EFFECT OF SILICA FUME ON STEEL SLAG CONCRETE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
Structural Engineering

By

Jagadish Mallick

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008
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Jagadish Mallick

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, ***"EFFECT OF SILICA FUME ON STEEL SLAG CONCRETE"*** *submitted by* ***Jagadish Mallick*** *in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in "****Structural Engineering****" at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this Project review report has not been submitted to any other university/ institute for award of any Degree or Diploma.*

Date: *20th MAY 2010*

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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.

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.

CHAPTER 1

1.1 INTRODUCTION:

Concrete is a mixture of cement, sand, coarse aggregate and water. Its success lies in its versatility as can be designed to withstand harshest environments while taking on the most inspirational forms. Engineers and scientists are further trying to increase its limits with the help of innovative chemical admixtures and various supplementary cementitious materials SCMs.

Early SCMs consisted of natural, readily available materials like volcanic ash or diatomaceous earth. The engineering marvels like Roman aqueducts, the Coliseum are examples of this technique used by Greeks and Romans. Nowadays, most concrete mixture contains SCMs which are mainly byproducts or waste materials from other industrial processes.

1.2 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 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.

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 pozzalanic 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.

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 CO_2 as compared to zero CO_2 being produced using existing fly ash. New fly ash production, i.e., the burning of coal, produces approximately twenty to thirty tons of CO_2 per ton of fly ash. Since the worldwide production of Portland cement is expected to reach nearly 2 billion tons by 2010, replacement of any large portion of this cement by fly ash could significantly reduce carbon emissions associated with construction.

It has been used successfully to replace Portland cement up to 30% by mass, without adversely affecting the strength and durability of concrete. Several laboratory and field investigations involving concrete containing fly ash had reported to exhibit excellent mechanical and durability properties. However, the pozzolanic reaction of fly ash being a slow process, its contribution towards the strength development occures only at later ages . Due to the spherical shape of fly ash particles, it can also increase workability of cement while reducing water demand

1.2.3. 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.

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.

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. 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.

CHAPTER 2

2. 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.Shehata[1] 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 Popovics[2] 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 Bijen[3] 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. Poon[4] 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 Yazicioglu[5] 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 Nantung[6] 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. Basheer[7] 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 Delvasto[8], 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 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, Yongjie Xue, Qunshan Ye, Yongchun Chen[11] 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.

Tahir Gonen,Salih Yazicioglu[12] carried out research work in the influence of mineral admixtures on the short and long term performance of concrete, hence concluded that silica fume contributed to both short and long term properties of concrete, where as fly ash shows its beneficial effect in a relatively longer time. As far as the compressive strength is concerened, adding of both silica fume and fly ash slightly increased compressive strength, but contributed more to the improvement of transport properties of concrete. M. Maslehuddin, Alfarabi M. Sharif, M. Shameem, M. Ibrahim and M.S Barry[12] carried out experimental work on comparison of properties of steel slag and crushed limestone aggregate concretes, finally concluded that durability characteristics of steel slag cement concrete were better than those of crushed limestones aggregate concrete. Some of physical properties were better than of crushed lime stones concrete. J. G. Cabrera and P. A. Claisse[13] carried out experimental work on Oxygen and water vapour transport in cement pastes, hence concluded that the flow of oxygen is described by the Darcy equation, but the flow of water vapour is not. The different mechanisms of transmission cause the transmission rates for oxygen to be spread over a far greater range than those for water vapour with some of the SF samples almost impermeable to oxygen. Houssam A. Toutanji and Tahar El-Korchi[14] carried out experimental work on Oxygen and water vapour transport in cement pastes, hence concluded that the increase in compressive strength of mortar containing silica fume as a partial replacement for cement, greatly contributes to strengthening the bond between the cement paste and aggregate. It was also demonstrated that super plasticizer in combination with silica fume plays a more effective role in mortar mixes than in paste mixes. This can be attributed to a more efficient utilization of super plasticizer in the mortar mixes due to the better dispersion of the silica fume. Jigar p. patel[15] carried out experimental work on broader use of steel slag aggregate in concrete, hence concluded that durability of steel slag aggregates concrete under freeze-thaw environment was the main goal in this research, as there was a belief that the steel slag aggregates have expansive characteristics and would cause cracking in concrete. The results proved that if up to 50 to 75 % of steel slag aggregates are incorporated in the traditional concrete, there would not be much change in the durability of concrete. Micheline Moranville-Regourd[16] carried out experimental work on the Cements Made from Blastfurnace Slag, hence concluded that Slag has found a considerable use in the road and building industries, in the production of cementing materials, as an aggregate in concrete and tarmacdam, in the production of light weight aggregate, and in the manufacture of slag wool for thermal insulation. M. J. Shannag[17] carried out experimental work on the high strength concrete containing natural pozzolana and silica fume, hence concluded that use of natural pozzolana in combination with silica fume in the production of high strength concrete, and for providing technical and economical advantages in specific local uses in the concrete industry. Houssam A. Toutanji and Ziad Bayasi[18] carried out experimental work on the Effect of curing procedures on properties of silica fume concrete hence concluded that Steam curing was found to enhance the properties of silica fume whereas air curing exhibited adverse effects as compared to moist curing. Enhancement in the mechanical properties of silica fume concrete caused by steam curing was manifested by strength increase and permeability and permeable void volume decrease. A. M. Boddy, R. D. Hooton and M. D. A. Thomas[19] carried out experimental work on the effect of product form of silica fume on its ability to control alkali-silica reaction, hence concluded that slurried Silica fumes are significantly better at controlling the expansion of a reactive siliceous limestone aggregate than are densified or pelletized silica fume. Ha-Won Song, Seung-Woo Pack, Sang-Hyeok Nam, Jong-Chul Jang and Velu Saraswathy[20] carried out experimental work on the Estimation of the permeability of silica fume cement concrete, hence concluded that higher permeability reductions with silica fume are due to pore size refinement and matrix densification, reduction in content of $Ca(OH)_2$ and cement paste-aggregate interfacial refinement. Finally, optimum silica fume replacement ratios that reduce the permeability of concrete reasonably are proposed for durable concrete.

MATERIALS AND METHODOLOGY

3.1. MATERIALS

3.1.1 Silica Fume

Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 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.

3.1.1.1 Physical Properties of silica fume.

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

Table No. 3. 1

Materials	Specific gravity
Silica fume	2.27

3.1.1.2 Chemical Analysis of silica fume

The chemical analysis of silica fume is given below in TableNo 3.2. It is also compared wit ASTM

Table No. 3.2

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%

3.1.2 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.

In order to use these slags in cement, its hydraulic properties should be known. Chemical composition is one of the important parameters determining the hydraulic properties of the slags. In general, it is assumed that the higher the alkalinity, the higher the hydraulic properties. If alkalinity is> 1.8, it should be considered as cementitious material.

Investigations were carried out also on the usability of steel slag as construction material under laboratory and practical conditions. For this application, the required properties are high compression strength, wear strength and resistance to climatic conditions. The most important criterion is volume stability, in which free CaO and MgO contents of the slag play an important role. Both oxides can go into reaction with water. Hydration causes volume expansion and affects stability of volume. This is one reason why steel slag aggregate are not suitable for use in Portland cement concrete b. But at the moment, most steel slag being used as unbound aggregate for ashphalt concrete pavement in many countries.

3.1.2.1Sieve Analysis of Steel slag

Sieve Analysis of steel slag in done to know the grade of the aggregate. This is given in Table 3.3

Table No. 3.3

Sieve size	Wt Retain	Cum Wt Ret^{n}	% Cu wt Ret^{n}	% Passing
2o mm	270 gm	0.270 kg	5.4	94.6
12.5 mm	3522 gm	3.792 kg	75.84	21.16
10 mm	790 gm	4.582 kg	91.64	8.36
4.75 mm	334 gm	4.916 kg	98.62	1.68
Total	5000 gm			

No gradation was found from the above test.

3.1.2.2 Physical properties of Steel slag.

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

Table No.3.4

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

3.1.2.3 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.3.5

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.

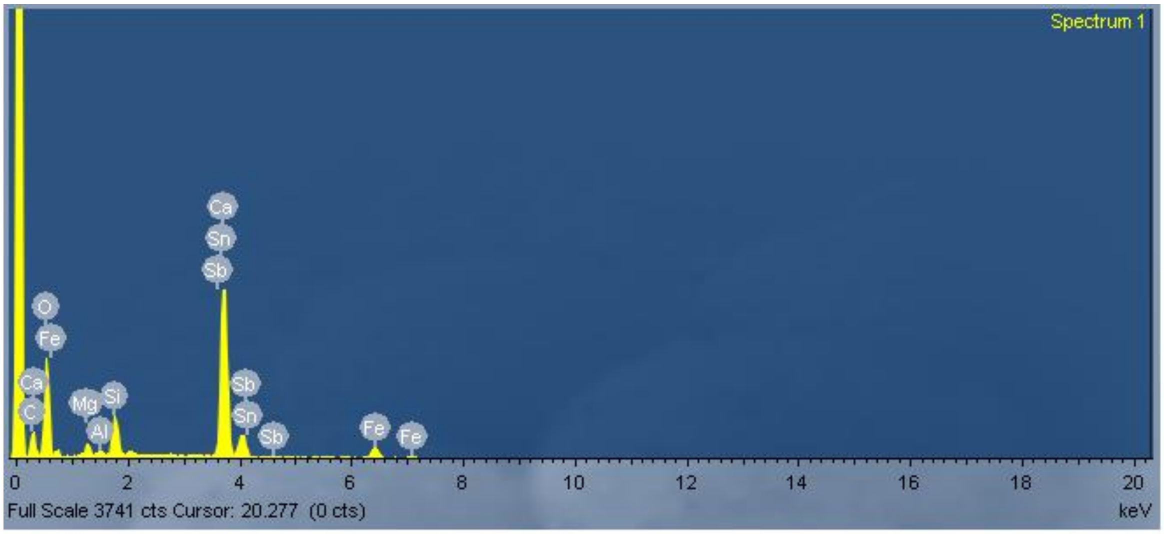

Figure 3.1 XRD Analysis of Steel Slag

3.1.3 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.

Fly ash cement is also known as green concrete. It binds the toxic chemicals that are present in the fly ash in a way that should prevent them from contaminating natural resources. Using fly ash cement in place of or in addition to Portland cement uses less energy, requires less invasive mining, and reduces both resource consumption and CO2 emissions.

Table No. 3.6

cement	Consistency in %	Specific gravity	Initial setting time	Final setting time
Fly ash cement	37.5	3	3 hour 50 min	11 hour 35 min
FC10	47			
FC20	55.5			

3.1.3.1 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:

Table No 3.7

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

3.1.3.2 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 3.8

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

3.1.4 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

3.1.4.1 Physical Properties of Slag cement.

Before proceeding to experimental work , the physical properties of slag cement is determined. Consistency is the main properties of cement for determining water content for mortar. Vicat‘s apparatus is used to determine consistency, initial setting time and final setting time. Specific gravity of cement was determined by Lechatelier’s apparatus. The properties of slag cement is given in Table No. 3.9

Table No 3.9

cement	Consistency in %	Specific gravity	Initial setting time	Final setting time
Slag cement	32	2.95	2 hour	4 hour
SC10	35			
SC20	40.5			

SC 10 - Slag cement with 10% silica fume Replacement.

SC20 - Slag cement with 20% silica fume Replacement.

3.1.4.2 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 3.10

Chemical Compound	Visible	Reference Code	Score
Ca54MgAl2Si16O19	Yes	13-0272	68
MgAl2O4	Yes	84-0377	19
SiO2	Yes	43-0596	36

3.1.4.3 Chemical Analysis of Slag 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 determine actual chemical composition of the specimen provided by the company. The chemical analysis of slag cement is listed in Table No. 3.11.

Table No 3.11

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

3.1.5 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 SiO_2), 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.

3.1.5.1 Sieve Analysis of sand

The Sieve Analysis of sand is carried out to know the zone of the sand. The results of sieve analysis is given in Table No. 3.12.

Table No. 3.12

Sieve size	Weight Retained in gm	% passing
4.75 mm	16 gm	98.4
2.36 mm	11 gm	97.3
1.18 mm	65 gm	90.8
600 micron	391 gm	51.6
300 micron	420 gm	9.4
150 micron	82 gm	1.2
Total	1000 gm	-

From the sieve analysis result, Sand falls under Zone II.

3.1.5.2 Physical properties of sand.

Before going to do experimental work the physical properties of sand is determined like specific gravity and water absorption.The physical properties of sand is given below in Table No 3.13.

Table No 3.13

Fine aggregate	Specific gravity	Water absorption in %
Sand	2.65	0.6

3.2 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.

3.3 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].

Procedure:

1) The specimen was dried in oven at about 105^0C until constant mass was obtained.
2) Specimen was cool down to room temperature for 6hr.
3) The sides of the specimen was coated with paraffin to achieve unidirectional flow.
4) The specimen was exposed to water on one face by placing it on slightly raised seat (about 5 mm) on a pan filled with water.
5) The water on the pan was maintained about 5mm above the base of the specimen during the experiment as shown in the figure below.
6) The weight of the specimen was measured at 15 min and 30 min. intervals.
7) The capillary absorption coefficient (k) was calculated by using formula:

$k=Q/A*\text{sqrt}(t)$ where Q is amount of water absorbed

A is cross sectional area in contact with water

t is time

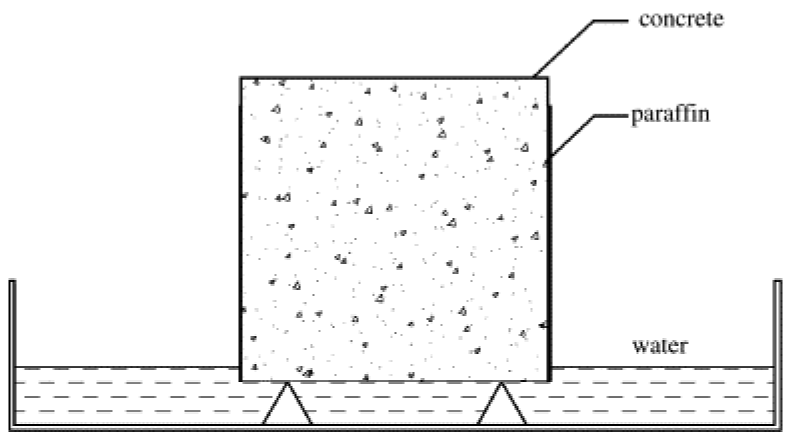

Figure No. 3.2 Capillary absorption test in progress

3.3.3 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

Procedure

1) The specimen was dried in oven at about 100^0C until constant mass W_{dry} was obtained.

2) The specimens were placed in a desiccators filled with distilled water under vacuum for 3 hrs.

3) Weight of the saturated specimen W_{sat} in distilled water is taken.

4) The specimens are taken out and its weight is taken in air i.e. W_{wat}

5) The vacuum saturated porosity is calculated by the formula:

$$P = ((W_{sat} - W_{dry}) / (W_{sat} - W_{wat}))*100$$

Where, p = vacuum saturation porosity (%)

W_{sat} = the weight in air of saturated sample

W_{wat} = the weight in water of saturated sample

W_{dry} = the weight of oven dried sample

3.3.4 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

CHAPTER-4: RESULTS AND DISCUSSIONS

4.1 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):

1) 300 gm of sample coarser than 150 micron sieve is taken.
2) Approximate percentage of water was added to the sample and was mixed thoroughly for 2-3 minutes.
3) Paste was placed in the vicat's mould and was kept under the needle of vicat's apparatus.
4) Needle was released quickly after making it touch the surface of the sample.
5) Check was made whether the reading was coming in between 5-7 mm or not and same process was repeated if not
6) The percentage of water with which the above condition is satisfied is called normal consistency.

Normal consistency of different binder mixes were tabulated below in Table No. 4.1.

Table No.4.1

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

Where, SC = slag cement

FC = fly ash cement

SF = silica fume

SFC = slag and fly ash cement

SC0 = Slag cement with 0% silica fume replacement.

SC10 = Slag cement with 10% silica fume replacement.

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.

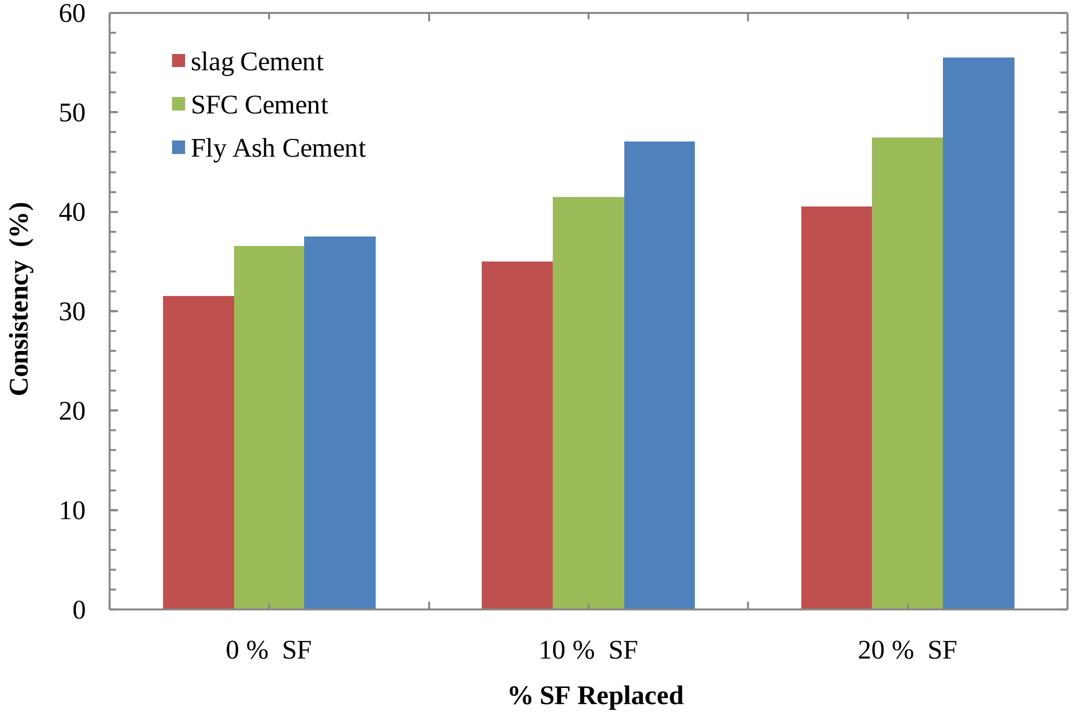

Figure.4.1 Consistency of Mortar.

From the above graph we can conclude that water requirement increases with increase in percentage of replacement by silica fume and fly ash cement consumes more water due to its fineness. Water requirement or normal consistency of a binder mix increases with increment in percentage of silica fume replacement.

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

4.1.2 Compressive Strength of Mortar.

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

Table No. 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

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

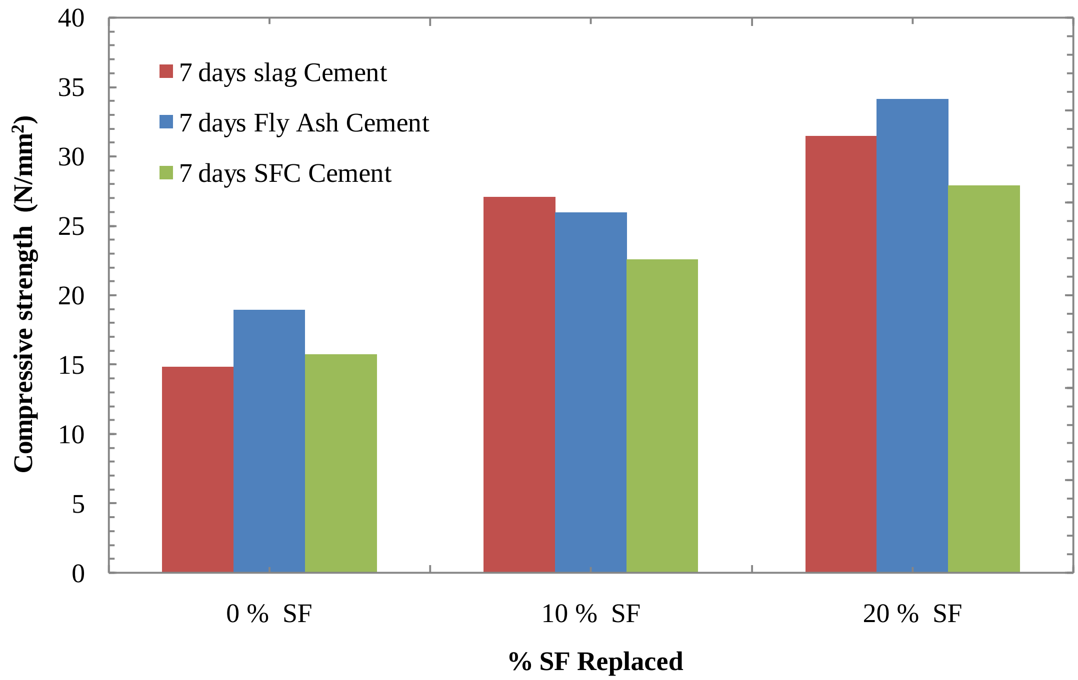

Figure.4.2 Compressive strength for mortar for 7 days

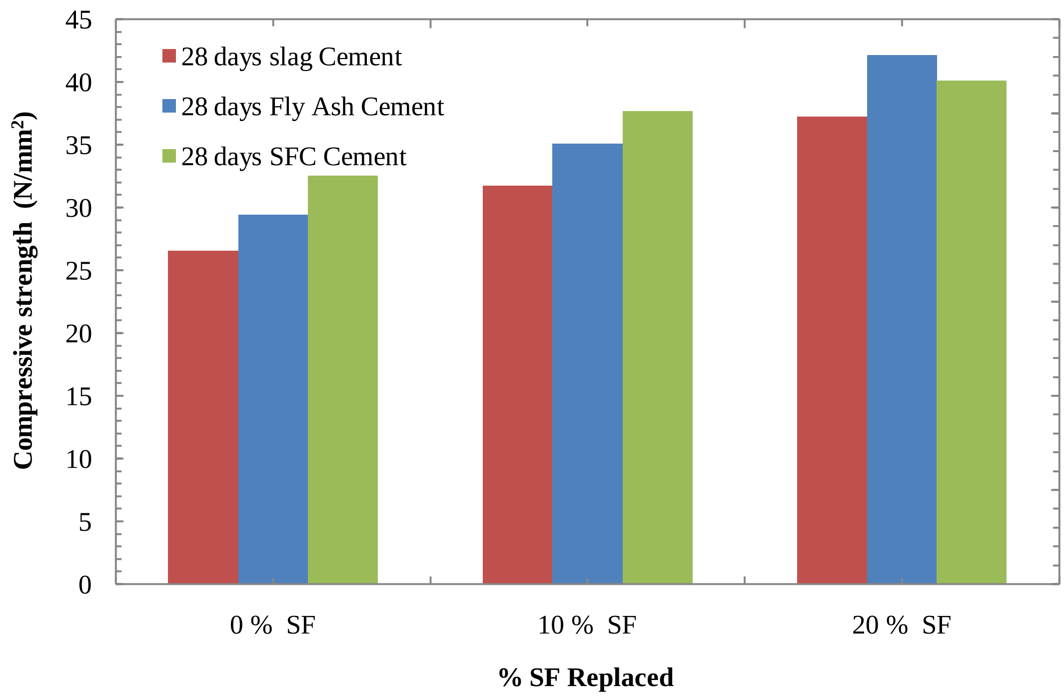

Figure.4.3 compressive strength for mortar for 28 day

4.1.3 Capillary Absorption

Coefficients of capillary absorption of different mortars after 7 days and 28 days of curing were tabulated in Table No. 4.4

Table No. 4.4

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

From the above table, we can conclude that capillary absorption decreases with increase in percentage of replacement by silica fume. The reason could be the inclusion of silica fume to the different cements actually forms denser matrices thereby improve resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete. All binder mixes shows that up to 20% replacement of cement with silica fume the durability in terms of capillary absorption coefficients decreases with increasing dose of silica Fume. Capillary absorption coefficient decreases with increasing % of silica fume up to 20% replacement. This indicates that inclusion of silica fume to the different cements actually forms denser matrices thereby improve resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete. Decrease in capillary absorption coefficient between 7day to 28 day of curing is about 16% observed in slag cement with 15% silica fume and is about 3% observed in fly ash cement with 20% silica fume and is about 6% observed in blended binder mix with 20% silica fume

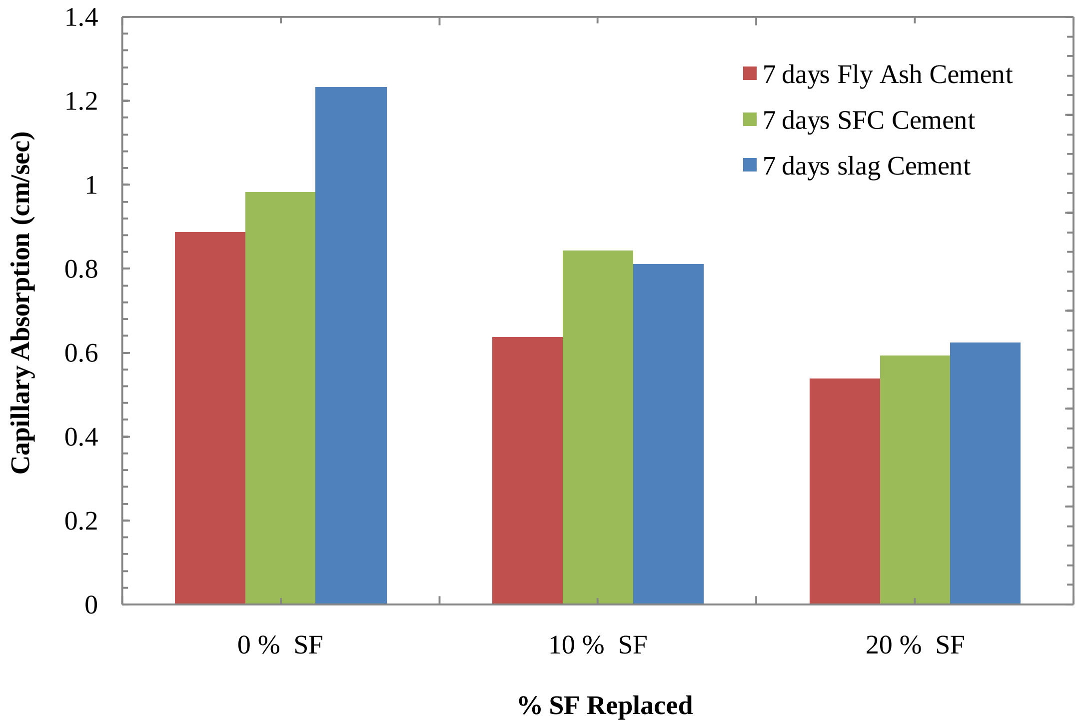

Figure.4.4Capillary Absorption for mortar for 7 days

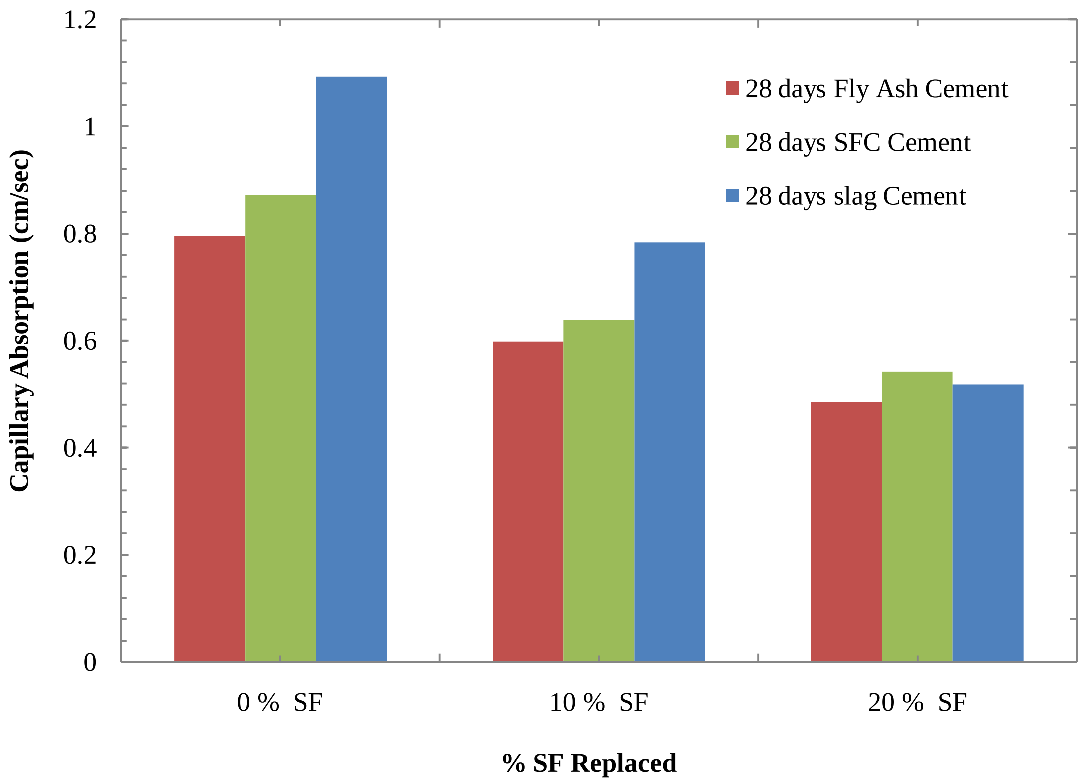

Figure.4.5 Capillary Absorption for mortar for 28 days

4.1.4 Porosity Test of Mortar.

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

Table No. 4.5

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

From the above table, we can conclude that porosity decreases with increase in percentage of replacement by silica fume. The reason could be the inclusion of silica fume to the different cements actually forms denser matrices thereby improve resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete. All binder mixes shows that up to 20% replacement of cement with silica fume the durability in terms of decreases with increasing dose of silica Fume. Porosity decreases to about 16 % in slag cement, about 17 % in Fly ash cement and about 17% in blended binder mix with 20% addition of silica fume between 7days to 28 days of curing.

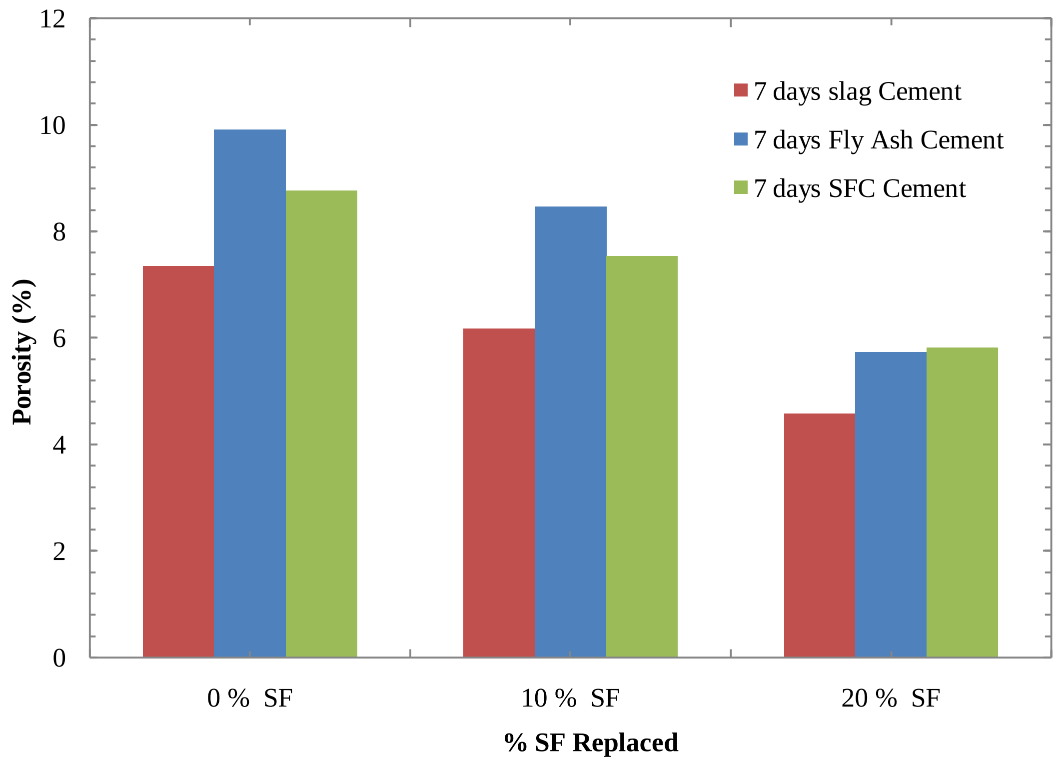

Figure.4.6 Porosity of mortar for 7 days

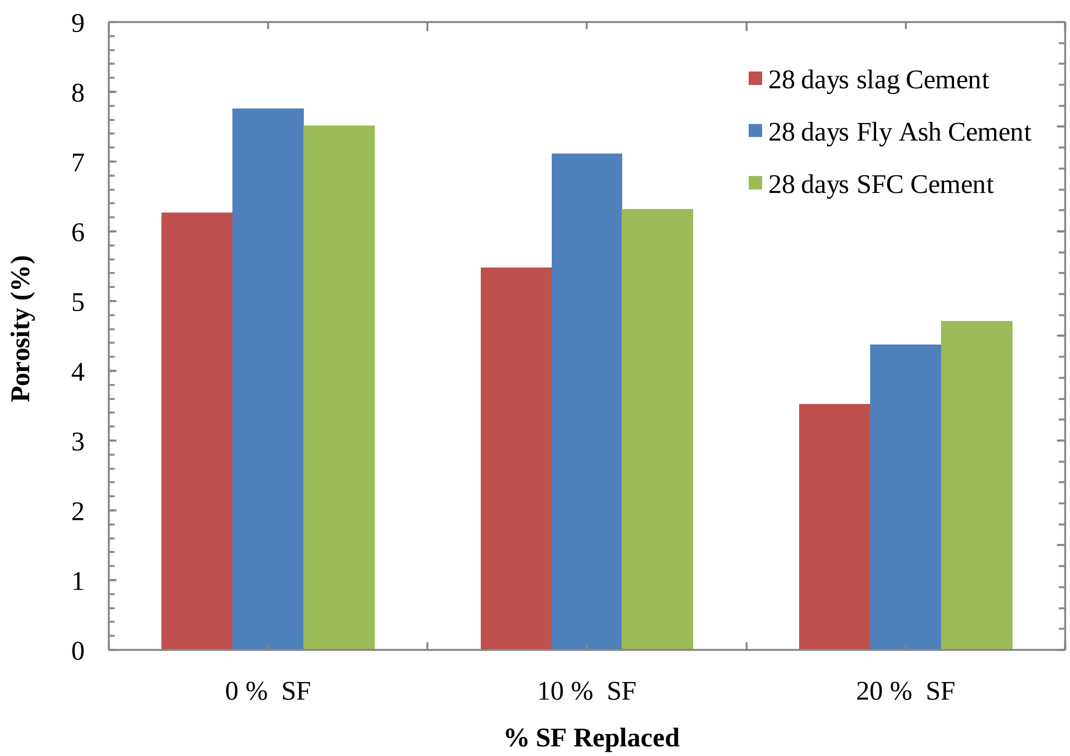

Figure.4.7 Porosity of mortar for 28 days

4.2 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.

4.2.1 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. 4.6

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

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

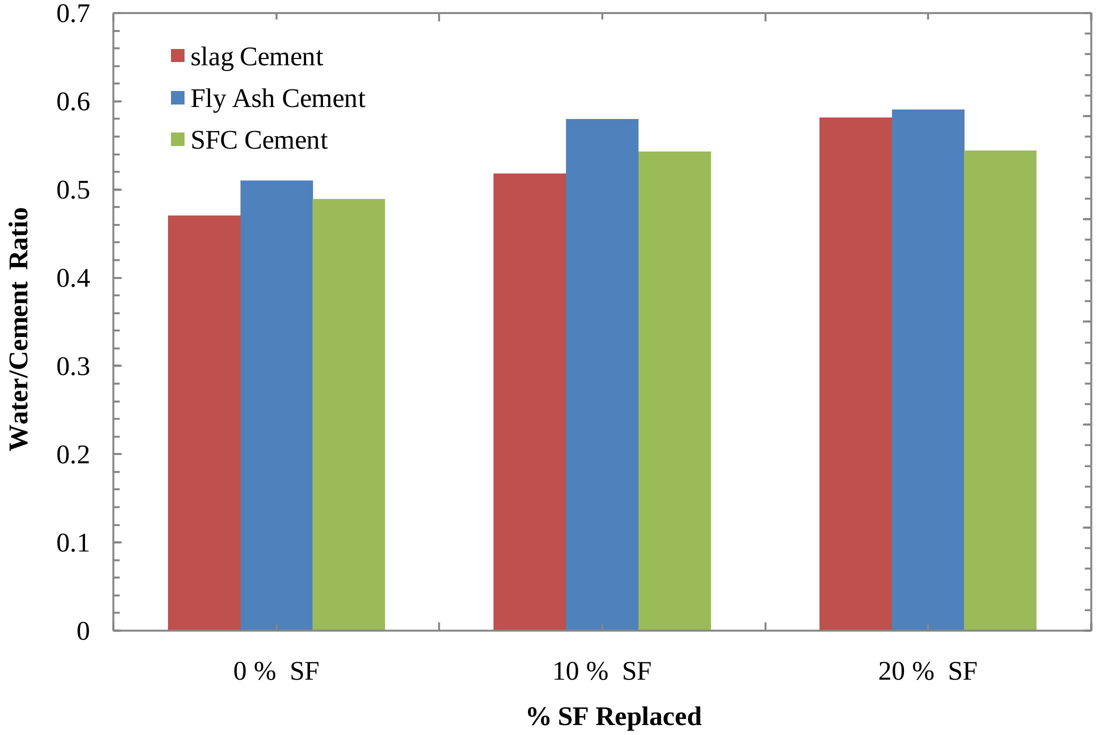

Figure.4.8 Water Cement Ratio for steel slag concrete

4.2.2 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. 4.7.

Table No .4.7

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

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.

4.2.3 Compressive Strength by Compression Testing Machine.

Compressive Strength of different mortars after 7days ,28days and 56 days were tabulated in Table No. 4.8.

Table No 4.8

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

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

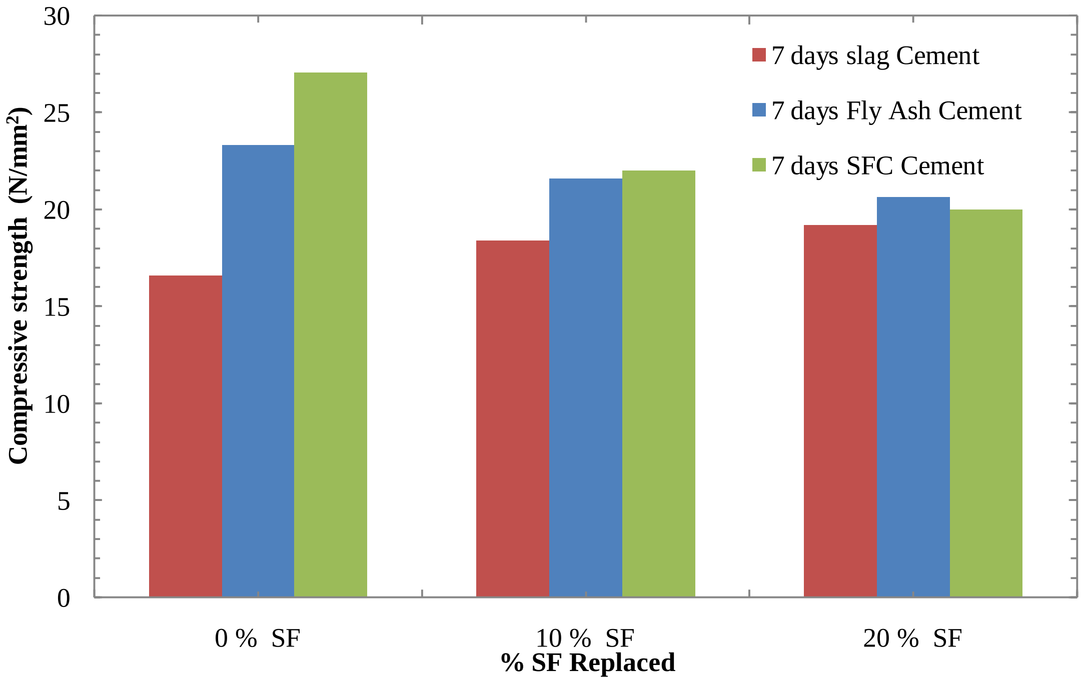

Figure.4.9 Compressive strength of concrete for 7 days

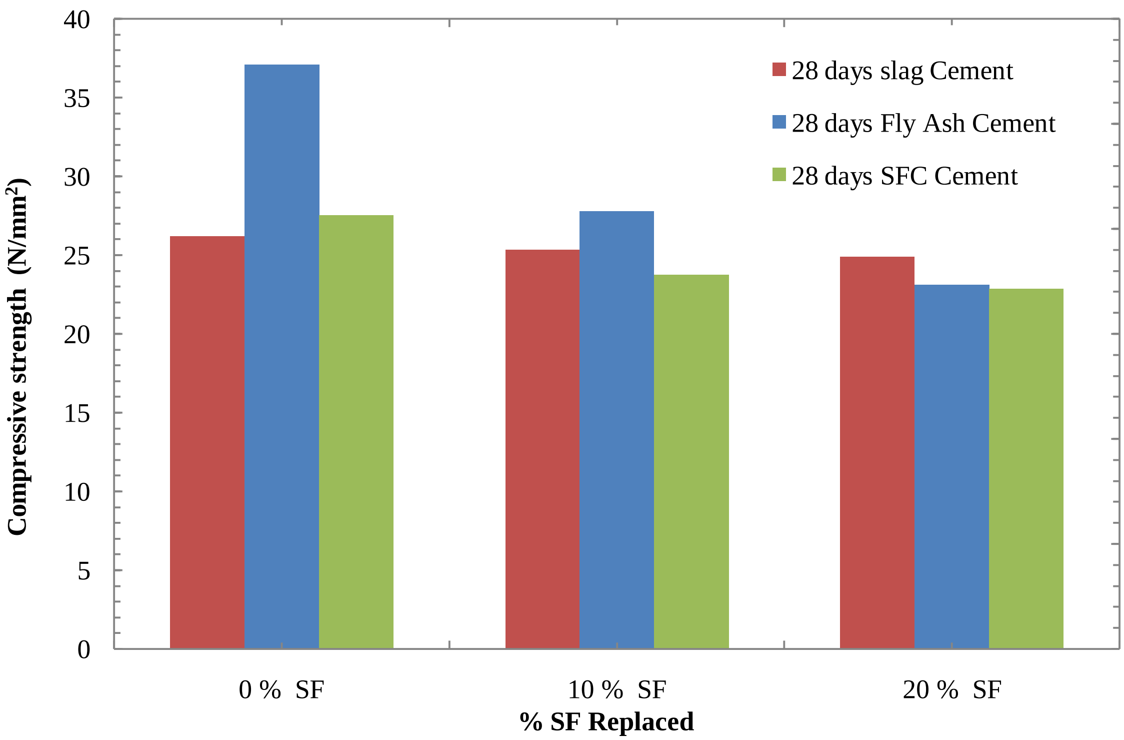

Figure.4.10 Compressive strength of concrete for 28 days

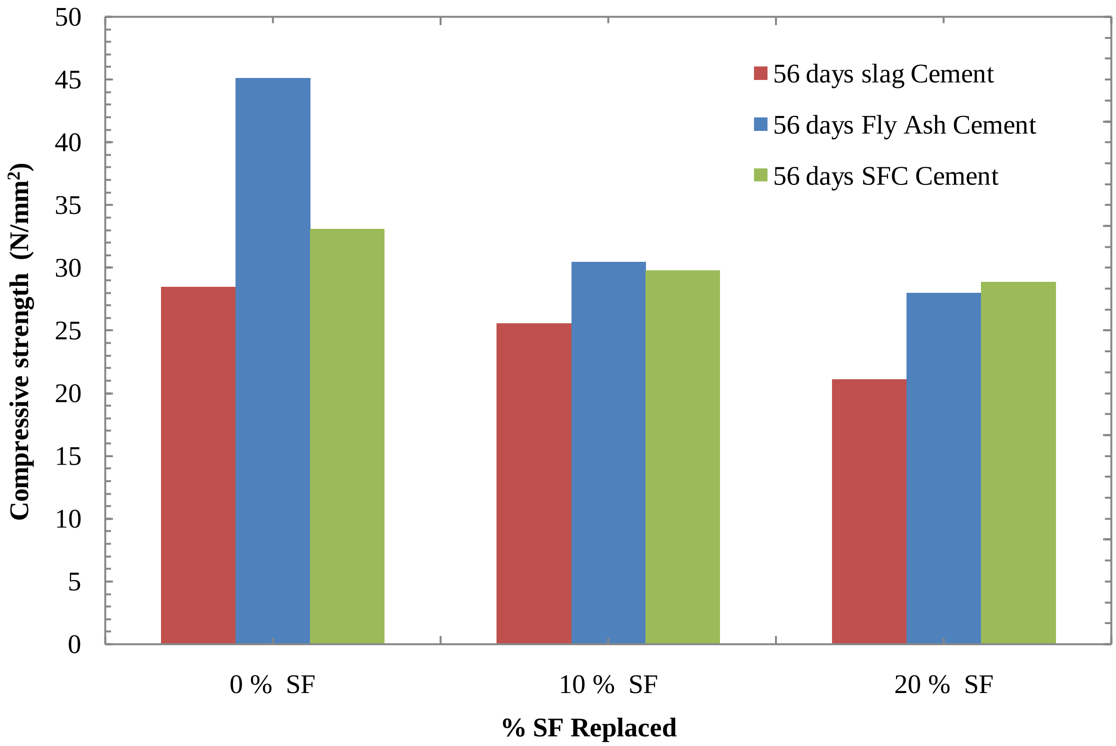

Figure.4.11 Compressive strength of concrete for 56 days

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

Fig.4.12 Compressive Testing Machine

Figure 4.13 Scanning Electron Microscope

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

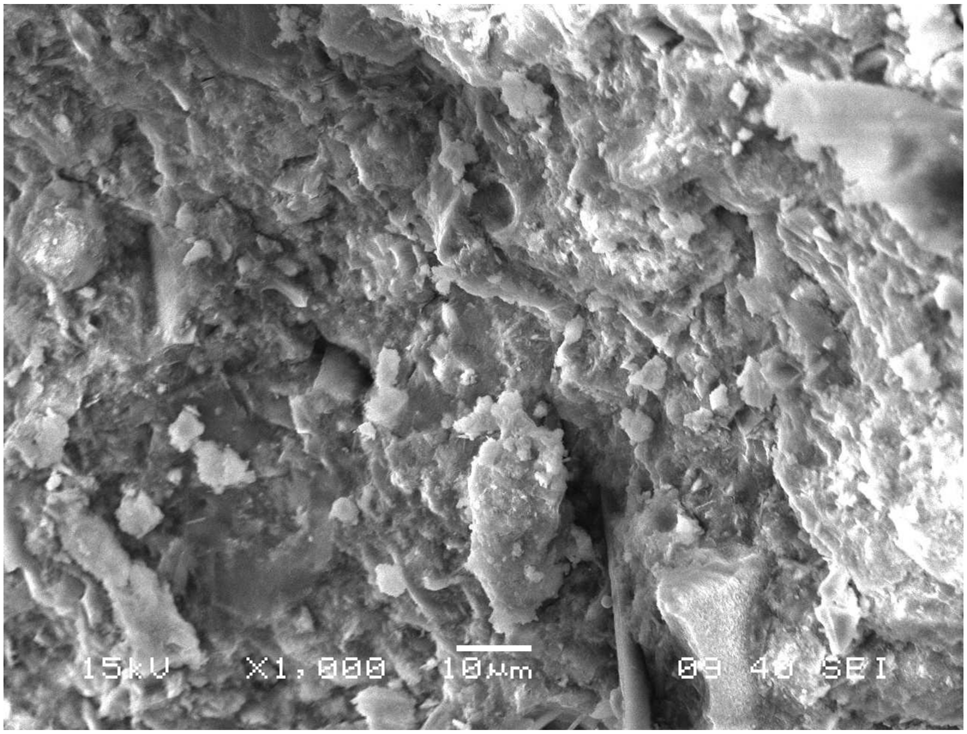

Figure4.14 Steel slag concrete with 0% silica fume replacement.

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

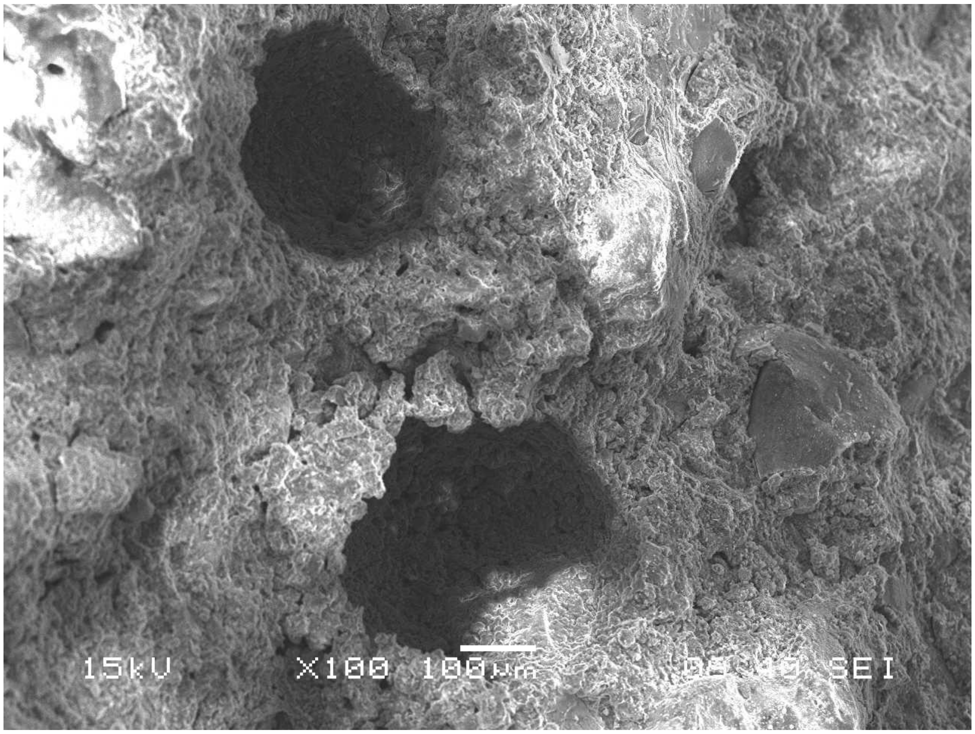

Figure4.15 Steel slag concrete with 10% silica fume replacement.

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.

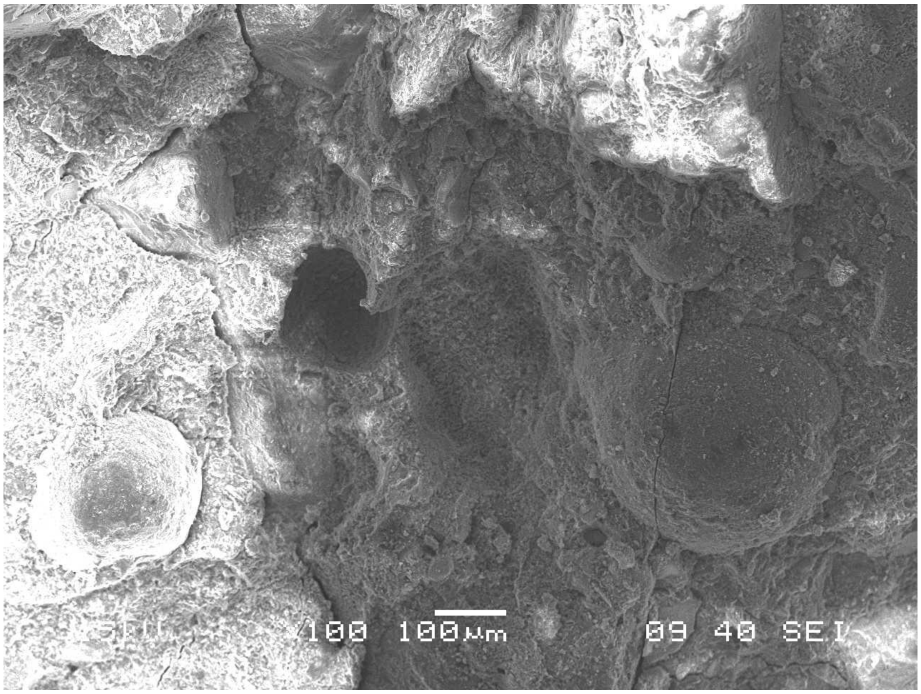

Figure 4.16 Steel slag concrete with 20% silica fume replacement.

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

4.2.4 Wet and Dry Test.

Table No.4.9 shows 28 days and 56 days wet and dry test of concrete cube.

Table No. 4.9

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

From above table we concluded that steel slag concrete shows good result. Its 28 days and 56 days strength increased prominently. So steel slag concrete is very useful for marine structure.

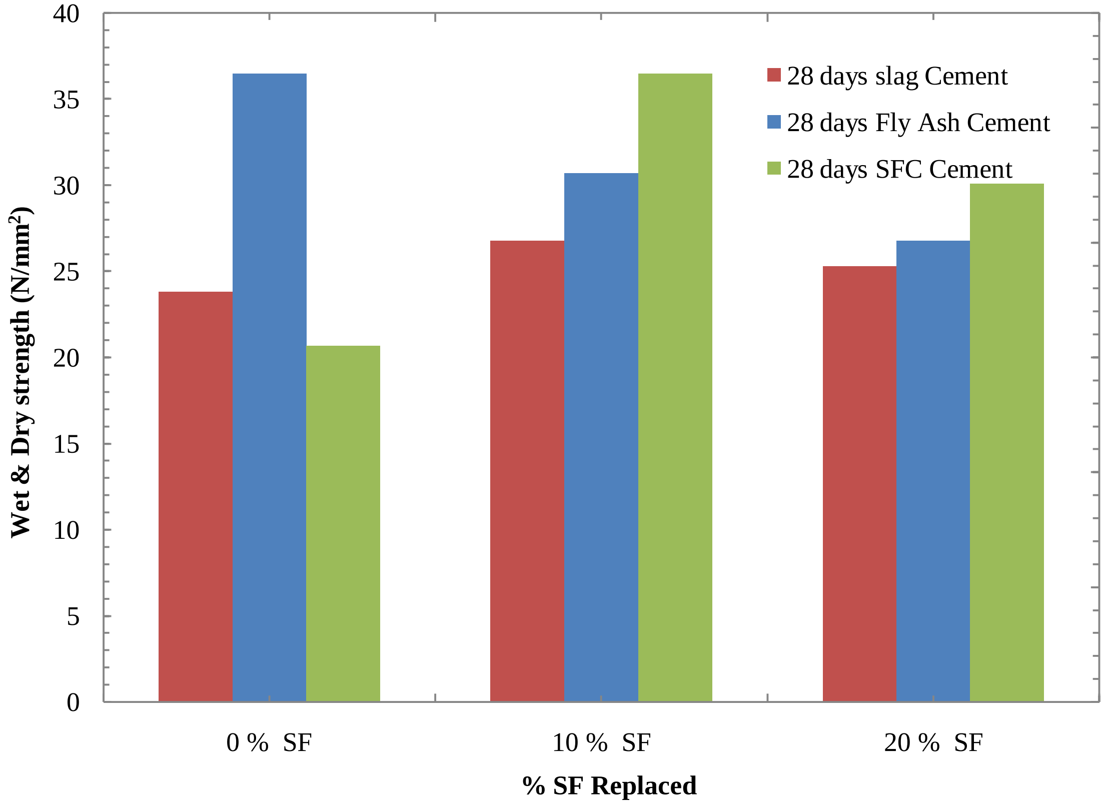

Figure.4.17 Wet and Dry test strength of concrete for 28 days

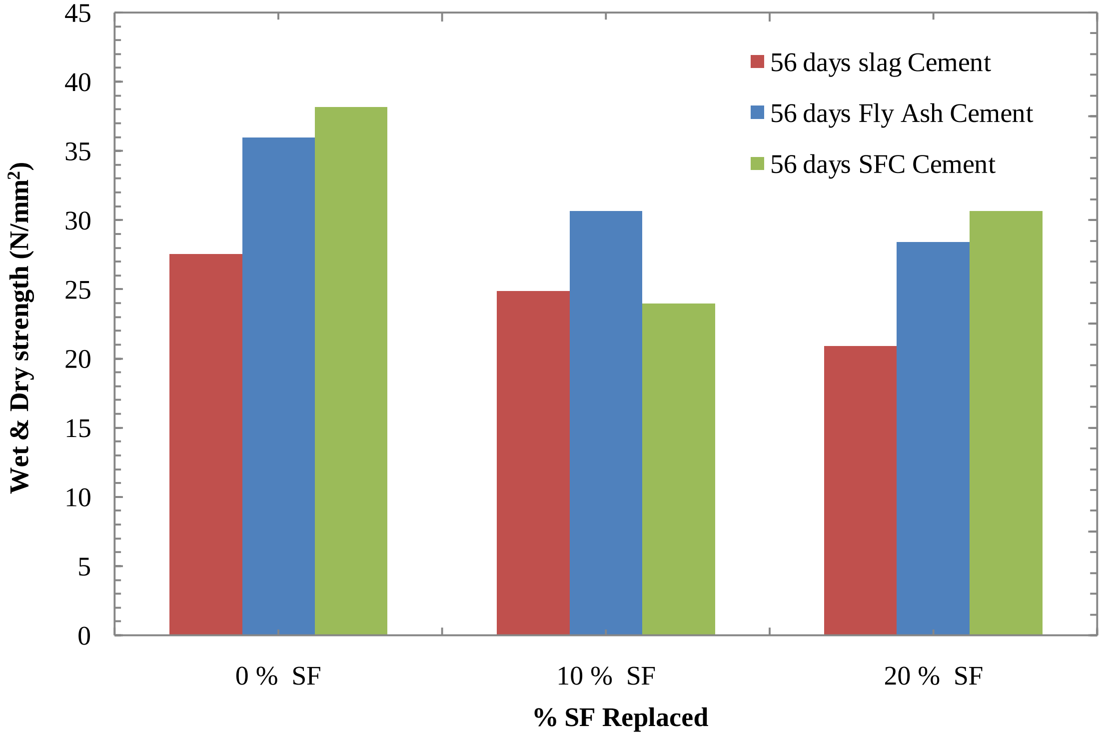

Figure.4.18 Wet and Dry test strength of concrete for 56 days

4.2.5 Flexural Test.

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

Table 4.10

Type of cement	% of SF replaced	28 days(N/mm^2)	56 days (N/mm^2)
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.

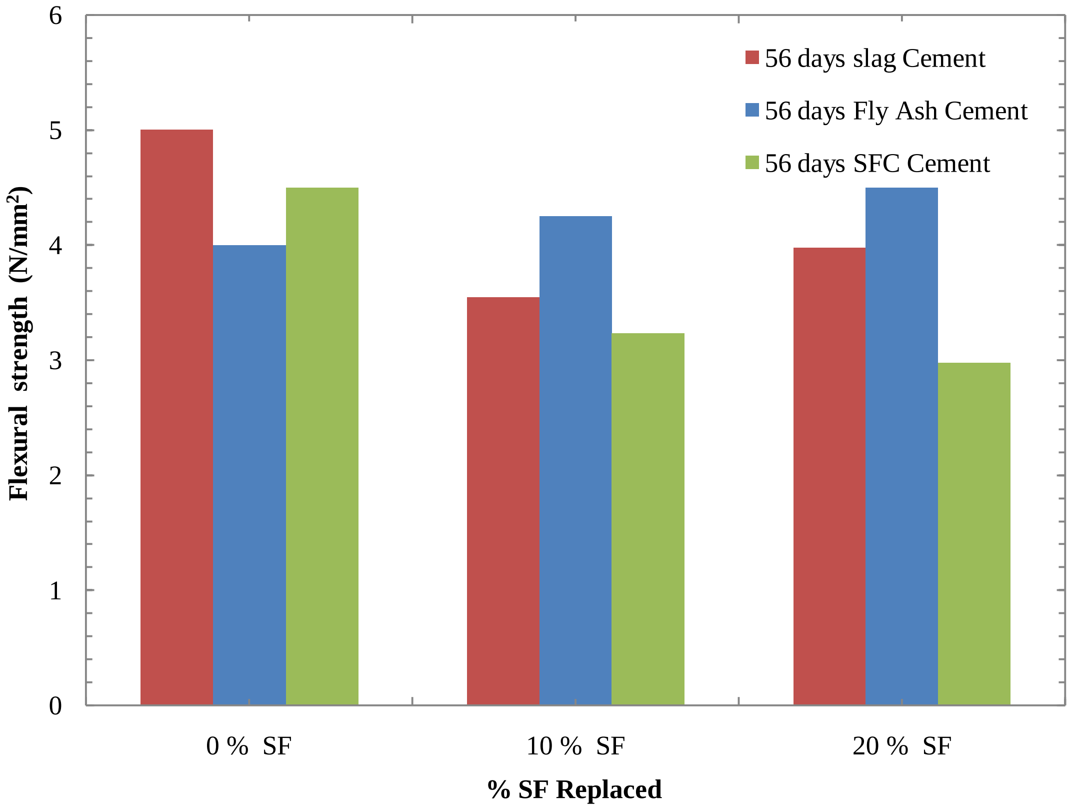

Figure.4.19 Flexural strength of concrete for 56 days

Figure 4.20 Flexural Strength of concrete.

4.2.6 Porosity Test.

The 28 days and 56 days porosity test is given below

Table 4.11

Type of cement	% of SF replaced	28 days (%)	56 days (%)
Fly ash cement (FC)	0	6.1	4.8
	10	8.3	6.7
	20	9.1	7.4
Slag cement (SC)	0	9.3	7.3
	10	16	11.11
	20	18	13.23
Slag and fly ash cement blend (1:1) (SFC)	0	5.7	3.79
	10	7.1	5.21
	20	12	9.83

From the above table, we can conclude that porosity increases with increase in percentage of replacement by silica fume. The reason could be the inclusion of silica fume to the different cements actually forms denser matrices thereby improve resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete.

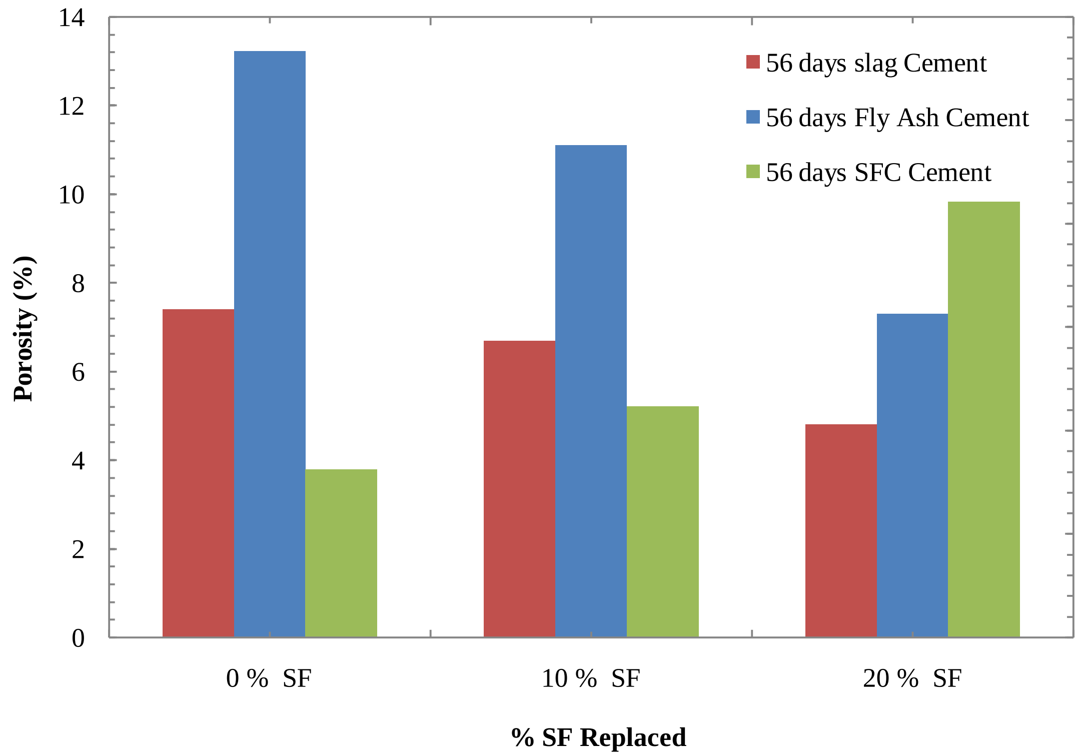

Figure.4.21 Porosity of concrete for 56 days

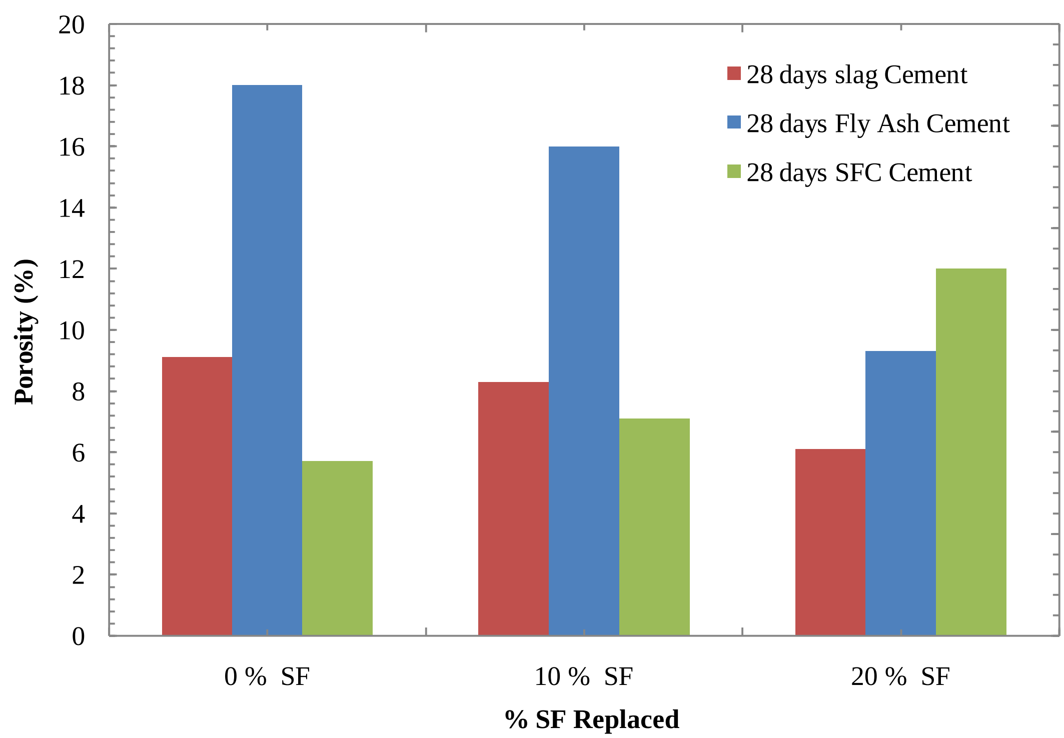

Figure.4.22 Porosity of concrete for 28 days.

4.2.7 Capillary Absorption Test.

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

Table 4.12

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

From the above table, we can conclude that capillary absorption decreases with increase in percentage of replacement by silica fume. The reason could be the inclusion of silica fume to the different cements actually forms denser matrices thereby improve resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete.

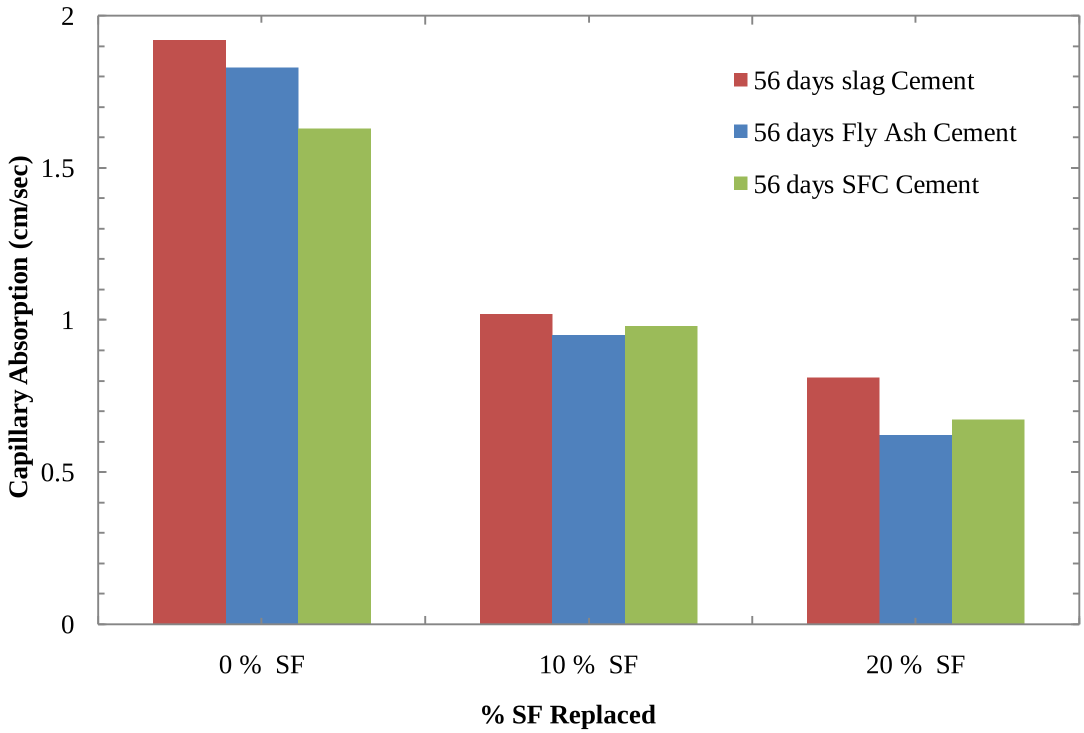

Figure.4.23 Capillary Absorption of concrete for 56 days

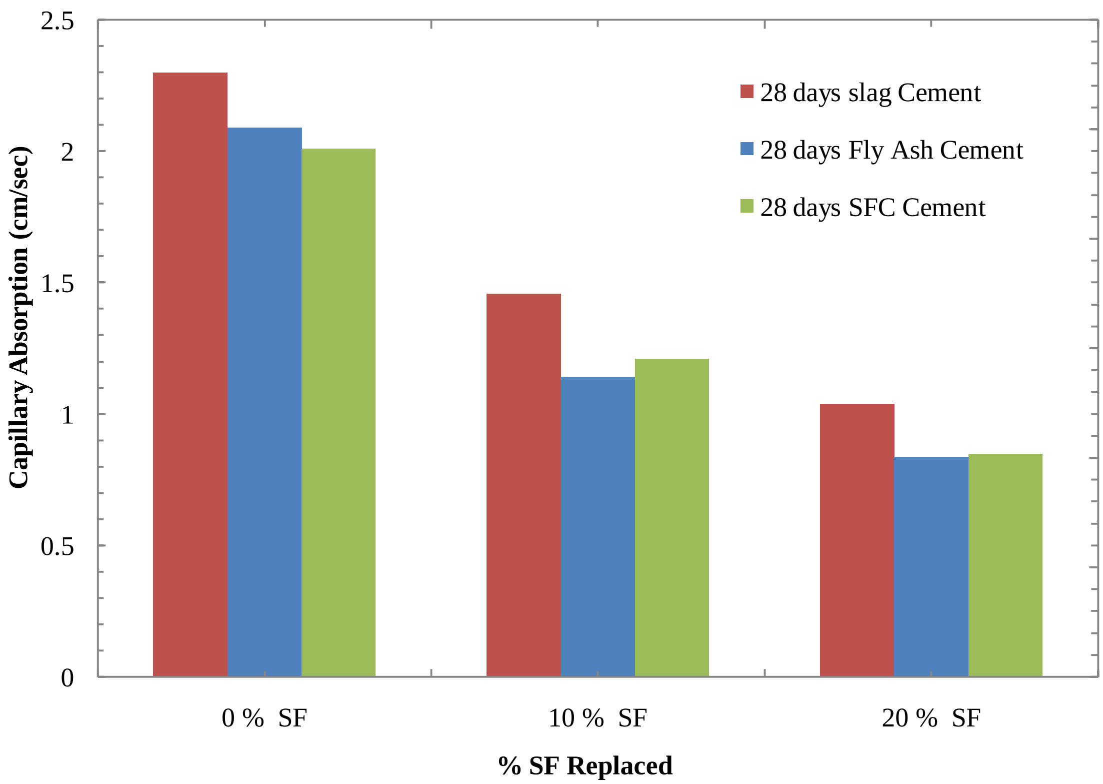

Figure.4.24 Capillary Absorption of concrete for 28 days

CHAPTER 5

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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