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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. Most concrete produced today includes one or both of these materials.. 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.

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. 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.

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

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with cement or lime react with calcium hydroxide to form products possessing cementitious prosperities.

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.

Fly ash: It is pozzalanic SC material.

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.

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 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.Shehata1 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 Popovics2 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 Bijen3 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. Poon4 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 Yazicioglu5 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 Nantung6 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. Basheer7 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 Delvasto8, 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 9 carried out

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Research work in Use of low CaO unprocessed steel slag in concrete as fine aggregate.Their conclusion is That Regarding the compressive and tensile strengths of concrete steel slag is more advantageous for concretes of lower strengths.

MATERIALS

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.

Chemical Analysis of silica fume:

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%

Steel Slag: 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.

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.

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

From above table we can conclude that some amount of Alkalis present in steel slag.

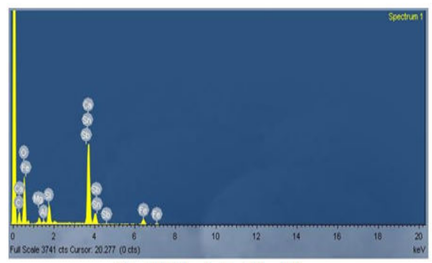

Fig: XRD Analysis of Steel Slag

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 Rourkela. The chemical compound found in this analysis was listed below:

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

Methedology:

Stage 1: This experimental investigation was carried out for three different combinations of slag cement and fly ash cement. In each

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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.

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.

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LABORATORY TEST CONDUCTED:

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.

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].

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

Wet-dry Test:

Concrete cube were dipped inside a sea water for 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.

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 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.

RESULTS AND DISCUSSIONS:

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.

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

From the above table 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.

Compressive Strength of Mortar.

Compressive Strength of different mortars after 7 days and 28 days are tabulated in table 4.2.

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

Capillary Absorption

Coefficients of capillary absorption of different mortars after 7 days and 28 days of curing were tabulated in Table.

Types of cement	% silica fume replace	28 days(k*10^{-3} cm/s)	56 days(k*10^{-3} cm/s)
Slag cement	0	1.232	1.093
	10	0.811	0.783
	20	0.624	0.518
Fly ash cement	0	0.886	0.795
	10	0.637	0.598
	20	0.538	0.485
Slag and fly ash cement blend (1:1)	0	0.982	0.871
	10	0.842	0.638
	20	0.593	0.541

Porosity Test of Mortar.

Porosity of different mortar after 7 days and 28 days of curing were tabulated in Table.

Type of cement	% of 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

EXPERIMENTAL STUDY ON CONCRETE CUBE.

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.

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

Compressive Strength by Rebound Hammer Method:

Compressive Strength of different concrete cubes after 7 days, 28 days and 56 days were tabulated in Table.

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

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Compressive Strength by Compression Testing Machine:

Compressive Strength of different mortars after 7days ,28days and 56 days were tabulated in Table .

Type of cement	% of SF replaced	7days	28days	56 days
Fly ash cement	0	23.33	37.1	45.1
	10	21.61	27.77	30.44
	20	20.66	23.1	28
Slag cement	0	16.6	26.21	28.44
	10	18.44	25.33	25.55
	20	19.2	24.89	21.1
Slag and fly ash cement blend (1:1)	0	27.05	27.55	33.11
	10	22	23.77	29.77
	20	20	22.88	28.88

Wet and Dry Test:

Table shows 28 days and 56 days wet and dry test of concrete cube.

Type of cement	% of SF replaced	28 days (N/mm2)	56 days (N/mm2)
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

Flexural Test:

The flexural strength of steel slag concrete at 28 days and 56 days is given below.

Type of cement	% of SF replaced	28 days(N/mm2)	56 days (N/mm2)
Fly ash cement (FC)	0	6.875	4
	10	7	4.25
	20	6.875	4.5
Slag cement (SC)	0	7	5
	10	6.5	3.55
	20	6.125	3.975
Slag and fly ash cement blend (1:1) (SFC)	0	7	4.5
	10	6.725	3.23
	20	4.75	2.975

From above table we see that flexural strength of steel slag concrete is decreased from 28 days to 56 days.

Capillary Absorption Test:

The capillary coefficients for different types of steel slag is given below.

Type of cement	% of SF replaced	28 days (k*10-3 cm/s)	56 days (k*10-3 cm/s)
Fly ash cement	0	2.09	1.83
	10	1.142.30	0.95
	20	0.838	0.621
Slag cement	0	2.30	1.92
	10	1.46	1.02
	20	1.04	0.81
Slag and fly ash cement blend (1:1)	0	2.01	1.63
	10	1.21	0.98
	20	0.85	0.671

CONCLUSION:

From the present study the following conclusions are drawn:

1. Inclusion of silica fume improves the strength of different types of binder mix by making them more denser.
2. Addition of silica fume improves the early strength gain of fly ash cement whereas it increases the later age strength of slag cement.
3. The equal blend of slag and fly ash cements improves overall strength development at any stage.
4. Addition of silica fume to any binder mix reduces capillary absorption and porosity because fine particles of silica fume reacts with lime present in cement and form hydrates dancer and crystalline in composition.
5. The capillary absorption and porosity decreases with increase dose up to 20% replacement of silica 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 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.

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 CaO & 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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