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 cementations material which forms part of the cementations 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 cementations property, thus reducing the cost of using Portland cement. The fast growth in instralisation 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.

Index Terms— concrete, chemical admixtures, SCMs, silica fume

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.

1.1SUPPLEMENTARYCEMENTITIOUS 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 prevents 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.

1.1.1 GROUND GRANULATED BLAST FURNACE SLAG S: 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 cementations 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.

1.1.2 Fly ash: 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 (SiO2) (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 CO2 as compared to zero CO2 being produced using existing fly ash. New fly ash production, i.e., the burning of coal, produces approximately twenty to thirty tons of CO2 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 towards the strength development occures only at later ages. Due to the spherical shape of fly ash particles, it can also increase workability of cement while reducing water demand.

1.1.3 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 ft²/lb (20,000 m²/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.

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.

MATERIALS

3.1.1 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 ft²/lb (20,000 m²/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 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 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.

3.1.2 Steel Slag

Steel slag is the residue of steel production process and

Materials	Specific gravity
Silica fume	2.27

Table No. 3. 1 Physical Properties of silica fume

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.

3.1.1.1 Physical Properties of silica fume.

The properties of silica fume were determined in laboratory. Specific gravity analysis is given below. Ifalkalinity 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. The most important criterion is volume stability, in which free CaO and MgO contents of the slag play an important role. Both oxides can go into reaction with water. Hydration causes volume expansion and affects stability of volume. This is one reason why steel slag aggregate are not suitable for use in Portland cement concrete b. But at the moment, most steel slag being used as unbound aggregate for asphalt concrete pavement in many countries.

Silica fume	ASTM-C-1240	Actual Analysis
SiO_2	85% min	86.7%
LOI	6% max	2.5%
Moisture	3%	0.7%
Pozz Activity Index	105% min	129%
Sp Surface Area	>15 m2/gm	22 m2/gm
Bulk Density	550 to 700	600
+45	10% max	0.7%

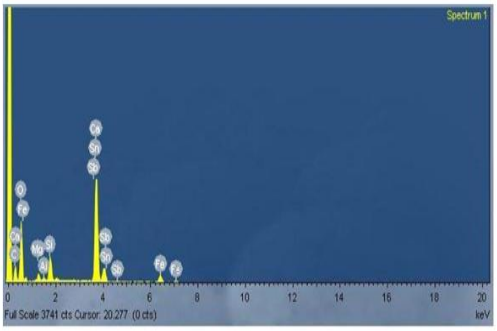

Figure 3.1 XRD Analysis of Steel Slag

3.3.1 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.

Compressive strength of concrete: Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. For cube test two types of specimens either cubes of 15 cm X 15 cm X 15 cm or 10cm X 10 cm x 10 cm depending upon the size of aggregate are used. For most of the works cubical moulds of size 15 cm x 15cm x 15 cm are commonly used.

This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of this specimen should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen.

Figure: 3.2 Compression testing machine

Percentage strength of concrete at various ages:

The strength of concrete increases with age. Table shows the strength of concrete at different ages in comparison with the strength at 28 days after casting.

AGE	STRENGTH PERCENTAGE
1 day	16%
3 day	40%
7 day	65%
14 day	90%
28 day	99%

Table: 3.15 average strength of concrete / time

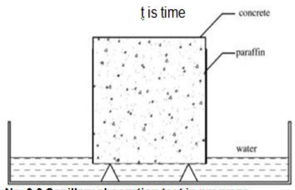

Figure No. 3.3 Capillary absorption test in progress

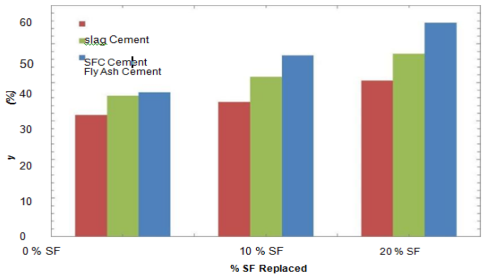

Figure.4.1 Consistency of Mortar.

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

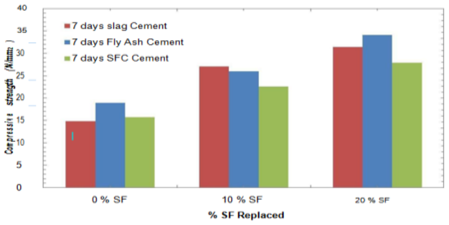

Figure.4.2 Compressive strength for mortar for 7 days

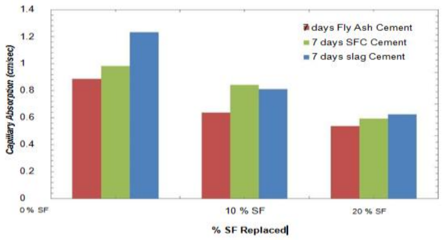

Figure.4.4 Capillary Absorption for mortar for 7 days

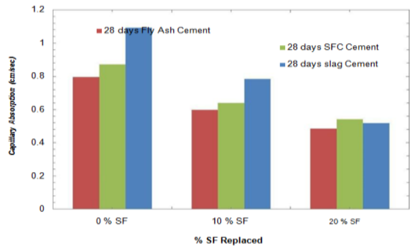

Figure.4.5 Capillary Absorption for mortar for 28 days

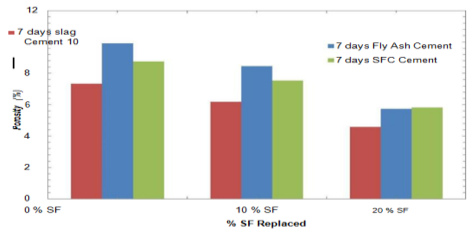

Figure.4.6 Porosity of mortar for 7 days

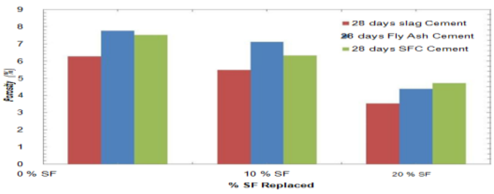

Figure.4.7 Porosity of mortar for 28 days

4.2 Water /Cement Ratio and Slump.

4.1.4 Porosity Test of Mortar. Porosity of different mortar after 7 days and 28 days of curing were tabulated in Table No.4.5.

Table No. 4.3 Porosity Test of Mortar.

Type of cement	% SF replaced	7 days (%)	28 days (%)
Slag cement	0	9.92	7.76
	10	8.47	7.12
	20	5.73	4.38
Fly ash cement	0	7.35	6.27
	10	6.18	5.48
	20	4.58	3.53
Slag and fly ash cement blend (1:1)	0	8.76	7.52
	10	7.54	6.32
	20	5.82	4.71

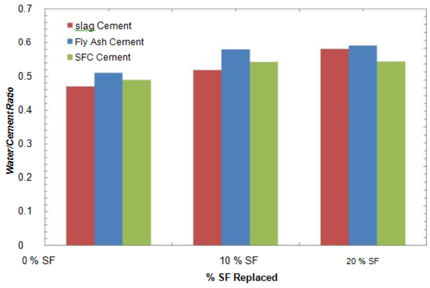

Figure.4.8 Water Cement Ratio for steel slag concrete

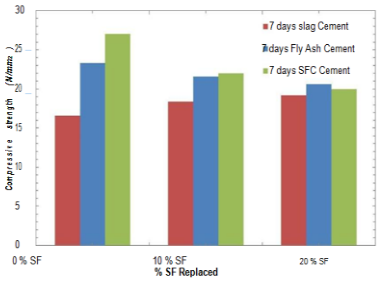

Figure.4.9 Compressive strength of concrete for 7 days

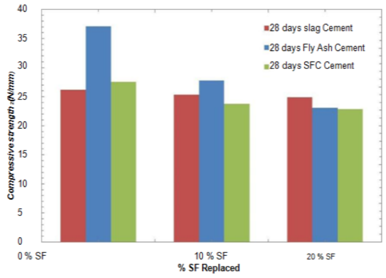

Figure.4.10 Compressive strength of concrete for 28 days

From the above graph, we can conclude that early or 7 days strength, 28 days and 56 days strength decreases with increase in percentage of replacement by silica fume. This is due to the weak bond formation between cement paste and steel slag. There are lots of voids present in concrete, which is shown by SEM (Scanning Electron Microscope) Analysis, which are given below

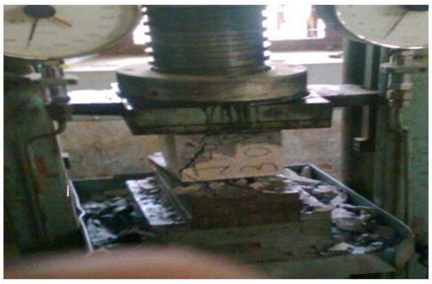

Fig.4.12 Compressive Testing Machine

Figure 4.13 Scanning Electron Microscope

Scanning electron microscopy (SEM) uses a focused electron probe to extract structural and chemical information point-to-point from a region of interest in the sample. The high spatial resolution of a scanning electron microscopy makes it a power full tool to characterize a wide range of specimens at the nanometer to micrometer length scales.

This is the instrument in which we done the SEM analysis of concrete specimen. Since our strength is decrease with increase in silica fume replacement. By this analysis we can know that there is a good bond formation between cement paste and steel slag or not.

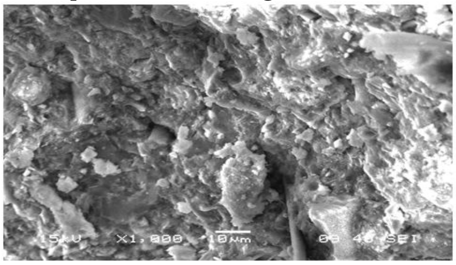

Figure: 4.14 Steel slag concrete with 0% silica fume replacement

This Fig. shows that there is good bond formation between gel matrices and the aggregate. But some voids are visible. We conclude that uniform and dense gel matrices formation is visible in the fig. this is due to addition of silica fume. But figure shows interfacial bond failure between the aggregate and gel matrices. This is because of alkali-aggregate reaction

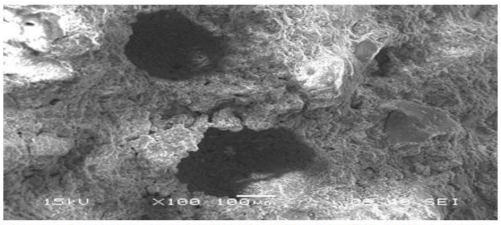

Figure: 4.15 Steel slag concrete with 10% silica fume replacement

The above fig shows voids, which are form due to increased cohesiveness of concrete matrix, because of addition of silica fume. Due to the presence of voids and failure of bond between gel matrices and steel slag. So strength of concrete is less.

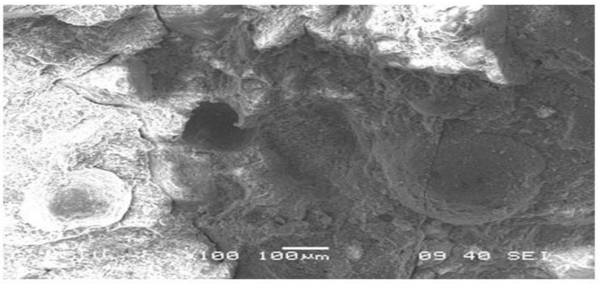

Figure 4.16 Steel slag concrete with 20% silica fume replacement.

This fig shows voids, which are form due to increased cohesiveness of concrete matrix, because of addition of silica fume. Due to the presence of voids and failure of bond between gel matrices and steel slag. So strength of concrete is less. Here binder mix gel matrices are more uniform and more dense. It contains more voids .It shows that interfacial bond failure is prominently visible.

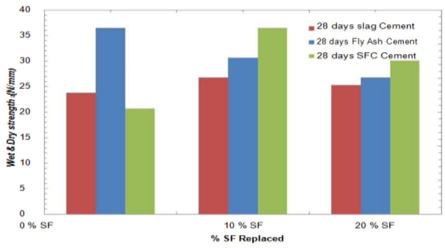

Figure.4.17 Wet and Dry test strength of concrete for 28 days

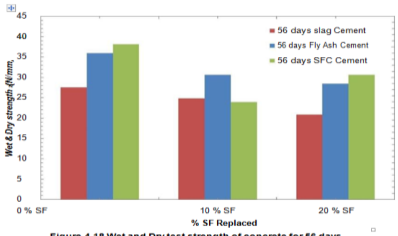

Figure.4.18 Wet and Dry test strength of concrete for 56 days

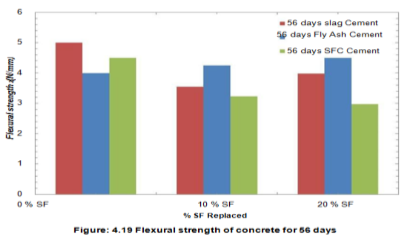

Figure: 4.19 Flexural strength of concrete for 56 days

Figure: 4.20 Flexural Strength of concrete.

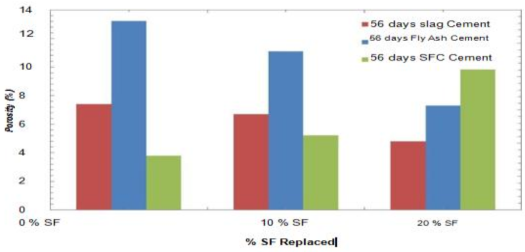

Figure: 4.21 Porosity of concrete for 56 days

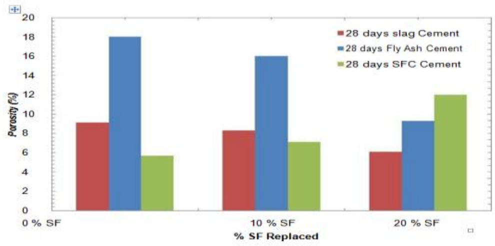

Figure: 4.22 Porosity of concrete for 28 days.

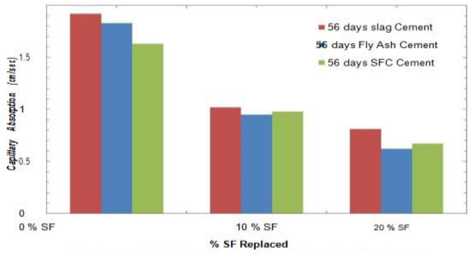

Figure.4.23 Capillary Absorption of concrete for 56 days

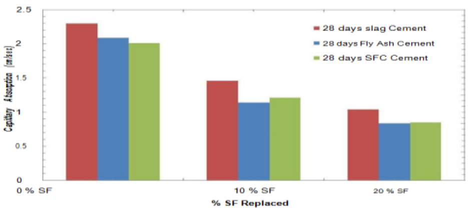

Figure.4.24 Capillary Absorption of concrete for 28 days

CONCLUSION

Inclusion of silica fume improves the strength of different types of binder mix by making them more denser. .Addition of silica fume improves the early strength gain of fly ash cement whereas it increases the later age strength of slag cement. The equal blend of slag and fly ash cements improves overall strength development at any stage. 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. The capillary absorption and porosity decreases with increase dose up to 20% replacement of silica fume for mortar. Addition of silica fume to the concrete containing steel slag as coarse aggregate reduces the strength of concrete at any age. 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. 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.

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