STRENGTH PROPERTIES OF STEEL SLAG CONCRETE PREPARED WITH PARTIAL REPLACEMENT OF SILICA FUME

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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 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. 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. 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. The main conclusions drawn are inclusion of silica fume increases the water requirement of binder mixes to make paste of normal consistency. Water requirement increase with increasing dose of silica fume. Water requirement is more with fly ash cement than slag cement. The same trend is obtained for water binder ratio while making concrete to achieve a target slump of 50-70mm. The mortar strength (1:3) increases with increasing percentage of silica fume. Comparatively higher early strength gain (7-days) is obtained with fly ash cement while later age strength (28 days) gain is obtained with slag cement. Their blended mix shows comparatively moderate strength gain at both early and later ages. Mixing of silica fume had made concrete sticky ie more plastic specifically with fly ash cement. The porosity and capillary absorption tests conducted on mortar mixes show decrease in capillary absorption and porosity with increase in silica fume percentage with both types of cements. The decrease is more with fly ash cement than slag cement. But the reverse pattern is obtained for concrete i.e. the results show decrease in 7days,28 days and 56 days compressive strength of concrete due to inclusion of silica fume in the matrix. The increasing dose of silica fume show further decrease in strength at every stage. Almost same trend is obtained for flexural strength also. The specimens without silica fume had fine cracks which are more visible in concrete made with slag cement than fly ash cement.

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.

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.

1.2.1. 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: It is pozzalanic SC material.

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally capturedfrom 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.

"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.

The replacement of Portland cement with fly ash is considered to reduce the greenhouse gas

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.

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^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 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.

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.

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. 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 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.

Physical Properties of silica fume.

The properties of silica fume were determined in laboratory. Specific gravity analysis is given below.

Table No. 3. 1 Physical Properties of Silica Fume

Materials	Specific gravity
Silica fume	2.27

Physical properties of Steel slag.

The different physical properties of steel slag are given below in Table No 3.4.

Table No.3.4 Physical properties of Steel slag

Material	Specific gravity	Water absorption in %
Steel slag	3.35	1.1%

XRD Analysis of Steel slag.

From XRD Analysis of steel slag we can find what type Alkalis present. These are tabulated in Table No 3.5.

Table No.3.5XRD Analysis of Steel slag

Chemical Compound	Visible	Ref-Code	Score
Na_2O	Yes	03-1074	10
K_2O	Yes	77-2176	10

XRD Analysis of Fly ash cement.

By XRD (X ray diffraction) Analysis we can know what type of chemical composition present in cement. This analysis were done in metallurgical dept. of NIT Srinagar. The chemical compound found in this analysis was listed below:

Table No 3.7XRD Analysis of Fly ash cement.

Chemical Compound	Visible	Reference Code	Score
Ca54MgAl2Si16O90	Yes	13-0272	59
CaAl2O4	Yes	34-0440	17
$CaCO_3$	Yes	72-1937	20
(MgO) 0.593(FeO).41	Yes	77-2367	14
$Mg(CO_3)$	Yes	80-0042	16

2 Chemical Analysis of Fly ash cement.

The chemical analysis of cement is done to know the amount of chemical composition present in cement. Its procedure is accordingly Vogel‟s Inorganic Quantitative Analysis. This experiment was done in our institute chemistry laboratory. Here our aim is to determined actual chemical composition of the specimen provided by the company. The chemical analysis of fly ash cement is listed in Table 3.8

Table No 3.8Chemical Analysis of Fly ash cement.

Chemical Compound	Fly Ash Cement in (%)
Sio_2	6
Cao	49
MgO	0.66
Fe_2O_3	15
Al_2O_3	16

III. METHODOLOGY

TEST PROCEDURE:

The Experimental programme was carried out in two stages

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

Stage2: Experimental works were conducted on steel slag concrete mixes by using different binder mix modified with different percentages of silica fume.

Stage 1: This experimental investigation was carried out for three different combinations of slag cement and fly ash cement. In each combination three different proportion of silica fume had been added along with the controlled mix without silica fume.

Binders being used were different combinations of slag cement, fly ash cement in the proportions 1:0, 0:1 and 1:1 hence total three combinations. Further in each type of combination of binder mix 0%,10 % and 20 % percentage of silica fume had been added. Hence total 12 sets of mortar of 1:3 proportion were prepared by mixing one part of binder mix and three parts of naturally available sand.

Stage2: Here concrete is prepared with three different types of binder mix with silica fume.

A: DETERMINATION OF STRENGTH OF CONCRETE OF 1:1.5:3 MIX PROPORTION BY
USING FLY ASH CEMENT + SILICA FUME AS BINDER MIX, SAND AS FINE AGGREGATE AND STEEL SLAG AS COARSE AGGREGATE.

In this phase concrete of mix proportion 1 : 1.5 : 3 will be prepared by using fly ash cement + silica fume as binder mix with different proportion of silica fume, sand as fine aggregate and steel slag as coarse aggregate. The different proportion of silica fume in the concrete mix will vary from 0%, 10%, and 20%. The concrete mixes will be tested for following strengths.

- Compressive strength after 7 days,28 days, 56 days
- Flexural strength after 28 days, 56 days
- Porosity test after 28 days and 56 days
- Capillary absorption test after 28 days and 56 days
- Wet - dry test after 26 days and 56 days Compressive strength by Rebound hammer method.

B: DETERMINATION OF STRENGTH OF CONCRETE OF 1:1.5:3 MIX PROPORTION BY USING SLAG CEMENT+SILICA FUME AS BINDER,SAND AS FINE AGGREGATE AND STEEL SLAG AS COARSE AGGREGATE

In this phase concrete of mix proportion 1 : 1.5 : 3 will be prepared by using slag cement + silica fume as binder mix with different proportion of silica fume ,sand as fine aggregate and steel slag as coarse aggregate. The proportion of silica fume in the concrete mix will vary from 0% , 10% and 20 % of the blend. The concrete mixes will be tested for following strengths.

- Compressive strength after 7 days,28 days, 56 days
- Flexural strength after 28 days, 56 days
- Compressive strength by Rebound hammer method.
- Porosity test after 28 days and 56 days
- Capillary absorption test after 28 days and 56 days
- Wet - dry test after 28 days and 56 days.

C: DETERMINATION OF STRENGTH OF CONCRETE OF 1:1.5:3 MIX PROPORTION BY USING

FLY ASH CEMENT+SLAG CEMENT + SILICA FUME AS BINDER MIX, SAND AS FINE AGGREGATE AND STEEL SLAG AS COARSE AGGREGATE.

In this phase concrete of mix proportion 1 : 1.5 : 3 will be prepared by using fly ash cement + slag cement + silica fume as binder mix with different proportion of silica fume, sand as fine aggregate and steel slag as coarse aggregate. The different proportion of silica fume in the concrete mix will vary from 0%,10%, and 20%. The concrete mixes will be tested for following strengths.

- Compressive strength after 7 days,28 days, 56 days
- Flexural strength after 28 days, 56 days
- Porosity test after 28 days and 56 days
- Capillary absorption test after 28 days and 56 days
- Wet - dry test after 26 days and 56 days
- Compressive strength by Rebound hammer method.

IV. LABORATORY TEST CONDUCTED:

3.3.1 Compressive StrengthTest
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.

3.3.2 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 [8].

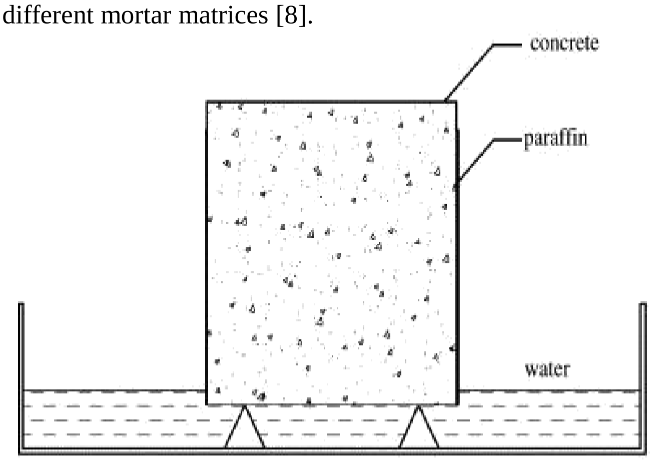

Figure No. 3.2 Capillary absorption test in progress

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.

3.3.5 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.

3.3.6 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.

Flexural strength = $PL/BD^{2.}$

Where P is load

L= Length of Prism.

B = Breadth of Prism.

D = Breadth of Prism

V. 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.

4.1.1 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.

VI. CONCLUSION

From the present study the following conclusions are drawn:

- 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. By nature cement paste is alkaline. The presence of alkalis Na2O, K2O 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.
- 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.
- 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.
- The steel slag should be properly treated by stock piling it in open for at least one year to allow the free CaO & MgO to hydrate and thereby to reduce the expansion in later age.
- 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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