Comparative Study of Waste Glass Powder as Pozzolanic Material in Concrete

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

Bachelor of Technology
In
Civil Engineering

Under the Guidance of
Prof. Asha Patel

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2012

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled, **"Comparative Study of Waste Glass Powder as Pozzolanic Material in concrete"** submitted by **Ankur Meena & Randheer Singh** in partial fulfilments for the requirements for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

We express our deepest appreciation and sincere gratitude to Prof. Asha Patel for her valuable guidance, constructive criticism and timely suggestions during the entire duration of this project work, without which this work would not have been possible.

We would also like to thank Mr Shushil, Mr.Lugun bhai and Mr. Samir for their help in casting and operating the machine.

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ABSTRACT

Glass is used in many forms in day-to-day life. It has limited life span and after use it is either stock piled or sent to landfills. Since glass is non-biodegradable, landfills do not provide an environment friendly solution. Hence, there is strong need to utilize waste glasses.

Many efforts have been made to use waste glass in concrete industry as a replacement of coarse aggregate, fine aggregate and cement. Its performance as a coarse aggregate replacement has been found to be non-satisfactory because of strength regression and expansion due to alkali-silica reaction. The research shows that there is strength loss due to fine aggregate substitution also.

The aim of the present work was to use glass powder as a replacement of cement to assess the pozzolanic activity of fine glass powder in concrete and compare its performance with other pozzolanic materials like silica fume and fly ash.

A series of tests were conducted to study the effect of 15% and 30% replacement of cement by silica fume, fly ash and glass powder on compressive strength and durability in the form of capillary absorption. The particle size effect was evaluated by using glass powder of size 150µm-100µm and glass powder of size less than 100µm.

The present study shows that waste glass, if ground finer than 100µm shows a pozzolanic behavior. It reacts with lime at early stage of hydration forming extra CSH gel thereby forming denser cement matrix. The early consumption of alkalis by glass paticles mitigate alkali-silica reaction hence increase durability of concrete.

CONTENTS

List of figures

List of tables

CHAPTER 1

INTRODUCTION

INTRODUCTION:

Concrete is a blend of cement, sand, coarse aggregate and water. The key factor that adds value to concrete is that it can be designed to withstand harshest environments significant role. Today global warming and environmental devastation have become manifest harms in recent years, concern about environmental issues, and a changeover from the mass-waste, mass-consumption, mass-production society of the past to a zero-emanation society is now viewed as significant. Normally glass does not harm the environment in any way because it does not give off pollutants, but it can harm humans as well as animals, if not dealt carefully and it is less friendly to environment because it is non-biodegradable. Thus, the development of new technologies has been required.The term glass contains several chemical diversities including soda-lime silicate glass, alkali-silicate glass and boro-silicate glass. To date, these types of glasses glass powder have been widely used in cement and aggregate mixture as pozzolana for civil works. The introduction of waste glass in cement will increase the alkali content in the cement. It also help in bricks and ceramic manufacture and it preserves raw materials, decreases energy consumption and volume of waste sent to landfill. As useful recycled materials, glasses and glass powder are mainly used in fields related to civil engineering, for example, in cement, as pozzolana(supplementary cementitious materials), and coarse aggregate. Their recycling ratio is close to 100%, and it is also used in concrete without adverse effects in concrete durability. Therefore, it is considered ideal for recycling

Recently, Glasses and its powder has been used as a construction material to decrease environmental problems. The coarse and fine glass aggregates could cause ASR(alkali-silica reaction) in concrete , but the glass powder could suppress their ASR tendency, an effect similar to supplementary cementations materials (SCMs). Therefore, glass is used as a replacement of supplementary cementitious materials.

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

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 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 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 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 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 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 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 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, 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 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 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 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 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 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 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 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 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.

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CHAPTER 3

PRESENT EXPERIMENTAL WORK

This research work has the following objective:

- To evaluate the recyclability of powdered waste glass as a pozzolana (SCM) as partial replacement of cement in the concrete.
- To study the comparative effects of addition of powder glass , fly ash and silica fumes in concrete as pozzolana to mitigate alkali aggregate reaction.
- A comparative studies of different mixes at microscopic level were made with the help of EDS and SEM analysis of the mixes.

3.1 Experimental Program

Materials

- The materials used in this present work are glass powder, Ordinary Portland cement(43 grade), fly ash, silica fumes, coarse aggregates and fine aggregates.

Glass Powder

- The glass powder used in the present study is brought from Kolkata market. This material replaces the cement in mix proportion. Particle size distribution graph and XRD analysis of glass powder was done and shown in Fig.3.1 and Fig.3.2 respectively.

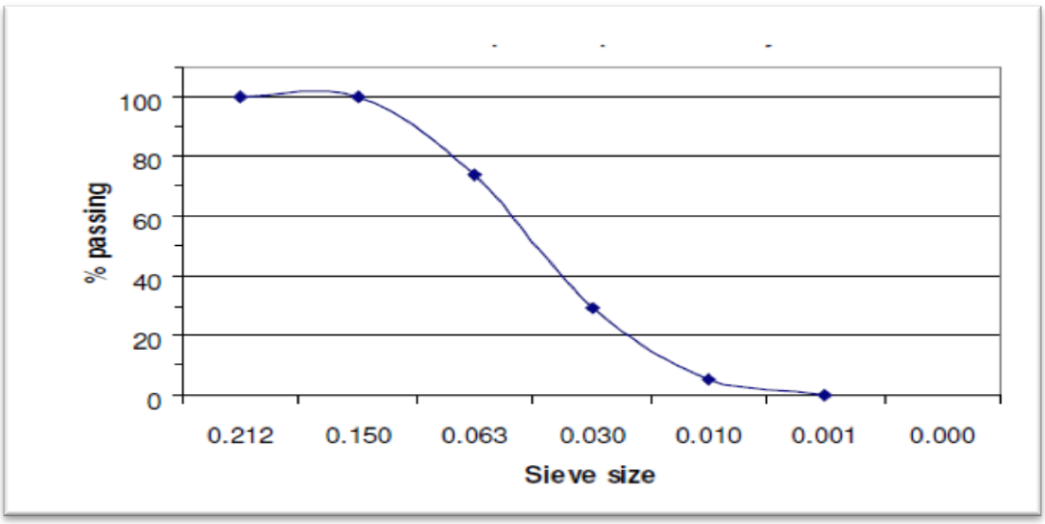


Fig.3.1

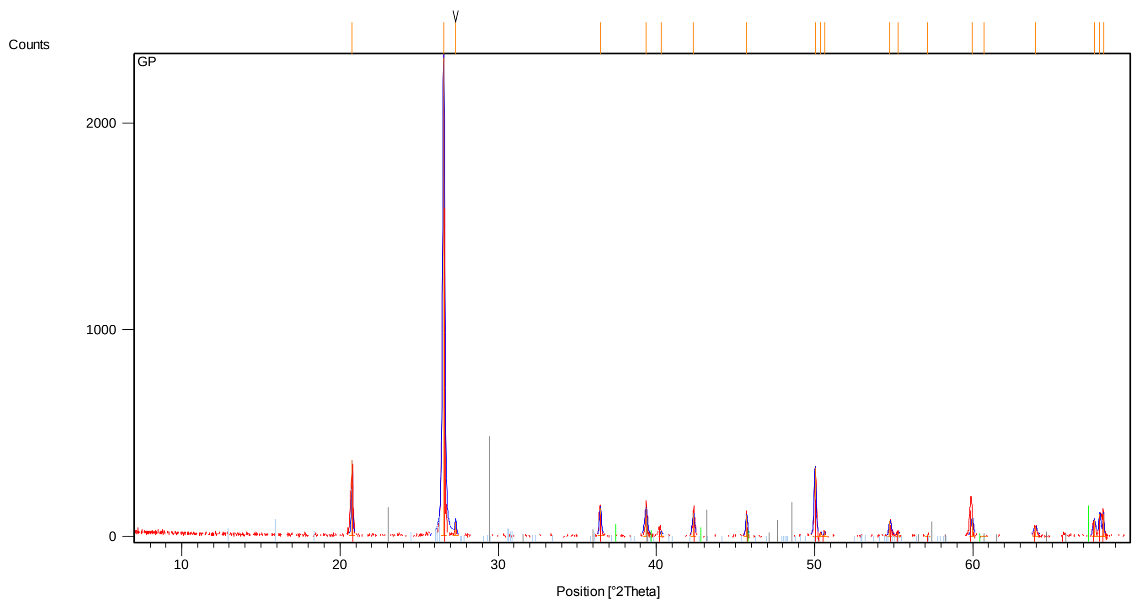


Fig.3.2

Silica Fumes

The silica fume used in the present work is supplied by Structural Laboratory of Department of Civil Engineering, NIT Rourkela. Silica fume is highly reactive pozzolanic material and is a by product from the production of silicon or ferro- silicon metal. It is composed from the flue gases from electric arc furnaces. Silica fume is very fine powder, with particles about 100th times minor than average cement grain. It is available in a water slurry form. It is used at 5% to 12% by mass of supplementary cementitious materials for concrete structures that requires high strength. The XRD analysis of silica fume is shown in Fig.3.3 and the analysis is given in table 3.1.

Chemical Properties of silica fume as supplied by the supplier:

Silica fume	ASTM-C-1240	Actual Analysis
SiO_2	85% min	86.7%
LOI	6% max	2.5%
Moisture	3%	0.7%
Pozz Activity Index	105% min	129%
Sp Surface Area	>15 m2/gm	22 m2/gm
Bulk Density	550 to 700	600
+45	10% max	0.7%

Table 3.1

XRD analysis of silica fume

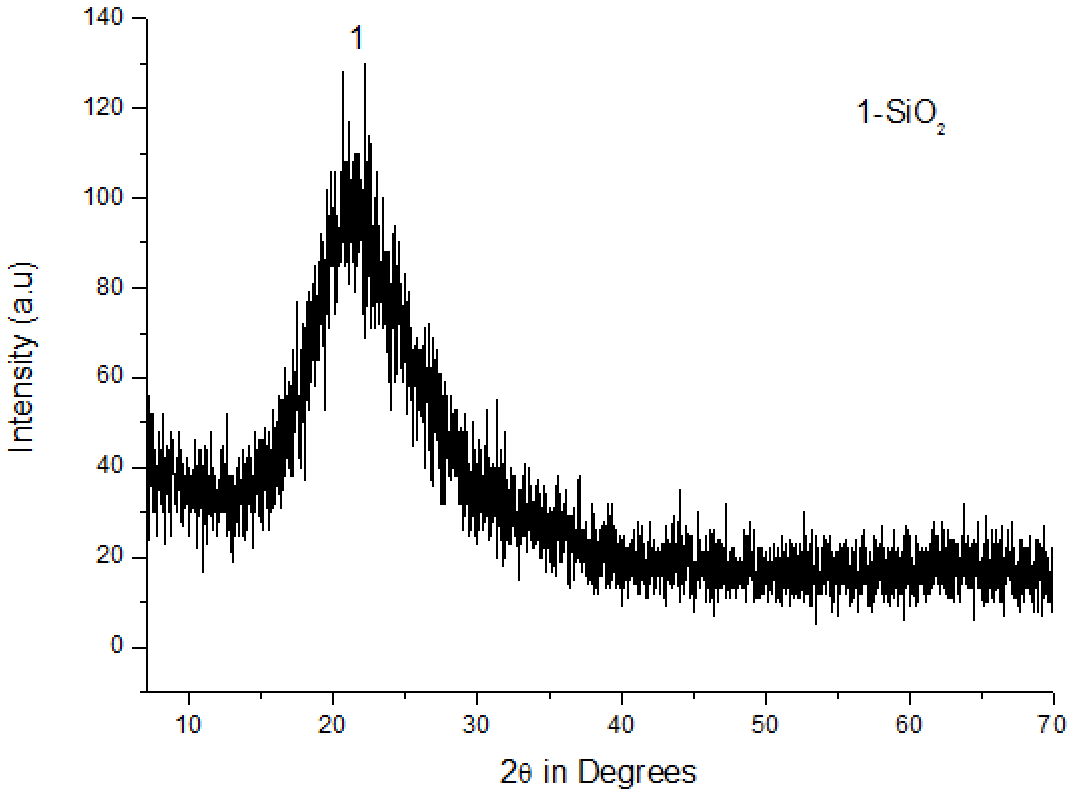


Fig.3.3

Fly Ash

The fly ash used in the present work is supplied by CPP2 of Rourkela steel plant. Fly ash is largely made up of calcium oxide and silicon dioxide can be used as a substitute or as a supplent for Portland cement. Fly ash is also known as **Green concrete**. . The XRD analysis of silica fume is shown in Fig.3.4 and the sieve analysis is given in Fig. 3.5.

XRD analysis of fly ash

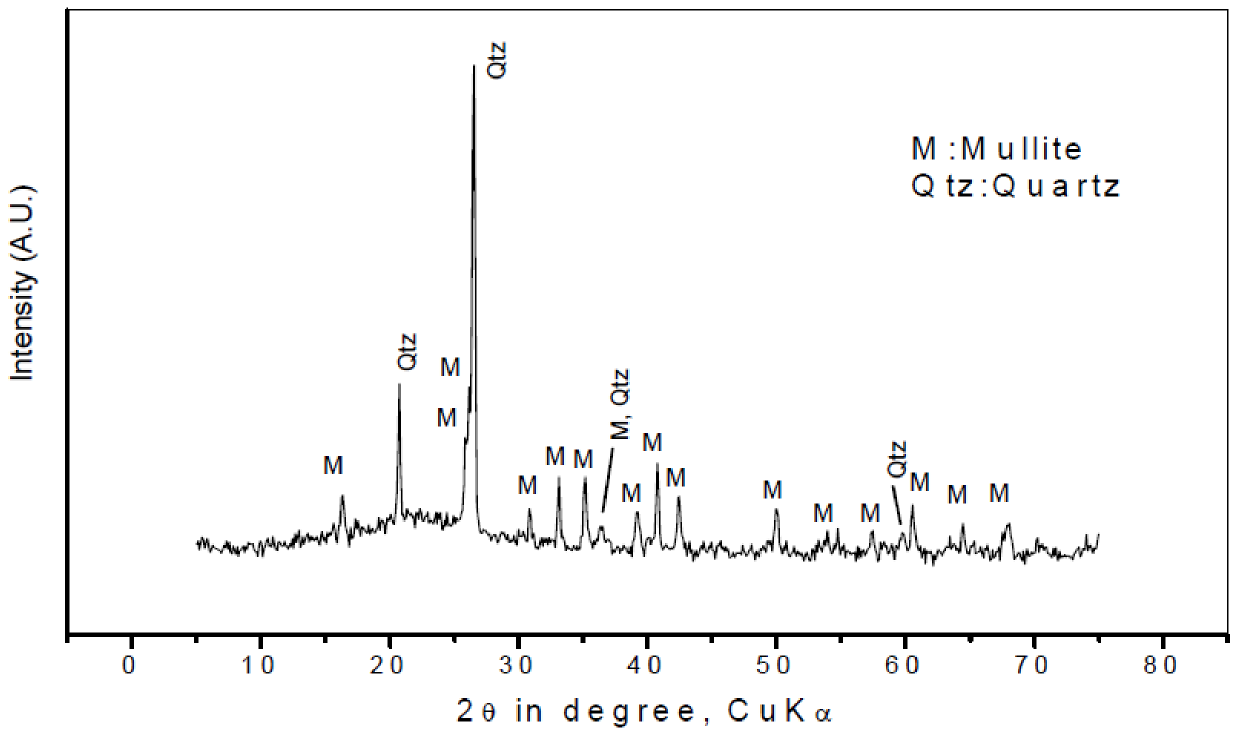


Fig.3.4

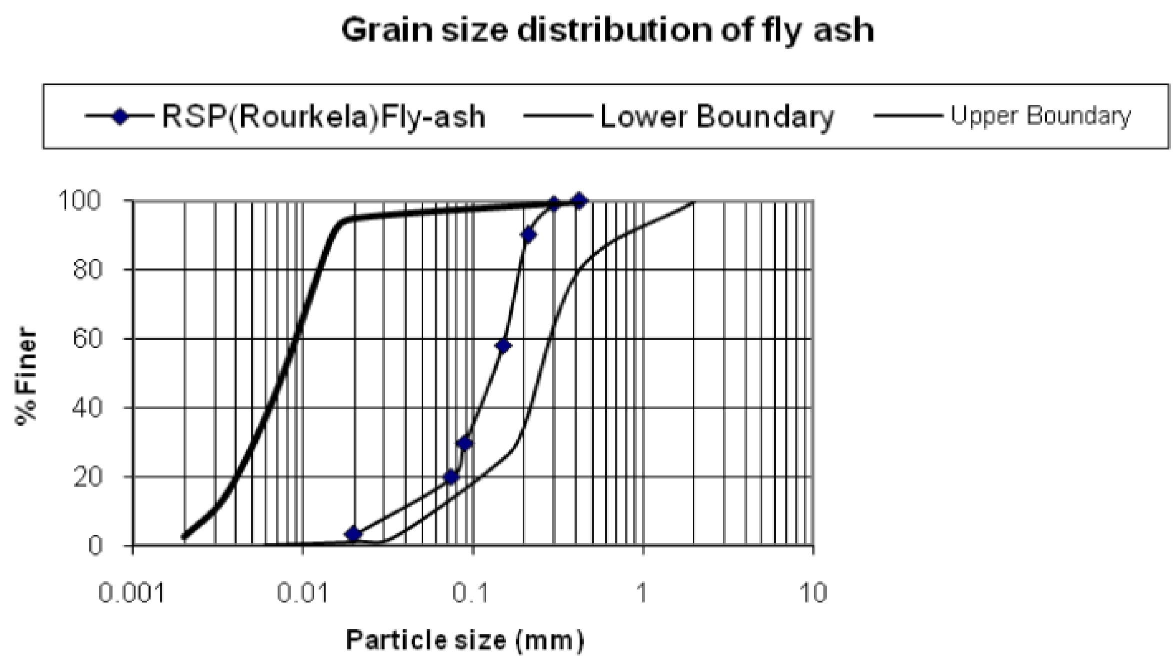


Fig.3.5

Ordinary Portland Cement

The OPC(43 grade) used in the present work is of Ultratech brand. This is used as main binder in the mixes. The XRD analysis of fly ash is given in Fig.3.6.

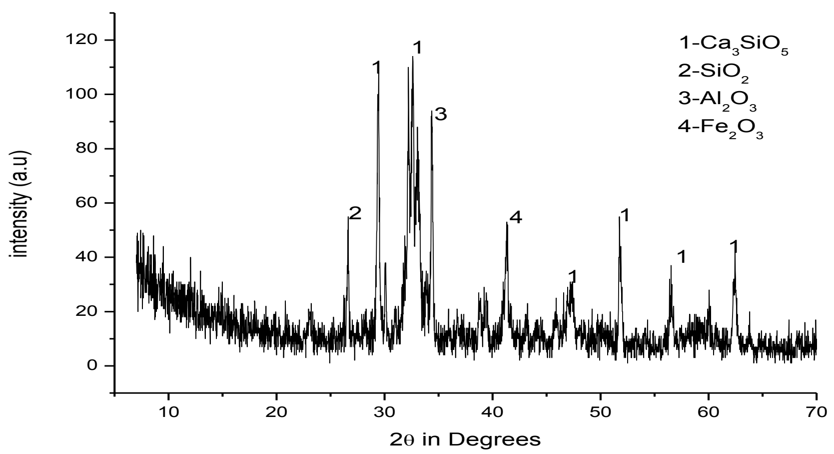


Fig.3.6

Fig.3.7 XRD

Fine Aggregate

Naturally available sand from Koel river bed is used as fine aggregate in the present work. The most common constituent of sand is silica, usually in the form of quartz, which is chemical inert and hard. Hence used as a fine aggregate in concrete. The sieve analysis of sand is shown in table 3.2. As per IS383 the sand falls under zone 4.

Sieve size(mm)	Aggregate wt. retained(Kg)	% wt. retained	Cumulative % wt. retained	100 – cumulative % passing
4.25	.039	3.9	3.9	96.1
2.36	0.27	2.7	6.6	93.4
1.18	.088	8.8	15.4	84.6
.6	.176	17.6	33	67
.3	.416	41.6	74.6	25.4
.15	.234	23.4	98	2
Pan	.014	1.4	99.4	.6

Table 3.2

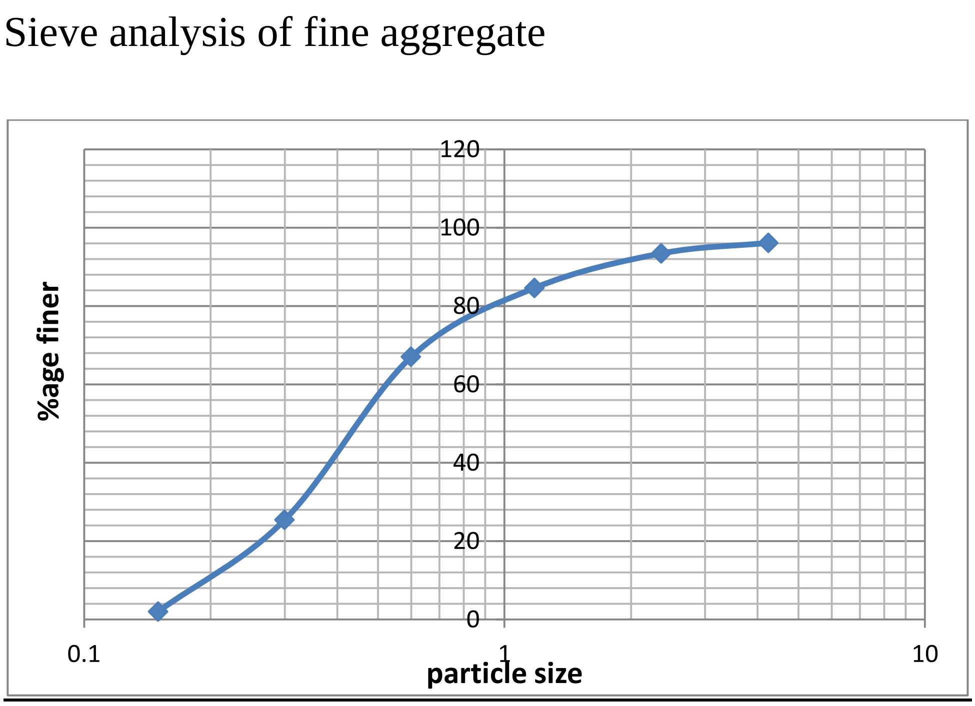


Fig. 3.8

Coarse Aggregate

The coarse aggregate available in structural engineering lab of civil engineering department. The sieve analysis of 20mm and 10mm down size is shown in table 3.3 & 3.4 and sieve analysis in Fig.3.8 respectively.

Sieve analysis of coarse aggregate

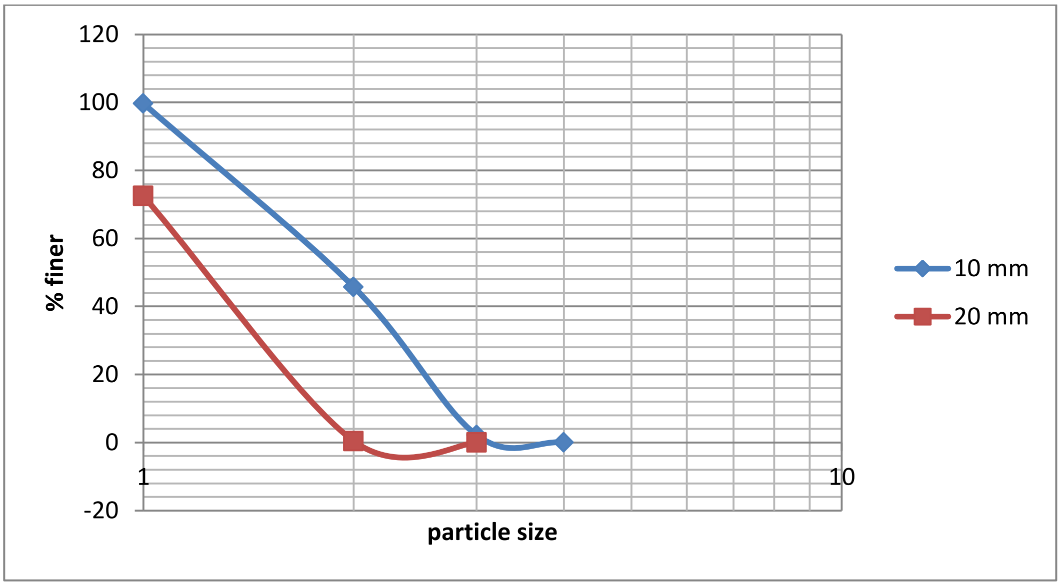


Fig.3.9

Sieve size(mm)	Aggregate wt. retained(Kg)	% wt. retained	Cumulative % wt. retained	100 – cumulative % passing
20	1.374	27.48	27.48	72.52
10	3.604	72.08	99.56	.44
4.75	.022	.44	100	0

Table 3.3(20 mm)

Sieve size(mm)	Aggregate wt. retained(Kg)	% wt. retained	Cumulative % wt. retained	100 – cumulative % passing
20	.016	.32	.32	99.68
10	2.696	53.92	54.24	45.76
4.75	2.178	43.56	97.8	2.2
Pan	.108	2.16	99.96	.04

Table 3.4 (10 mm)

Physical characteristics of materials were given below:

Description	Specific gravity
Cement (OPC)	3.09
Silica fume	2.28
Fly ash	2.96
Glass powder	3.01
Coarse aggregate	2.9
Fine aggregate	2.62
Water	1

Table 3.5

3.2 Methodology:

A nominal mix of concrete of proportion 1:2:4 was adopted for the present study. The first mix MC1 is control mix having only cement as binder. The MCF series had fly ash as replacement of cement. The MCS & MCG series had silica fume and glass powder as replacement of cement. The compressive strength test were conducted to monitor the strength development of concrte containing 15% & 30% of these pozzolana as cement replacement. The particle size effect of glass powder studied by using glass powder of size (150-100)µ and (50-100)µ. Capillary absorption test is conducted to study the effect of alkali aggregate reaction.

The EDS analysis and SEM analysis of the mixes were done to study the change in the morphological characteristics of concrete mixes

- The tests were conducted in two series.
- In first Series 30 % of pozzolana were used as partial replacement of cement.
- In second series 15% of pozzolana were used as partial replacement of cement.
- Eleven numbers of standard cubes (150x150x150 mm) were cast to measure the compressive strength after 28days and 52 days. Two cube were retained to measure capillary absorption after 28 days and 52 days respectively.

- The EDS analysis and SEM analysis of the mixes were done after 28 days and 52 days to study the change in the morphological characteristics of concrete mixes.

To study the characteristics following tests were conducted:

Normal consistency

Normal consistency of different binder mixes determined by using the procedure referring to IS 4031: part 4 (1988) :

- 300 gram of sample coarser than 150μ sieve is taken.
- Approximate percentage of water added to sample and mixed methodically for 2-3 minutes.

Fig. 3.10

- After applying oil to the surface of mould, paste was filled in the vicat's mould and was placed under the needle of vicat's apparatus.
- Release quickly the needle allowing it to sink in the paste and note down the penetration reading when the needle becomes stable.
- If the penetration reading is less than 5 to 7 mm, prepare the paste again with more water and repeat the above procedure until the needle penetrate to a depth of 5 to 7 mm.
- The percentage of the water with which the above situation is satisfied is called normal consistency.

Compressive Strength Test

For each series five set were cast to determine compressive strength. Each set comprises of eleven standard cubes out of which nine cubes were cast to measure the compressive strength after 28days and 52 days. The size of the cube is as per the IS code 10086 – 1982.

Fig.3.11

Capillary absorption Test

Out of eleven standard cubes two cubes were retained to measure capillary absorption coefficients after 28 days and 52 days curing respectively. This test is conducted to measure the capillary absorption which indirectly measures the durability.

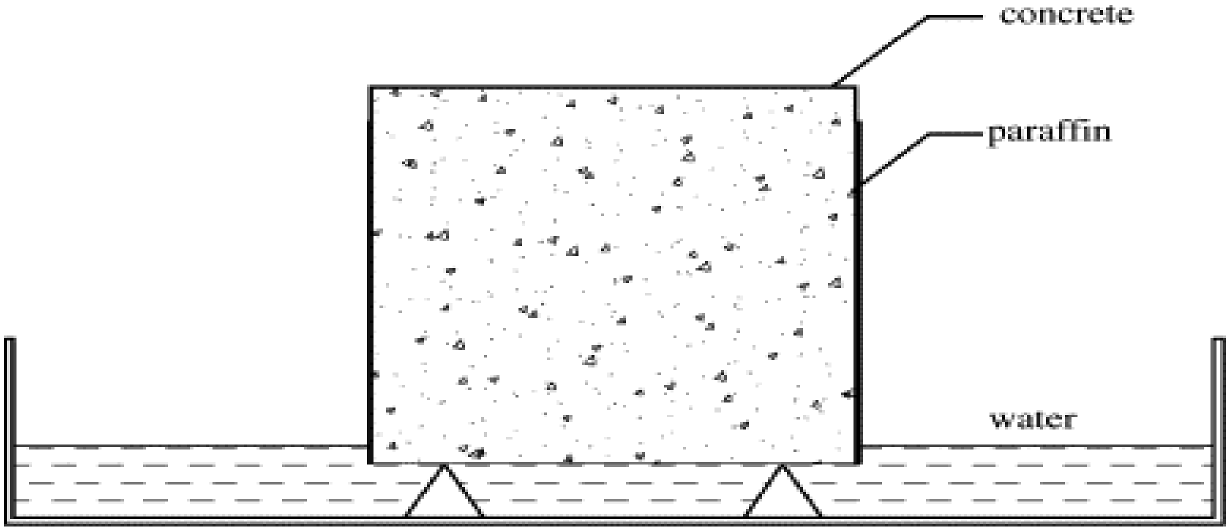


Fig. 3.12

Procedure:

- The sample was dried in oven at 105ºC until constant mass was obtained.
- Sample was cool down to room temperature for 6hr.
- The side of the sample was coated with paraffin to attain unidirectional flow.
- The sample was exposed to water on one side by placing it on a pan filled with the water.
- The water in the pan was kept about 5mm above the base of the specimen as shown in the figure below.
- The weight of the sample was measured at 15 and 30 minutes intervals.

- The capillary absorption coefficient (k) was calculated by using formula:

$$k = Q/A * \mathrm{sqrt}(t)$$

where, Q= amount of water absorbed

A = cross sectional area in contact with water

t = time

Fig. 3.13

CHAPTER 4

RESULTS & DISCUSSION

RESULTS AND DISCUSSIONS

Normal consistency of binder mixes were tabulated below:

Mix	Description	Cement(g)	Silica fume(g)	Fly ash(g)	Glass powder(g)	Consistency(%)
MC	CEMENT	300	0	0	0	31.2
MCS	MC with 15% SF	255	45	0	0	36.67
MCF	MC with 15% FA	255	0	45	0	38.3
MCG 1	MC with 15% GP	255	0	0	45	37.2
MCG 2	MC with 30% GP	210	0	0	90	38.5

Table 4.1

Where, MC= pure cement, SF= silica fume, FA= fly ash, GP= glass powder

Compressive Strength

The results of compressive strength testing of laboratory-cured cubes are presented in Table 4.2. and Table 4.3 for First series with 30% cement replacement and Second series with 15% cement replacement respectively. The strength values reported are the average of three test results. Fig. and Fig. are graphical representation of strength development of concrete cubes of various mixes for the First series and second series respectively.

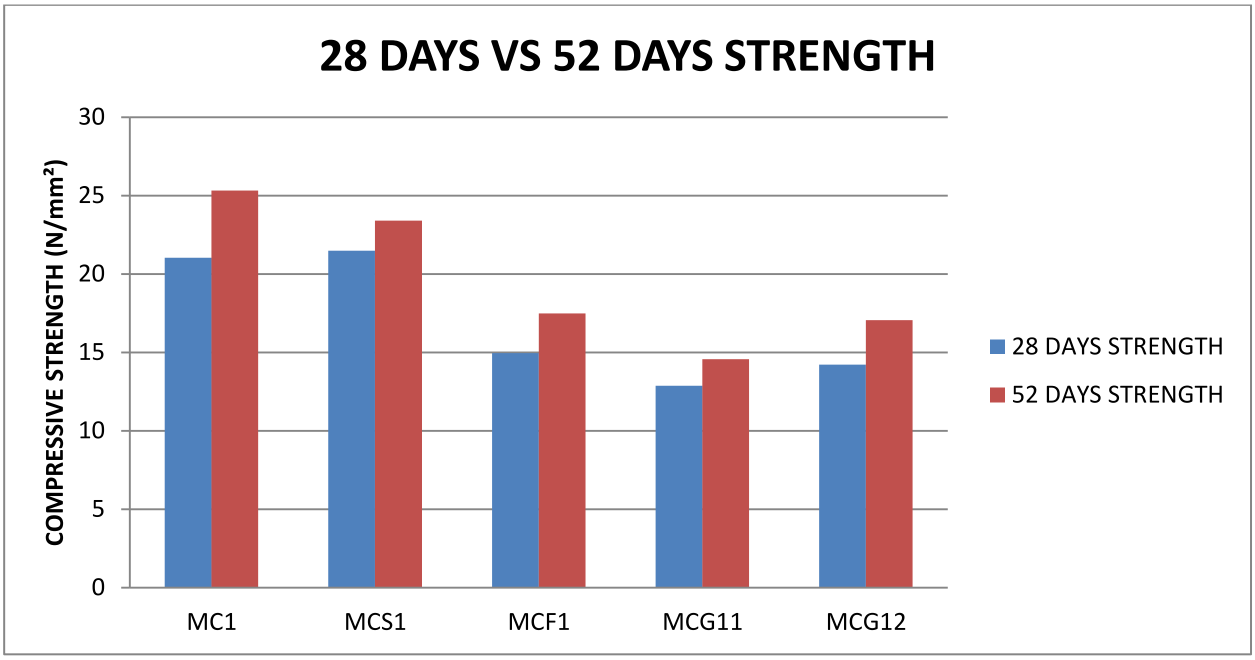
Compressive Strength of series after 28 days and 52 days were tabulated below:

First Series

DESIGN MIX	28 days (N/mm²)	52 days (N/mm²)
MC1	21.03	25.33
MCS1	21.48	23.41
MCF1	14.96	17.48
MCG11	12.88	14.57
MCG12	14.22	17.05

Table 4.2

Where, Where, Mix MC1= Only OPC cement
Mix MCS1= cement + 30% silica fume
Mix MCF1= cement + 30% fly ash
Mix MCG11= cement+ 30% glass powder (150-100) micron
Mix MCG12= cement + 30% glass powder (<100) micron



Compressive Strength of mixes with 30% replacement of cement.
Fig. 4.1a

<u>Second Series</u>

DESIGN MIX	28 days (N/mm²)	52 days (N/mm²)
MC2	21.03	25.33
MCS2	22.88	24.88
MCF2	15.556	18.815
MCG21	13.77	14.67
MCG22	15.11	19.57

Table 4.3

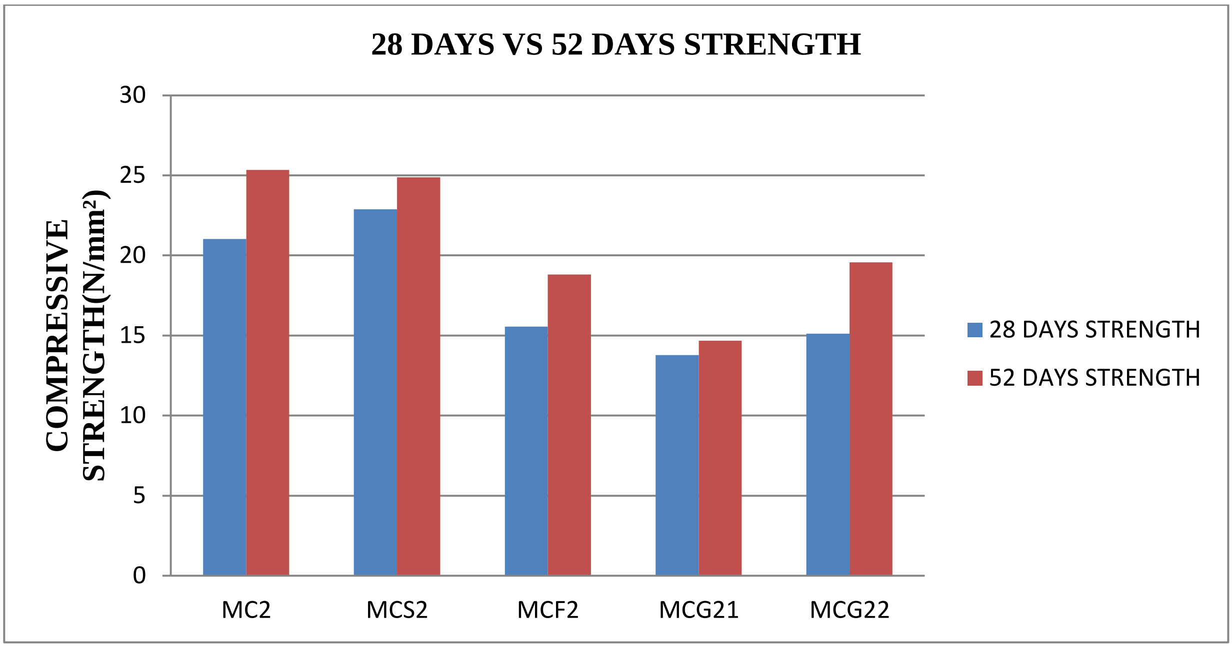
Where, Mix MC2= Only PPC cement

Mix MCS2= cement + 15% silica fume

Mix MCF2= cement + 15% fly ash

MixMCG21= cement+ 15% glass powder (150-100) micron

Mix MCG22= cement + 15% glass powder (100-50) micron



Compressive Strength of mixes with 15% replacement of cement

Fig. 4.1b

The results indicate that silica fume replacement produces higher strength than the glass powder and fly ash replacement. The strength development of concrete mix with glass powder of size <100μ is almost or more than the concrete mix with fly ash as cement replacement. This is confirmed from the results of both the series. The graphical representation of this result is shown in Fig.4.2& Fig 4.3.

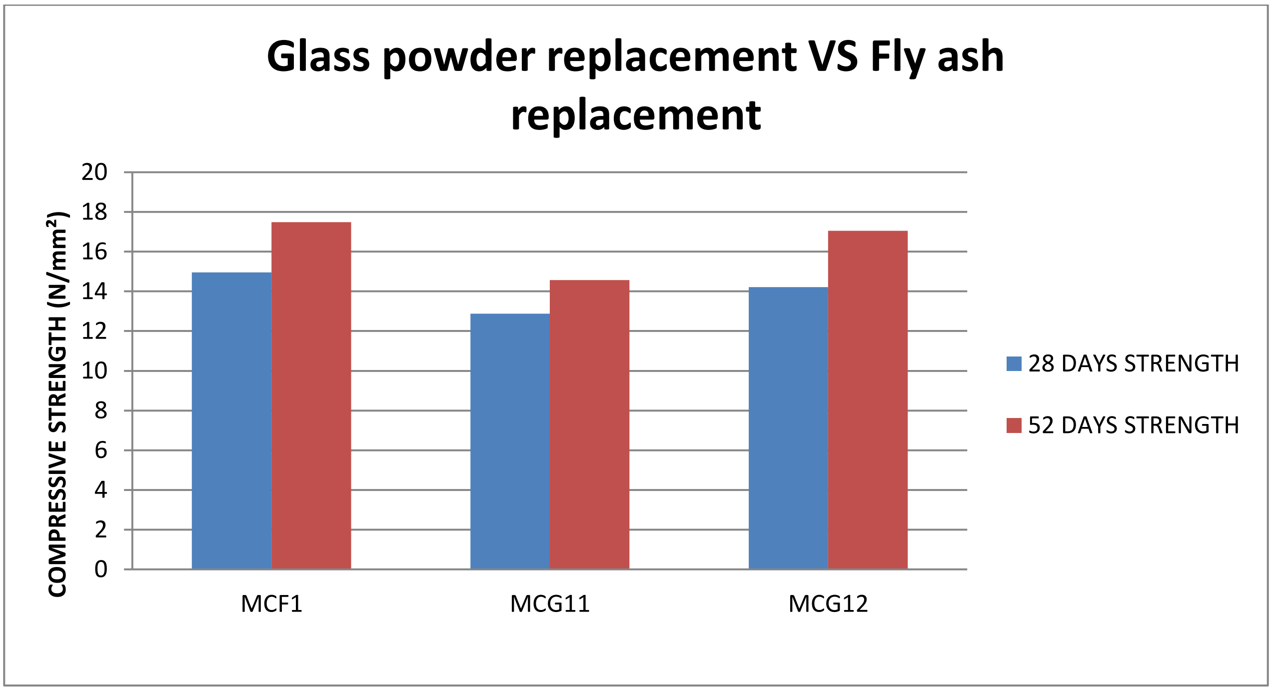


Fig. 4.2

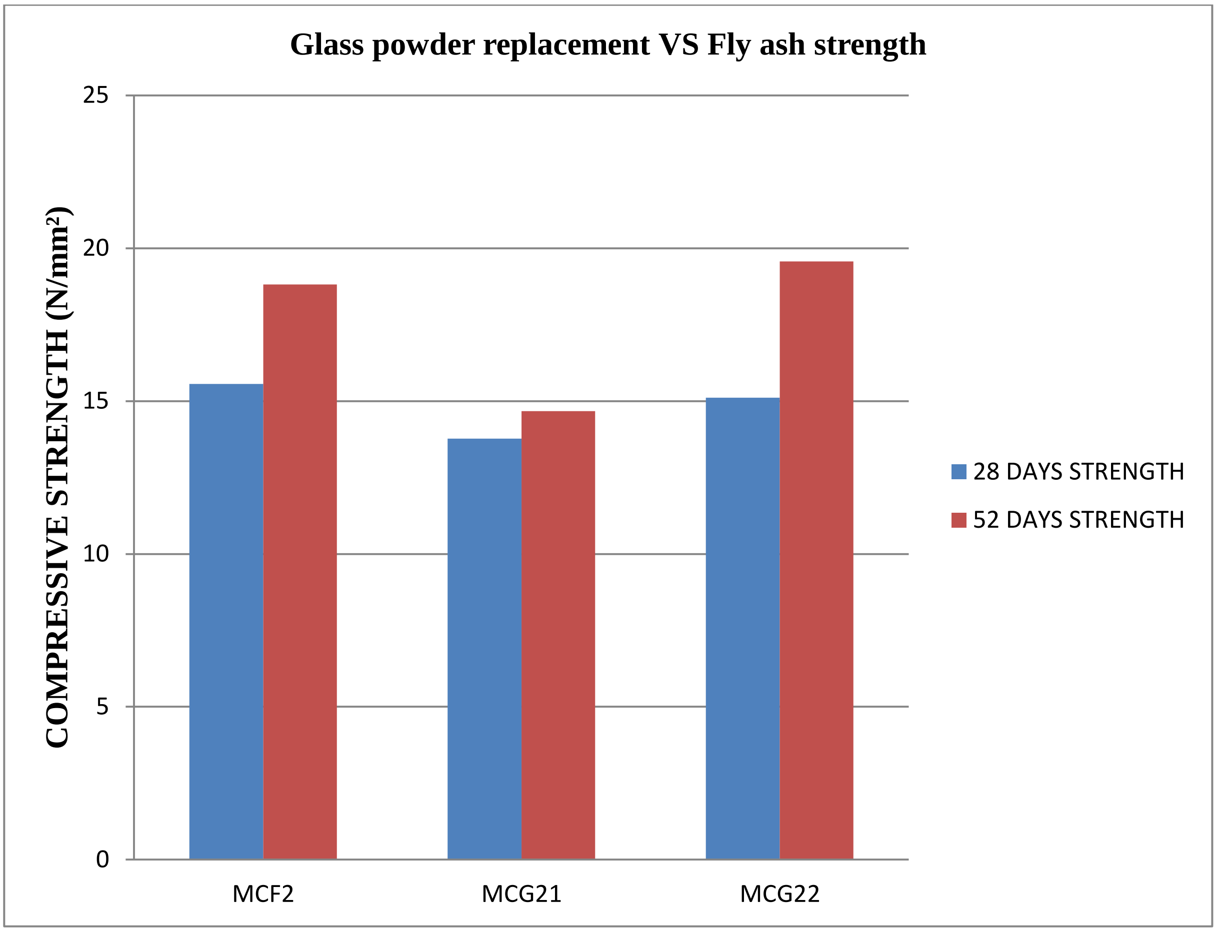


Fig. 4.3

Coefficients of capillary absorption of series after 28 days and 52 days were tabulated below:

Series 1

DESIGN MIX	28 days($k*10^{-3}$ cm/s)	52 days($k*10^{-3}$ cm/s)
MC1	3.02	2.98
MCS1	1.65	1.57
MCF1	1.52	1.82
MCG11	2.85	3.14
MCG12	1.73	1.59

Table 4.4

The data shows that capillary absorption reduces due to addition of SCMS because they act like fillers and pozzolanic reactions form extra gel which makes cement matrix denser .The k value is lowest for silica fume concrete.The glass powder concrete MCG12 also has lower k value ,indicating denser matrix formation . The mix MCG11 has highest k value probably due to bond failure because of alkali-silica reaction.The fly ash concrete shows better performance than the control mix MC1.

4.1MICROSTRUCTURAL EXAMINATION OF CONCRETE CORES

Scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) analysis were used to examine the nature of the hydrated binder and the binder-aggregate interfacial zones. The EDX analyses are also conducted . Note that the peak height in the EDX spectra is proportional to the amount of element present. A brief summary of SEM/EDX analysis is given below.

Figure below shows the typical composition of hydrated paste in Mix MC1(control mix) and its interface with the aggregate.

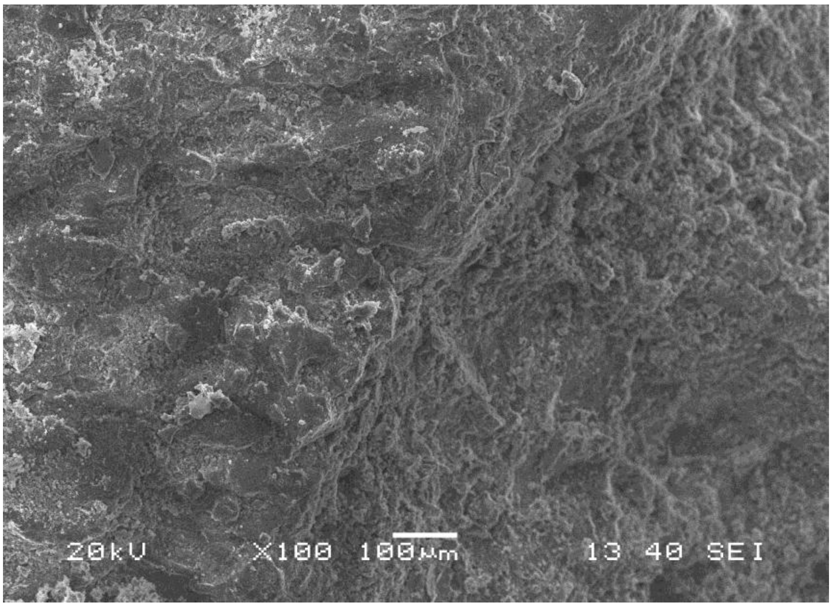


Fig4.4 (mc1)

Figure below shows the typical composition of hydrated paste in Mix MC1(control mix) and its interface with the aggregate.

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
O K	23.96	0.4956	55.48	28.78	72.89
Si K	13.11	0.8961	16.79	12.76	12.57
Ca K	24.07	0.9965	27.73	19.79	14.54
Totals			100.00		

Table 4.5

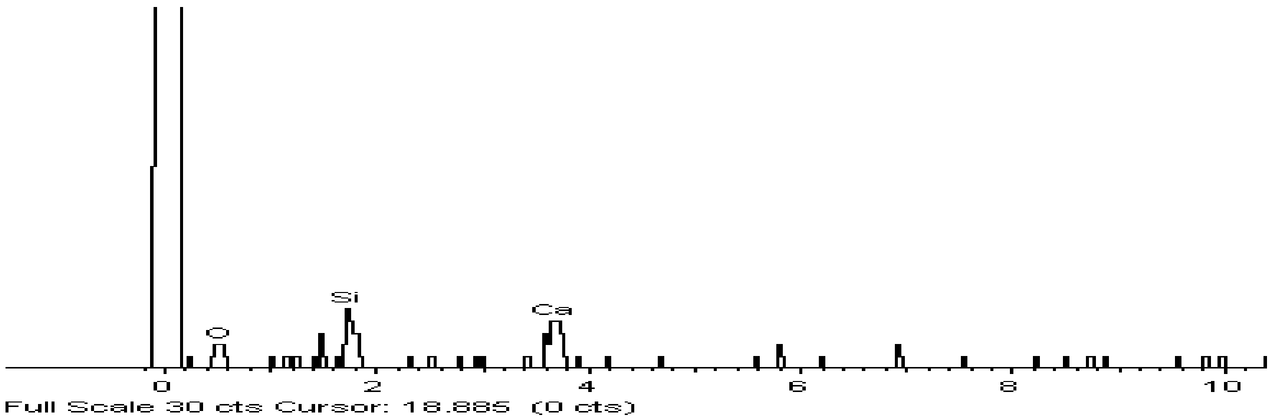


Fig.4.5 (XRD)

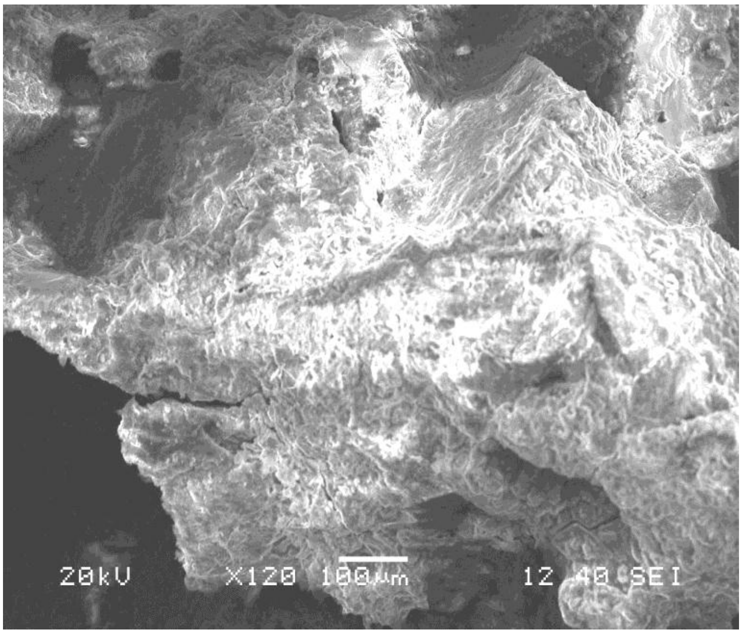


Fig.4.6 (mcs)

The paste in Mix 2, which contained silica fume was found to have been enriched with silica.The reaction product had small amounts of Na and large amounts of Ca and silica. The compositions may reflect the composition of the pozzolanic reaction product.

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
O K	61.61	0.6107	60.05	1.62	75.62
Na K	0.15	0.7054	0.13	0.40	0.11
Al K	3.25	0.8057	2.40	0.38	1.79
Si K	24.92	0.8698	17.06	0.88	12.23
K K	1.01	1.0638	0.57	0.25	0.29
Ca K	32.67	0.9823	19.80	1.00	9.95
Totals			100.00		

Table. 4.6

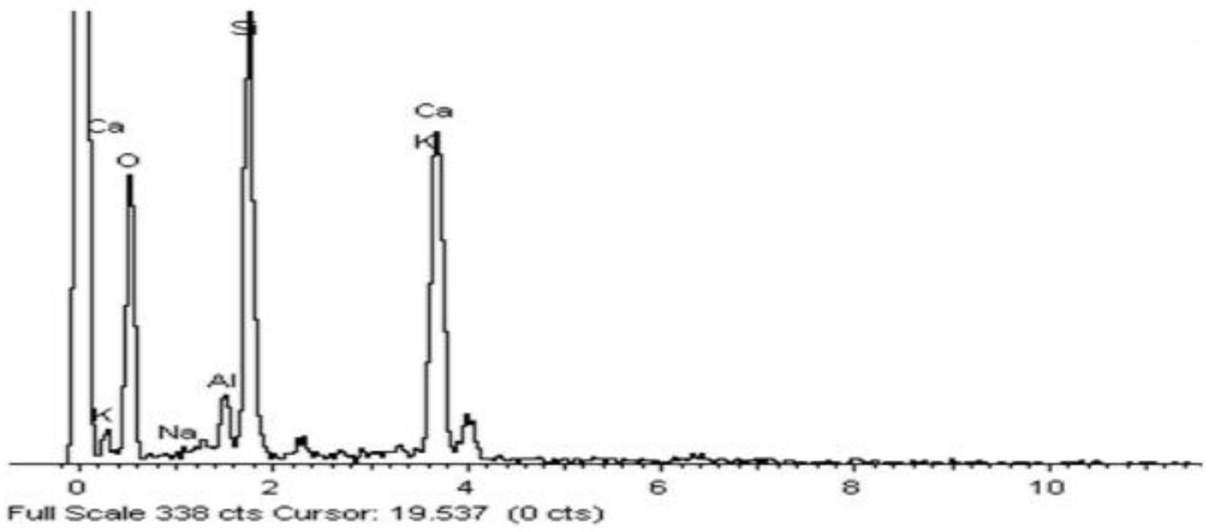


Fig. 4.7

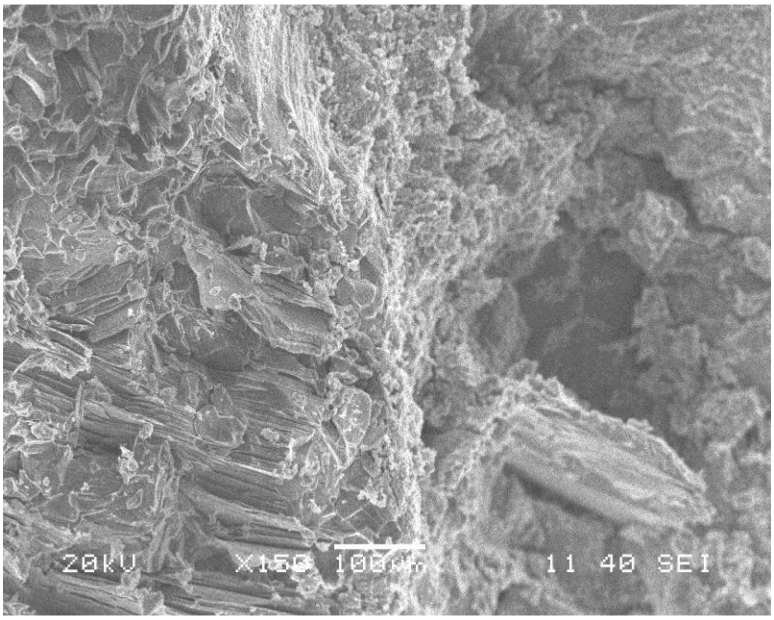


Fig.4.8 (mcf)

The SEM view of MCF shows a denser cement matrix having voids. The matrix is enriched with silica and Ca.

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
O K	69.37	0.7963	64.35	14.62	77.81
Al K	10.34	0.8148	9.37	7.10	6.72
Si K	14.63	0.7986	13.53	8.04	9.32
Ca K	16.84	0.9757	12.75	10.42	6.15
Totals			100.00		

Table 4.7

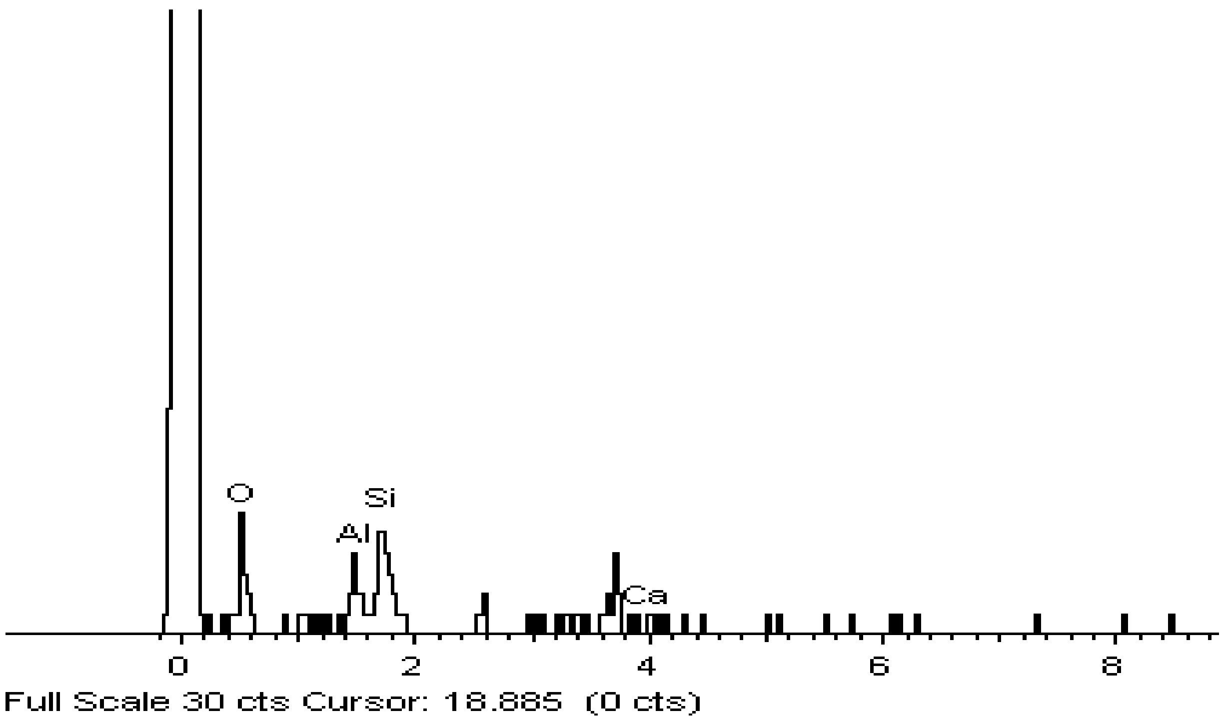


Fig.4..9

Glass powder

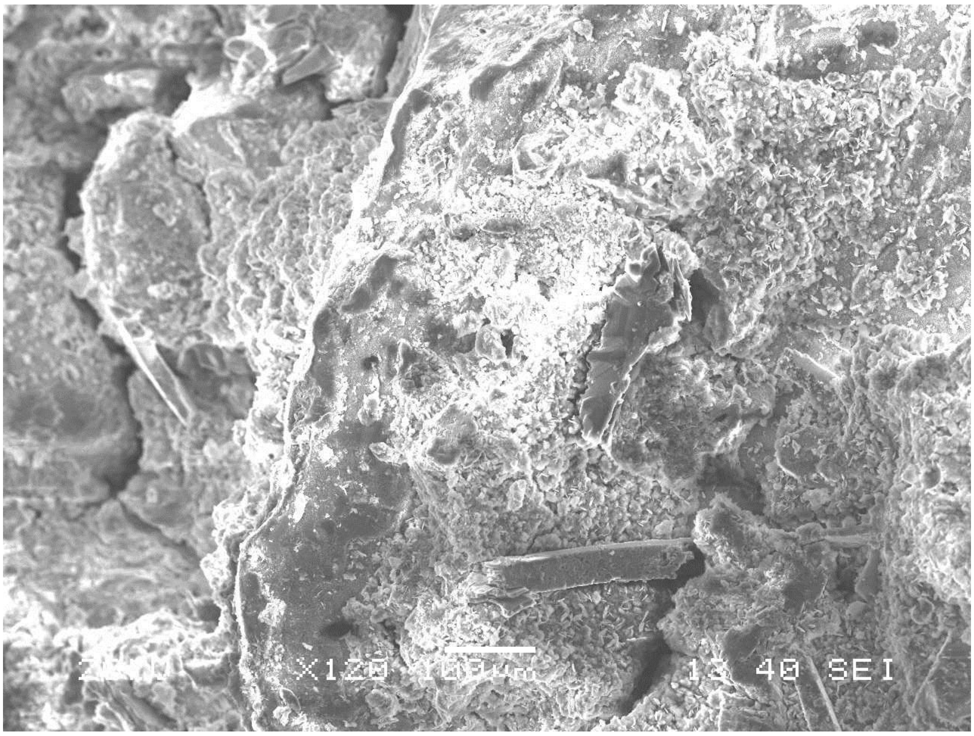
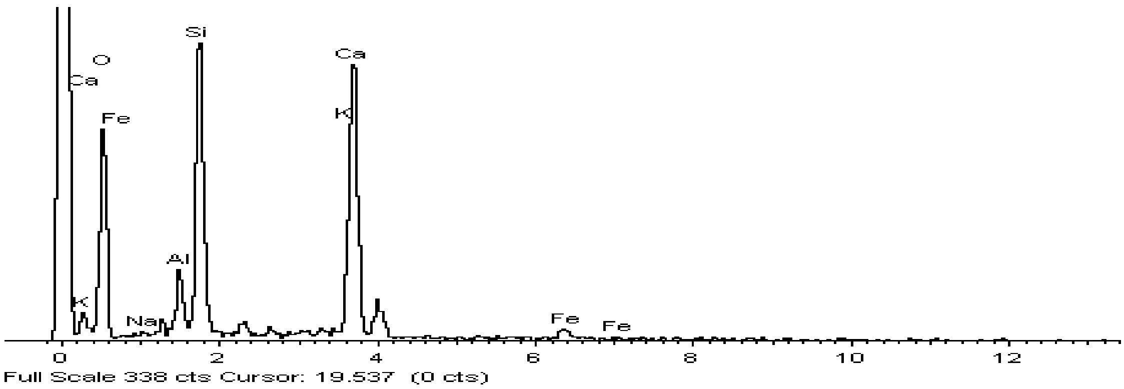


Fig.4.10 (mcg1)

The SEM view and EDX composition of the reacted surface of a GLP particle in Mix MCG11.Flakier glass particals are visible in the view. Near a glass particle (lower right) the fine needle-shaped crystals in the paste are probably ettringite. The analysis shows a presence of Na and interfacial bond failure is clearly visible.

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
O K	60.47	0.6016	58.71	1.68	75.01
Na K	0.36	0.6901	0.31	0.36	0.27
Al K	3.89	0.7925	2.87	0.41	2.17
Si K	22.42	0.8552	15.32	0.83	11.15
K K	0.42	1.0731	0.23	0.25	0.12
Ca K	35.51	0.9899	20.96	1.03	10.69
Fe K	2.24	0.8120	1.61	0.55	0.59
Totals			100.00		

Table 4.8



Si
Ca
O
Ca
Fe
K
Al
K
Na
Fe
Fe
0
2
4
6
8
10
12
Full Scale 338 cts Cursor: 19.537 (0 cts)

Fig. 4.11

MCG2

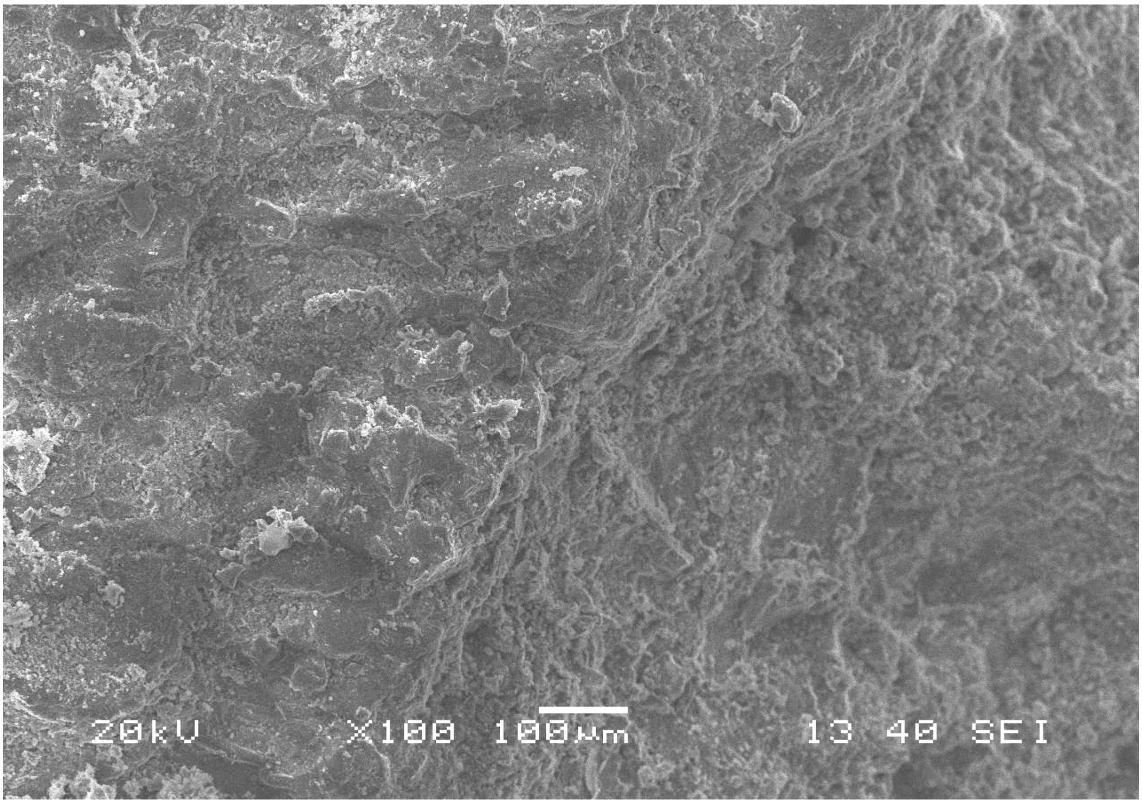


Fig.4.12

The SEM view and EDX composition of the reacted surface showed enrichment in silica, and incorporation of fine glass particles into the paste was clearly noted

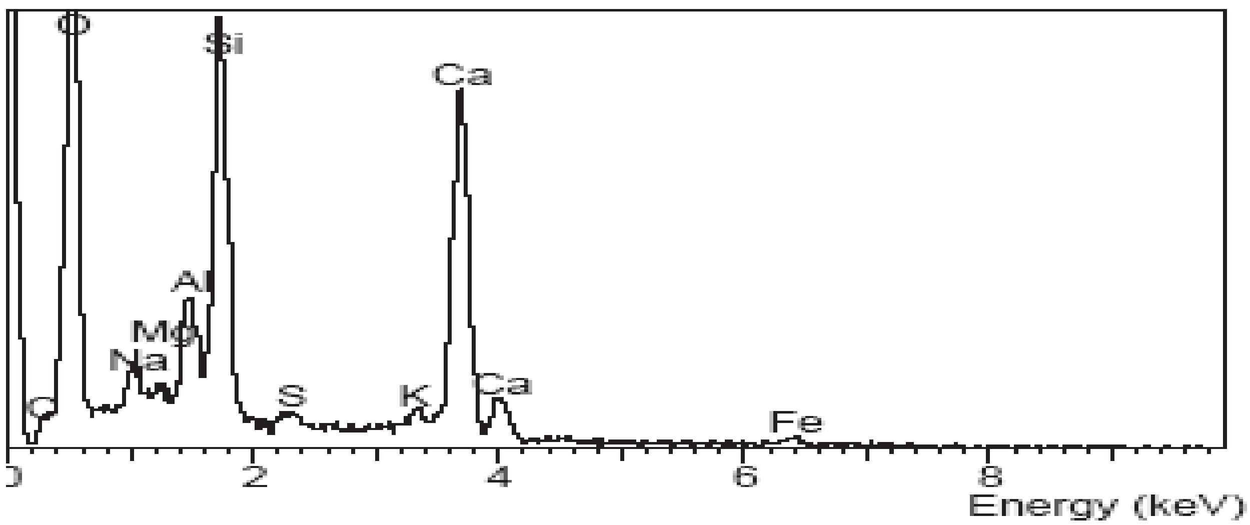


Fig. 4.13

CHAPTER 5

CONCLUSION

1. Waste glass, if ground finer than 100μm shows a pozzolanic behavior.
2. The smaller particle size of the glass powder has higher activity with lime resulting in higher compressive strength in the concrete mix.
3. Compared to fly ash concrete, finer glass powder concrete had slightly higher early strength as well as late strength.
4. Micro structural examination shows that glass powder produces a denser matrix which improves the durability property of concrete.
5. The coefficient of capillary absorption test also indicates that incorporation of finer glass powder improves durability.
6. Glass powder of size 150μm - 100μm exhibit initiation of alkali aggregate reaction. The presence of ettringite confirms this.
7. The data presented in this study indicates that silica fume is best SCM. It gives highest compressive strength because of its smaller grain size and spherical shapes.
8. The results obtained from the present study shows that there is great potential for the utilization of best glass powder in concrete as replacement of cement.
9. The fine glass powder can be used as a replacement for expensive materials like silica fume and fly ash.
10. It can be concluded that 30% of glass powder of size less than 100μm could be included as cement replacement in concrete without any unfavorable effect.

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