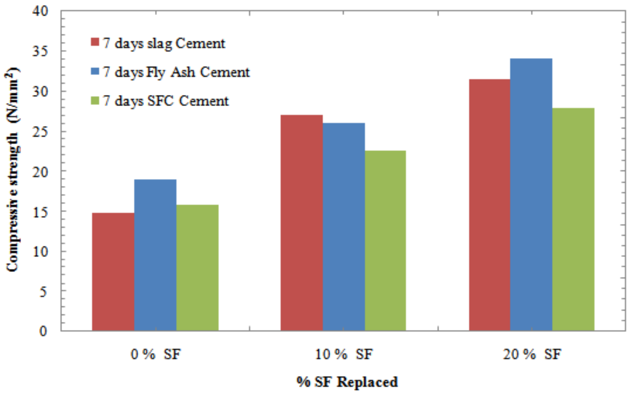


Figure.4.2 Compressive strength for mortar for 7 days

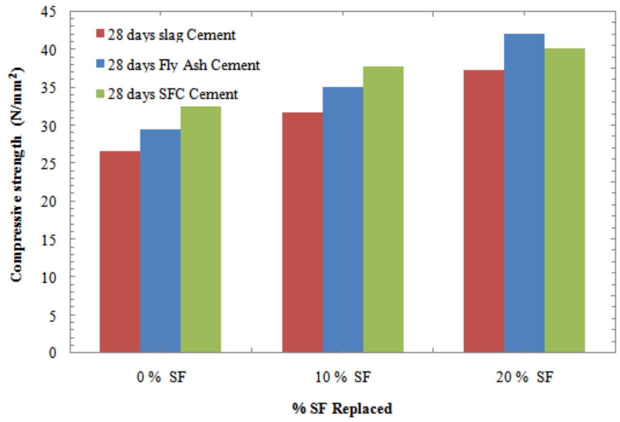


Figure.4.3 compressive strength for mortar for 28 day

## V. CONCLUSION

From the present study the following conclusions are drawn:

1. Inclusion of silica fume improves the strength of different types of binder mix by making them more denser.
2. Addition of silica fume improves the early strength gain of fly ash cement whereas it increases the later age strength of slag cement.
3. The equal blend of slag and fly ash cements improves overall strength development at any stage.
4. 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 dancer and crystalline in composition.
5. The capillary absorption and porosity decreases with increase dose up to 20% replacement of silica fumes for mortar.
6. Addition of silica fume to the concrete containing steel slag as coarse aggregate reduces the strength of concrete at any age.
7. This is due to the formation of voids during mixing and compacting the concrete mix in vibration table because silica fume make the mixture sticky or more cohesive which do not allow the entrapped air to escape. The use of needle vibrator may help to minimize this problem.
8. The most important reason of reduction 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 presence of alkalis $Na_2O$, $K_2O$ in the steel slag make the concrete more alkaline. When silica fume is added 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.

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