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AN EXPERIMENTAL STUDY OF AN EFFECT OF SILICA FUME ON FRESH AND HARDENED PROPERTIES OF 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 by-products 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 initialisation has resulted in tons and tons of by-product 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 by-products 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 by-product 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 by-product 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. 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.

Keywords: Supplementary Cementitious Materials, Steel Slag, Silica fume, Fly Ash, Slag Cement

I. INTRODUCTION

More recently, strict environmental – pollution controls and regulations have produced an increase in the industrial wastes and sub graded by-products 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.

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 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.
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.
The Steel slag, a by-product 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.

II. LITERATURE REVIEW

The relevant literature on present study was thoroughly reviewed and presented here.
Many works have been done to explore the benefits of using pozzolanic materials in making and enhancing the properties of concrete.
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.
HishamQasrawi , Faisal Shalabi, Ibrahim Asi 9 carried out 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.
O. Boukendakdji, S. Kenai, E.H. Kadri, F. Rouis 10 carried out Research work in Effect of slag on the rheology of fresh self- compacted concrete. Their conclusion is that slag can produce good self-compacting concrete.
Shaopeng Wu, YongjieXue, Qunshan Ye, Yongchun Chen11 carried out Research work in Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. Their conclusion is that The test roads shows excellent performances after 2-years' service, with abrasion and friction coefficient of 55BPN and surface texture depth of 0.8 mm.

III. OBJECTIVE OF STUDY

The primary objectives of the present study are

- To study the effect of different binder mixes (Slag cement and Flyash cement) on mortar mixes modified with different percentages of silica fume.
- To study the effect of different binder mixes (Slag cement and Flyash cement) on steel slag concrete modified with different percentages of silica fume.
- To determine the effect on strength properties of different concrete mixes when steel slag is used as coarse aggregate.
- To determine the compressive strength of different mixes after 7, 28 and 56 days.
- To study the effect of different percentages of silica fume (0%, 10%, and 20%) on the different concrete mixes

IV. MATERIALS AND METHODS

Silica Fume: Silica fume is a by-product 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: 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.

Fly ash cement: Fly ash, which is largely made up of silicon dioxide and calcium oxide, can be used as a substitute for Portland cement, or as a supplement to it. The materials which make up fly ash are pozzolanic, meaning that they can be used to bind cement materials together. Pozzolanic materials, including fly ash cement, add durability and strength to concrete.

Slag Cement: Slag cement has been used in concrete projects in the United States for over a century. Earlier usage of slag cement in Europe and elsewhere demonstrates that long-term concrete performance is enhanced in many ways. Based on these early experiences, modern designers have found that these improved durability characteristics help further reduce life-cycle costs, lower maintenance costs and makes concrete more sustainable. For more information on how slag cement is manufactured and it enhances the durability and sustainability of concrete.

Table 1 Chemical Analysis of Slag cement

Chemical Compound	Slag Cement in (%)
Sio_2	12
Cao	43
MgO	0.37
Fe_2O_3	12
Al_2O_3	26

Sand: Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The most common constituent of sand, in inland continental settings and non-tropical coastal settings, is silica(silicon dioxide, or SiO2), usually in the form of quartz which, because of its chemical inertness and considerable hardness, is the most common mineral resistant to weathering. It is used as fine aggregate in concrete.

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.

- 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

- 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.

- 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.

V. RESULTS AND DISCUSSIONS

Table 1 Normal Consistency for Mortar:

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

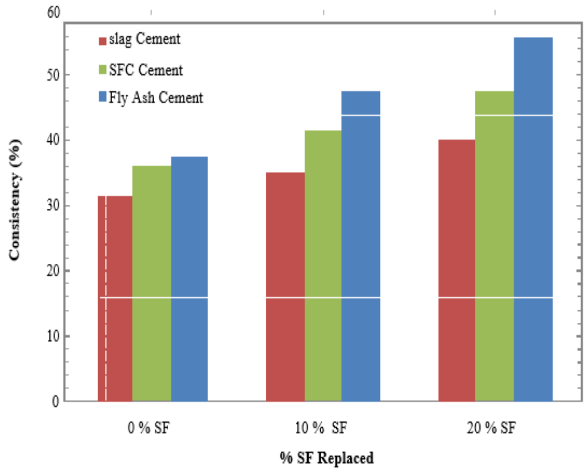


Figure.1 Consistency of Mortar.

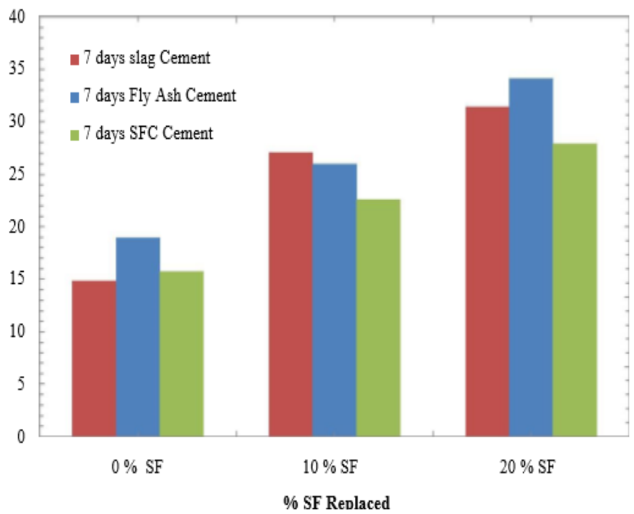


Figure.2 Compressive strength for mortar for 7 days

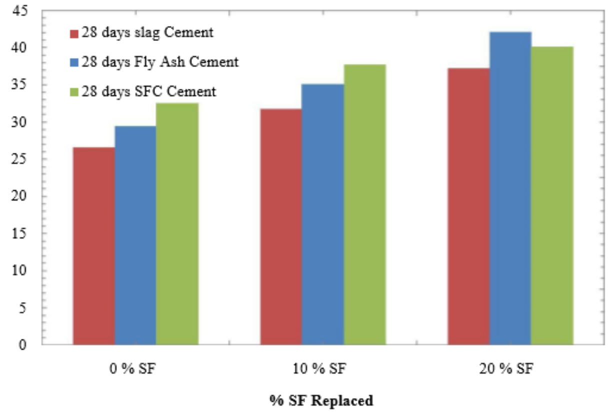


Figure. 3 Compressive strength for mortar for 28 day

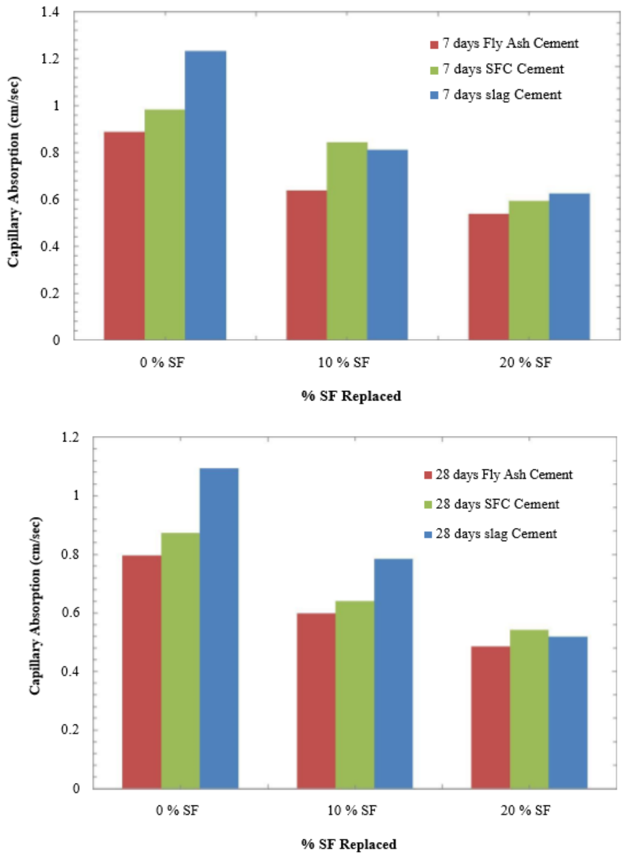


Figure.4 Capillary Absorption for mortar for 7 and 28 days

EXPERIMENTAL STUDY ON CONCRETE CUBE:

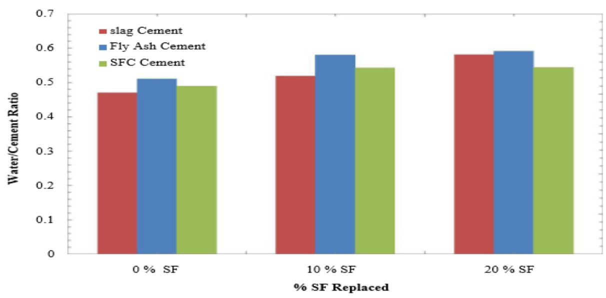


Figure.5 Water Cement Ratio for steel slag concrete

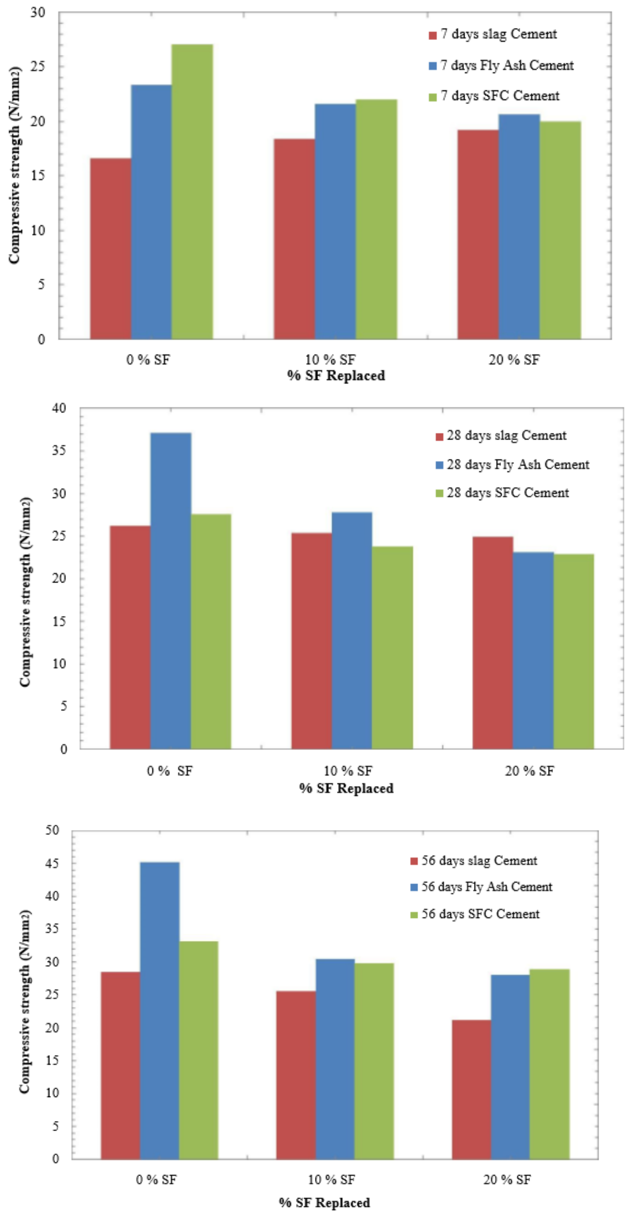
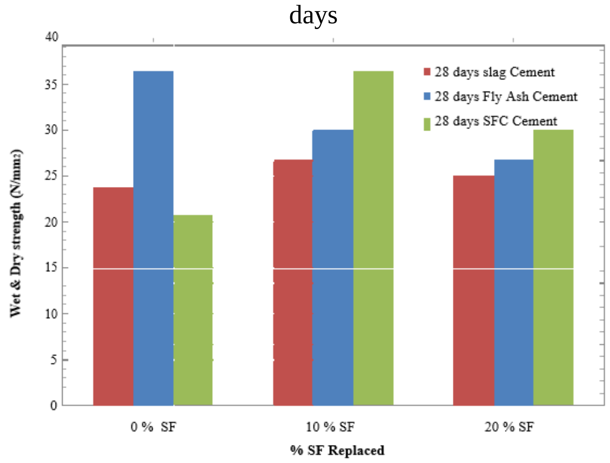


Figure.6 Compressive strength of concrete for 7, 28, and 56 days



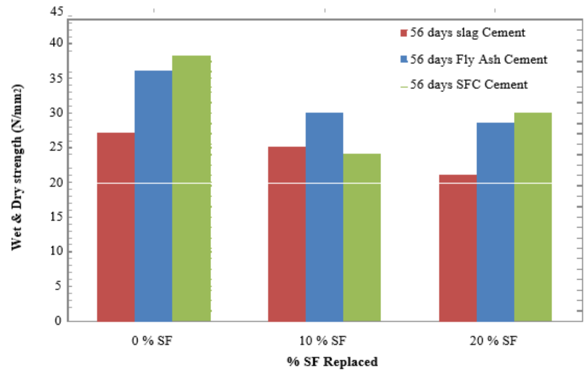


Figure.7 Wet and Dry test strength of concrete for 28, 56 days

VI. CONCLUSIONS

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 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.
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.

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