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COMPREHENSIVE STUDY ON 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 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. 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 matrix product with enhance overall quality. 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 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.

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 50-70 mm. 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.

Keywords: Cementitious Material, Steel Slag, Slag Cement, Silica Fume, 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 cementations materials SCMs.

1.2 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 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.

1.2.1. 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.

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.

1.2.2. 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 (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Fly ash is classified as Class F and Class C types.

1.2.3. 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 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.

1.3. 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.

II. MATERIALS & PROPERTIES

2.1.1. Physical Properties of silica fume

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

Table no: 2.1

Materials	Specific gravity
Silica fume	2.27

2.1.2 Chemical Analysis of silica fume

The chemical analysis of silica fume is given below in Table No 3.2. It is also compared with ASTM

2.1.3 XRD Analysis of Slag cement.

By XRD (x-ray diffraction) Analysis we can know what type of chemical composition present in cement .This analysis were done in metallurgical department of NIT Rourkela. The chemical compound found in this analysis was listed below in Table No 3.10

Table no: 2.2

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%

Table no: 2.3

Chemical Compound	Visible	Reference Code	Score
Ca54MgAl2Si16O19	Yes	13-0272	68
MgA12O4	Yes	84-0377	19
SiO2	Yes	43-0596	36

III. RESULTS AND DISCUSSIONS

3.1 Experimental Study on Mortar

3.1.1 Normal Consistency for Mortar:

Normal consistency of different binder tabulated below mixes were in Table No. 5.1

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Table No.3.1

Mix	Description	Cement (grams)	Silica fume (grams)	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) with 10% SF	135 each	30	41.5
SFC20	SC:FC (1:1) with 20% SF	120 each	60	47.5

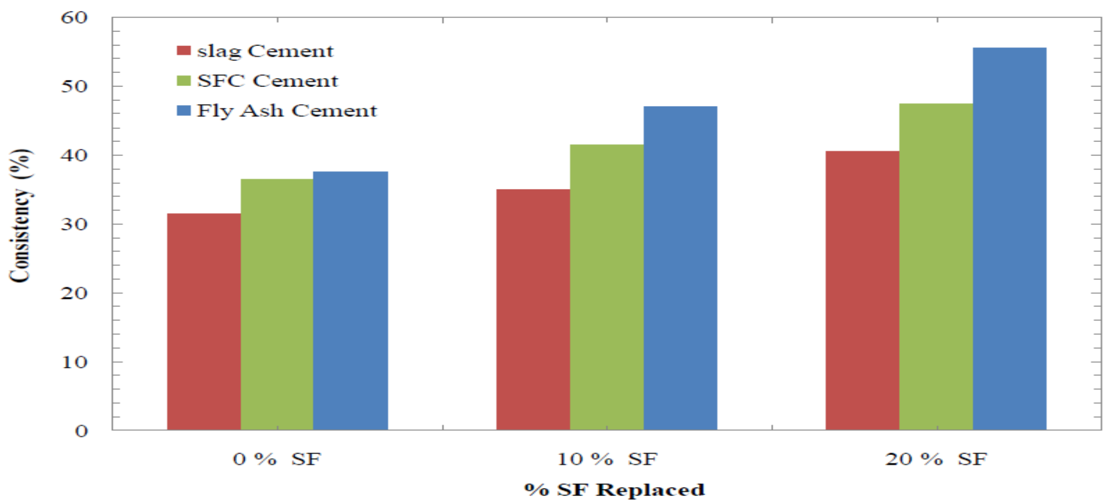

Figure.3.1 Consistency of Mortar

3.1.2 Compressive Strength of Mortar

Compressive Strength of different mortars after 7 days and 28 days are tabulated in table 5.2.

Table No. 3.2

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 cement blend (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. All binder mixes shows that up to 20% replacement of cement with silica fume the Compressive strength increases with increasing dose of silica Fume. Early strength in all binder mixes increases with 5% replacement by silica fume.

The same is observed in case of 10% replacement. But amongst three types of binders, gain in fly ash cement is more. The early days strength increases remarkably by replacing any type of cement by silica fume up to 15%. This increase is more remarkable in fly ash cement.

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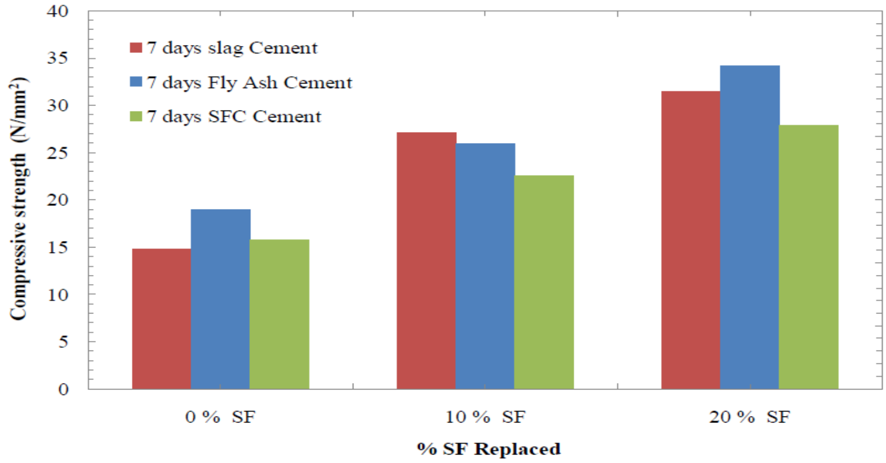

Figure.3.2 Compressive strength for mortar for 7 days

IV. EXPERIMENTAL STUDY ON CONCRETE CUBE

Here we prepared concrete with ratio 1:1.5:3 from different types of cement + silica fume replacement as binder mix sand as fine aggregate and steel slag as coarse aggregate. Then its physical properties like capillary absorption, water/cement ratio, compressive strength, porosity, flexural strength, and wet-dry test was predicted. These test results both in tabular form and graphical presentation are given below.

4.1.1 Water /Cement Ratio and Slump

The water cement ratio and slump of steel slag concrete with different binder mix with silica fume replacement is given below.

Table No. 4.1

Type of cement	% of SF Replaced	W/C Ratio	Slump in (mm)
Fly ash cement	0	0.51	52
	10	0.58	52
	20	0.591	58
Slag cement	0	0.47	63
	10	0.518	50
	20	0.581	55
Slag and fly ash cement blend (1:1)	0	0.489	60
	10	0.543	53
	20	0.544	52

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From the above table we concluded that W/C ratio increases with increase in silica fume replacement. Because silica fume consumes more water.

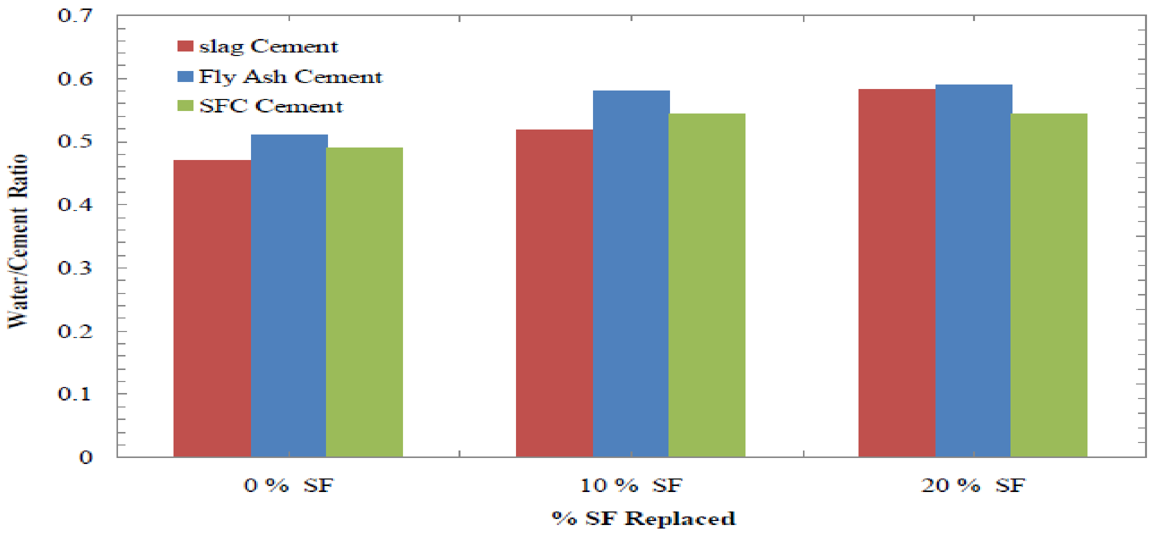

Figure.4.1 Water Cement Ratio for steel slag concrete

V. COMPRESSIVE STRENGTH BY REBOUND HAMMER METHOD

Compressive Strength of different concrete cubes after 7 days, 28 days and 56 days were tabulated in Table No. 4.1.

Table No .5.1

Type of cement	% of SF Replaced	7 days	28 days	56 days
Fly ash cement	0	24.54	29.55	36.4
	10	21	25,7	25.94
	20	21.4	22.9	29.2
Slag cement	0	18.2	22.3	26.35
	10	18.6	22.3	27.4
	20	18.3	21.4	27.5
Slag and fly ash cement blend (1:1)	0	20.9	25.4	31.45
	10	21.8	23	27.44
	20	21.4	20.9	28.23

5.1 Compressive Strength by Compression Testing Machine

Table No 5.2

Type of cement	% of SF replaced	7days	28days	56 days
Fly ash cement	0	10.88	31.33	42.1
	10	10	23.33	28.44
	20	9.55	19.55	25
Slag cement	0	19.33	28.66	30.44
	10	21.33	27.55	27.55
Slag and fly ash cement blend (1:1)	0	26.88	43.11	44.11
	10	21.77	37.11	39.77

From the above table, 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

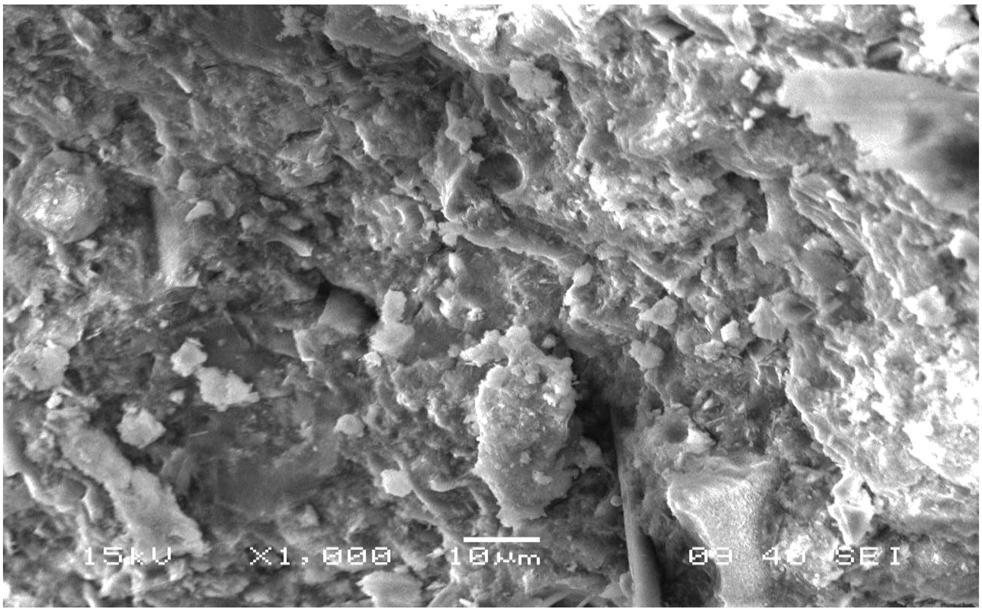

Figure5.1 Steel slag concrete with 0% silica fume replacement.

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.

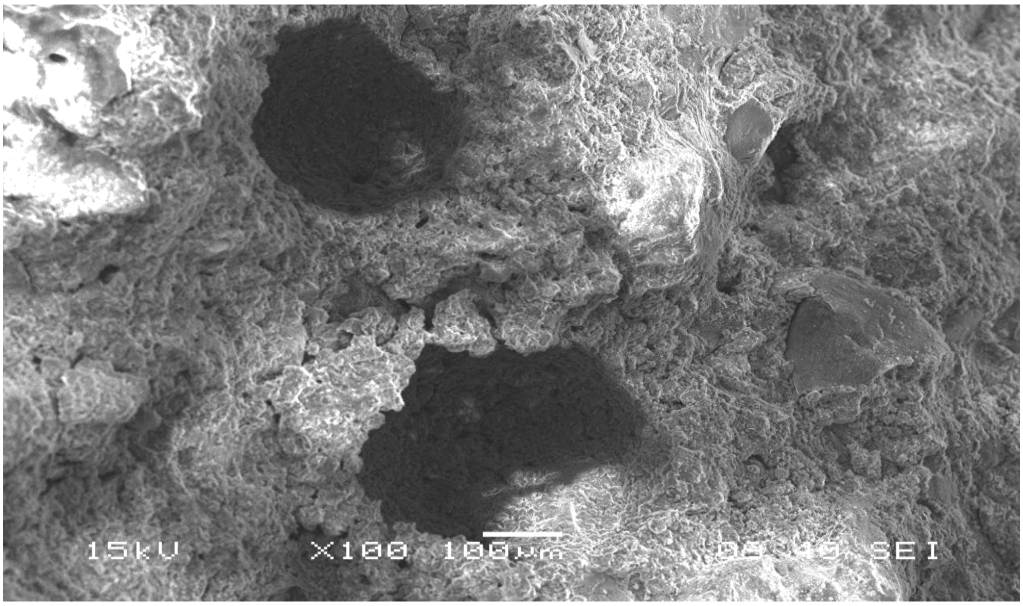

Figure5.2 Steel slag concrete with 10% silica fume replacement.

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.

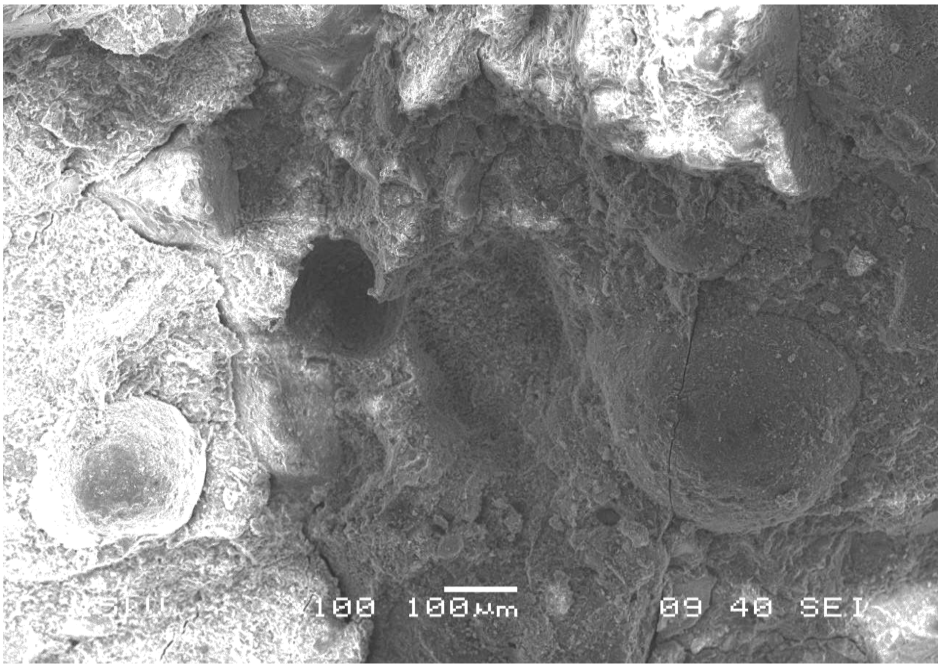

Figure 5.3 Steel slag concrete with 20% silica fume replacement.

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.

5.2.4 Wet and Dry Test

Table No.5.8 shows 28 days and 56 days wet and dry test of concrete cube.

Table No. 5.2

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

VI. 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 dancer 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.
9. 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.

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 CaO & MgO to hydrate and thereby to reduce the expansion in later age.

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