

# 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 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 in stralisation 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 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 byproduct 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 byproduct 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. 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(in1:1proportion). These binder mixes are modifiedby10%and20%of silica fume in replacement. The fine aggregate used is natural sand comply to zone II as per IS 383-1982.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.

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## 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 Greek sand Romans. Nowadays, most concrete mixture contains SCMs which are mainly byproducts or waste materials from other industrial processes.

### **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 properties.

***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.

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 by creating a denser matrix and thereby increasing the service life of concrete structures. It has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength.

***Flyash: It is pozzolanic SC material.***

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.

***Silica Fume: It is also a type of pozzolanic material.***

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 particle. 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 pozzolanic reactions between the silica fume and free 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-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.

**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 hydrate 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.

### 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 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.

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, where as fly ash shows its beneficial effect in a 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 limestone 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.

### MATERIALS AND METHODOLOGY

#### *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 ferro silicon 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 particle. 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 pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. The increased rate of hydration may be attributable to the ability of silica fume to provide nucleating sites to precipitating hydration products like lime,  $C\pm S\pm H$ , 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.

### ***SteelSlag***

Steel slag is the residue of steel production process and composed of silicates and oxides of unwanted elements in steel chemical composition. Fifty million tons per year of LD slag were produced as a residue from Basic Oxygen Process (BOP) in the world.

In order to use these slags in cement, its hydraulic properties should be known. Chemical composition is one of the important parameters determining the hydraulic properties of the slags. In general, it is assumed that the higher the alkalinity, the higher the hydraulic properties. If alkalinity is  $> 1.8$ , it should be considered as cementitious material. Investigations were carried out also on the usability of steel slag as construction material under laboratory and practical conditions. For this application, the required properties are high compression strength, wear strength and resistance to climatic conditions.

### ***Flyash cement***

Fly ash, which is largely made up of silicon dioxide and calcium oxide, can be used as a substitute for Portland cement, or as a supplement to it. The materials which make up flyash are pozzolanic, meaning that they can be used to bind cement materials together. Pozzolanic materials, including fly ash cement, add durability and strength to concrete. Fly ash cement is also known as green concrete. It binds the toxic chemicals that are present in the fly ash in a way that should prevent them from contaminating natural resources. Using fly ash cement in place of or in addition to Portland cement uses less energy, requires less invasive mining, and reduces both resource consumption and CO<sub>2</sub> emissions.

### **Methodology Test Procedure**

The Experimental programme was carried out in two stages

Stage 1: Experimental works were conducted on mortar mixes by using different binder mix modified with different percentages of silica fume.

Stage 2: Experimental works were conducted on steel slag concrete mixes by using different binder mix modified with different percentages of silica fume.

### **Laboratory Test Conducted:**

#### ***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.

#### ***Capillary absorption Test***

Two cube specimens were cast for both (Mortar and concrete cube) to determine capillary absorption coefficients after 7 days, 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<sup>[8]</sup>.

#### ***Porosity Test***

Two cylindrical specimen 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

#### ***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.

#### ***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 day's 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.

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

Where P is load

L= Length of Prism. B=Breadth of Prism. D=Breadth of Prism

## 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 microns 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. Water requirement in case of fly ash cement binder mix is more because it is finer when compared to slag cement.

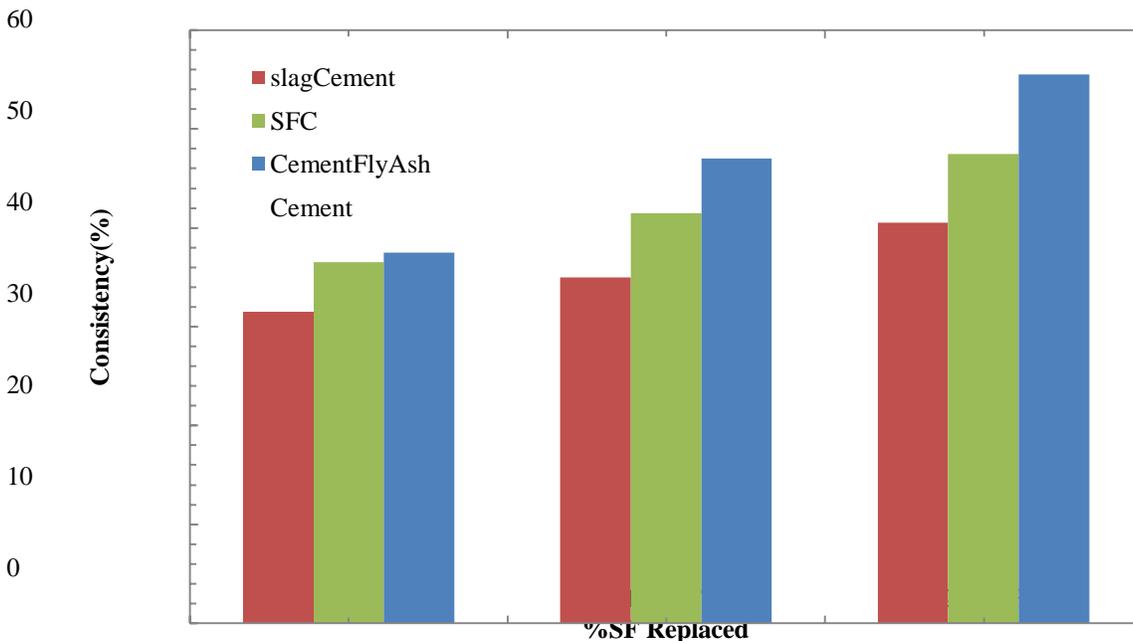
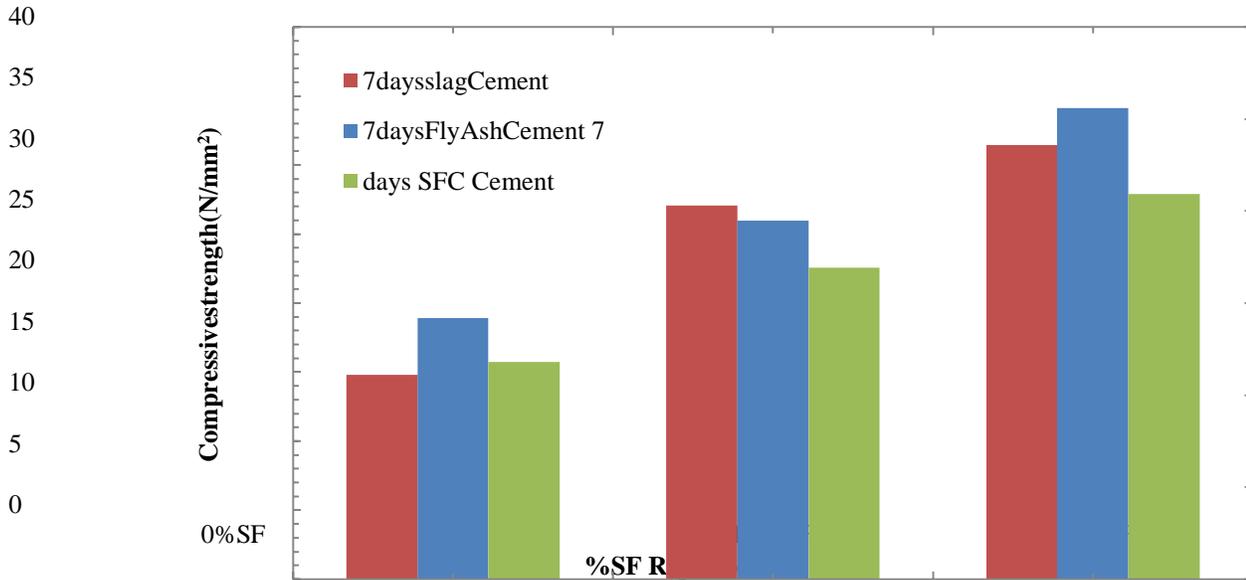


Figure. Consistency of Mortar.

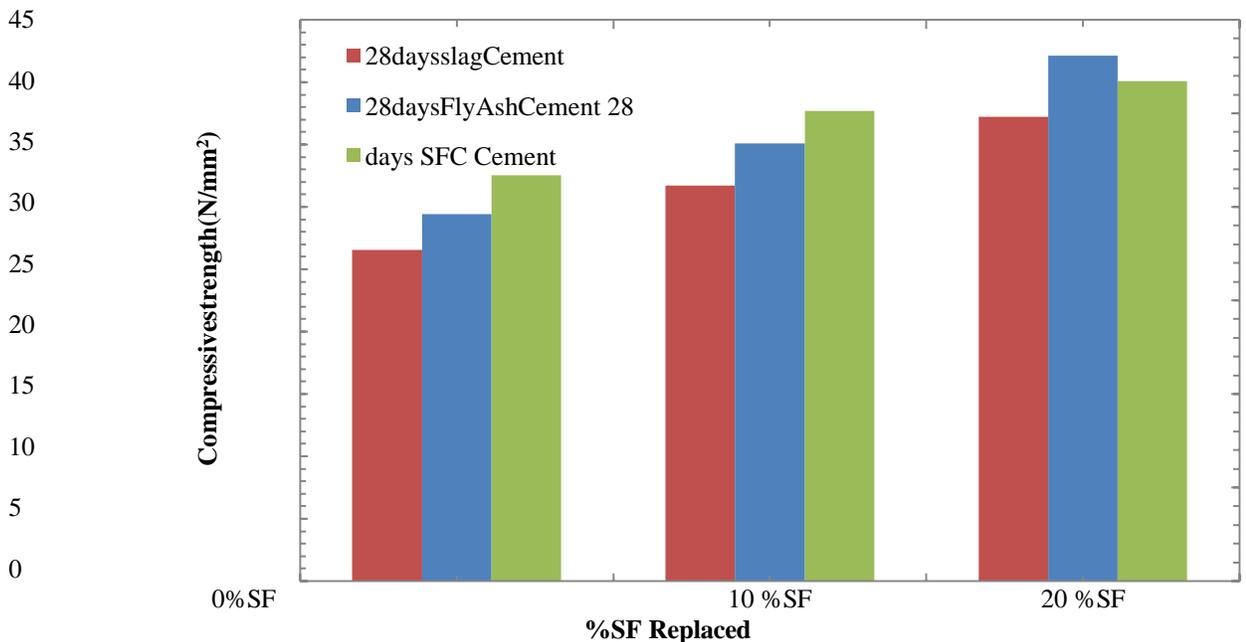
From the above graph we can conclude that water requirement increases with increase in percentage of replacement by silica fume and fly ash cement consumes more water due to its fineness. Water requirement or normal consistency of a binder mix increases with increment in percentage of silica fume replacement.

Water requirement in case of fly ash cement binder mix is more because it is finer when compared to slag cement. 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. All binder mixes shows that upto 20% replacment of cement with silica fume the Compressive strength increases with increasing dose of silica Fume. Early strength in all binder mixes increases with 5% replacment by silica fume. The same is observed in case of 10% replacment. But amongst three types of binders, gain in fly ash cement is more. The early days strength increases remarkably by replacment any type of cement by silica fume up to 15%. This increase is more remarkable in fly ash cement



**Figure. Compressive strength for mortar for 7 days**



**Figure. compressive strength for mortar for 28 day**

## 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 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 dancser and crystalline in composition.
5. The capillary absorption and porosity decreases with increase dose up to 20% replacement of silica fume 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  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  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.
9. Combination of fly ash cement and silica fume makes the concrete more cohesive or sticky than the concrete containing slag cement and silica fume causing formation of more voids with fly ash cement. Therefore the concrete mixes containing fly ash and silica fume show higher capillary absorption and porosity than concrete mixes containing slag cement and silica fume.
10. The total replacement of natural coarse aggregate by steel slag is not recommended in concrete. A partial replacement with fly ash cement may help to produce high strength concrete with properly treated steel slag.
11. The steel slag should be properly treated by stock piling it in open for at least one year to allow the free  $\text{CaO}$  &  $\text{MgO}$  to hydrate and thereby to reduce the expansion in later age.
12. A thorough chemical analysis of the steel slag is recommended to find out the presence of alkalis which may adversely affect to the bond between binder matrix and the aggregate.

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