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FLEXURAL BEHAVIOR OF SELF COMPACTING GEOPOLYMER CONCRETE USING GGBFS WITH VARIOUS REPLACEMENTS OF R-SAND AND M-SAND

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ABSTRACT

This paper presents an experimental investigation on flexural response of self-compacting geopolymer concrete (SCGC) beams by partial replacement of fly ash by GGBFS and various replacement of River sand by M-sand under two point loading. Mixtures were prepared with alkaline liquid to binder ratio by mass value is 0.33 for mix M1, M2, M3, M4, M5.The molarity of sodium hydroxide is 12M and replacement of fly ash by GGBFS of 30% is kept as constant for all mix. The ratio between sodium hydroxide to sodium silicate solution is 1:2.5. The specimen was cured for 48 hrs of heat curing and 28 days of ambient curing. Super Plasticizer is added to achieve the properties of self-compacting geopolymer concrete (SCGC). It is found that the SCGC beams have shown good improvement in flexural strength.

Keywords: self compacting geopolymer concrete, river sand, M-Sand, load deflection, failure modes, ductility.

INTRODUCTION

Self-compacting concrete is an innovative concrete that does not require any vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. Self-Compacting Concrete is a complex system that is usually proportioned with one or more additions and one or more chemical admixtures. A key factor for a successful formulation is a clear understanding of the role of the various constituents in the mix and their effects on the fresh and hardened properties [1]. Successful self-compacting concrete must have high fluidity (for flow under self-weight), high segregation resistance (to maintain uniformity during flow) and sufficient passing ability so that it can flow through and around reinforcement without blocking or segregating [12]. The longer curing time improves the geopolymerisation process resulting in higher compressive strength. Increase in compressive strength was observed with increase in curing time. The compressive strength was highest when the specimens were cured for a period of 96 hours however; the increase in strength after 48 hours was not significant. Compressive strength of concrete increased with the increase in curing temperature from 60°C to 70°Chowever an increase in the curing temperature beyond70°C decreased the compressive strength of self compacting geopolymer concrete [7]. One alternative to reduce the cost of self-compacting concrete is the use of additions. Due to the better engineering and performance properties, additions such as silica fume, fly Ash, and ground granulated blast-furnace slag are normally included in the production of high-strength and high-performance concrete[9]. The most often used fillers increasing viscosity of self-compacting concrete mixtures are fly ash, glass filler, limestone powder, silica fume and quartzite filler. More recently, environmental arguments began to prevail, in particular the need to decrease the overall CO_2 production related to the use of cement in concrete [1]. Fly ash [14], ground granulated blast furnace slag and silica fume [9] was the most frequently applied in self compacting concrete. The incorporation of mineral admixtures also eliminates the need for viscosity-enhancing chemical admixtures. The lower water content of the concrete leads to higher durability, in addition to better mechanical integrity of the structure. It is also known that some mineral admixtures may improve rheological properties and reduce thermally-induced cracking of concrete due to the reduction in the overall heat of hydration and increase the workability and long-term properties of concrete [2]. One of the most important differences between self-compacting concrete and conventional concrete is the incorporation of mineral admixture. Since cement is one of the most expensive components of concrete, reducing the cement content is one of the economical solutions. Besides these economical benefits, the use of by products or waste materials reduces environmental pollution.

In this study, it is aimed to investigate the effect of fly ash, silica fume, and ground granulated blast furnace slag as mineral admixtures on the fresh and hardened properties of Self-Compacting geopolymer Concrete. Fresh concrete tests such as slump-flow, L-box, T_{500}, U-box and hardened concrete tests such as compressive strength, split tensile strength, flexural strength were conducted.

B.V.Rangan suggested that the behavior and failure mode of reinforced geopolymer concrete beams were similar to those observed in the case of reinforced Portland cement concrete beams. The flexural capacity of beams was influenced by the concrete compressive strength and the tensile reinforcement ratio. The flexural strength of reinforced geopolymer concrete beams was calculated using the conventional flexural strength theory of reinforced concrete beams as described in standards and building codes such as the draft Australian Standard. The observation was mainly focused on reinforced concrete beam behavior at different points of interest which were then tabulated and compared. From these observation it shows that 1st cracking location is 0.43L ~ 0.45L from the support. Maximum load carrying capacity at 1st cracking was observed for over reinforced beam but on the other it was the balanced condition beam at ultimate load. Maximum deflection at failure was also observed for the beam that balanced reinforced [14].

MATERIALS

The materials used for making self-compacting geopolymer concrete specimens are low calcium fly ash and GGBFS as the source material, manufacture sand, river sand, coarse aggregate as the filler, alkaline such as sodium hydroxide solution, sodium silicate solution were as binder and water and super plasticizer as workability measure.

FLY ASH

In this investigation, class F type of fly ash shown in Figure-1 is obtained from mettur power plant, and their Physical and Chemical properties are given in Table 1 and 2.

Figure-1. Fly ash.

Table-1. Physical properties of fly ash.

Properties	Values
Finesses modulus (passing through 45 micro meter)	7.86
Specific gravity	2.21

Table-2. Chemical properties of fly ash.

Chemical properties Min% by mass	IS:3812-1981	Fly ash MTTP
Sio_2+Al_2O_3+Fe_2O_3	70	90.5
SiO_2	35	58
CaO	5	3.6
SO_3	2.75	1.8
Na_2O	1.5	2
L.O.I	12	2
MgO	5	1.91

FINE AGGREGATES

MANUFACTURED SAND

In the present investigation, the manufacture sand shown in Figure-2, which was available near Coimbatore, which belong to zone II was used as fine aggregate and the following tests were carried out as per IS:383-1970. The physical properties are shown in Table-3.

- Specific gravity
- Sieve analysis
- Fineness modulus

Figure-2. Manufactured sand.

Table-3. Physical properties of manufactured sand.

Properties	Value
Specific gravity	2.85
Finesses modulus (passing through 4.75mm sieve)	2.64

Table-4. Physical properties of river sand.

S. No.	Properties	Values
1	Specific Gravity	2.67
2	Fineness Modulus	2.25

RIVER SAND

Clean and dry river sand available locally will be used. Sand passing through IS 4.75mm Sieve will be used for casting all the specimens. The properties of fine aggregate are shown in Table-4

COURSE AGGREGATE

In the present investigation, locally available crushed granite stone aggregate of 12mm used and the various tests, were carried out as per IS:2386-1968 Part III. Their physical properties are shown in Table-5.

- Specific gravity
- Sieve analysis
- Fineness modulus

Table-5. Physical properties of coarse aggregate.

Proportion	Value
Specific gravity	2.66
Finesses modulus	7.00

WATER

In the present investigation, potable water was used as said IS 456-2000 for the plain and Reinforced concrete.

SODIUM HYDROXIDE

Generally the sodium hydroxide (NaOH) is available in solid state in the forms of pellets and flakes shown in Figure-3. The cost of the sodium hydroxide is very high according to the purity of the substance. In this investigation 94 to 96% purity NaOH is used. If NaOH is not used, the mixture was too viscous to cast and the slump was zero. The slump increased with increasing NaOH content from 5% to 12.5%.

In this investigation the sodium hydroxide pellets were used. Whose chemical property and physical property are given by manufacturer solid sodium hydroxide as shown in Tables 6 and 7 respectively?

Figure-3. Sodium hydroxide.

Table-6. Physical properties of sodium hydroxide.

Properties	Colour less
Specific gravity	2.13
pH	14

Table-7. Chemical properties of sodium hydroxide.

Assay	97 %	Min
Carbonate(Na_2co_3)	2%	Max
Chloride(Cl)	0.01%	Max
Sulphate(so_2)	0.05%	Max
Lead(pb)	0.001%	Max
Iron(Fe)	0.001%	Max
Potassium(K)	0.01%	Max
Zinc(Zn)	0.02%	Max

SODIUM SILICATE

Sodium silicate also known as water glass or liquid glass is available in liquid (gel) form. In present investigation the ratio between sodium hydroxide and sodium silicate is taken as 1:2.5. The chemical properties and the physical properties of the silicates are given by the manufacture as shown in Table-8.

Table-8. Physical and chemical properties of sodium silicate.

Chemical formula	Na_2O x SiO_2
Na_2O	15.9%
SiO_2	31.4%
H_2O	52.7%
Appearance	Liquid(gel)
Colour	Light yellow liquid (gel)
Boiling point	102 C for 40% aqueous solution
Molecular weight	184.04
Specific gravity	1.6

ALKALINE SOLUTIONS

There are varies alkaline solutions are available in market to produce geopolymer concrete. In this investigation Sodium hydroxide and Sodium silicate are used.

SUPER PLASTICIZER (GLENIUM B233)

Glenium B233 is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. It is free of chloride and low alkali. It is compatible with all types of cements. The hyper plasticizer shall be Glenium B233, high range water reducing, super plasticizer based on polycarboxylic ether formulation. Optimum dosage of Glenium B233 should be determined with trial mixes. As a guide, a dosage range of 500 ml to 1500ml per 100kg of cementitious material is normally recommended. Properties of Glenium B233 shown in Table-9.

Table-9. Properties of glenium B233.

Aspect	: Light brown liquid
Relative Density	: 1.09 ± 0.01 at 25°C
pH	: >6
Chloride ion content	: < 0.2%

Ground granulated blast furnace slag (GGBFS)

It 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.

It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, hydrates like portland cement (Admixtures and ground slag 1990; Lewis 1981; ACI Comm. 226 1987a). ASTM C 989-82 and AASHTO M 302 were developed to cover ground granulated blast furnace slag for use in concrete and mortar. The three grades are 80, 100, and 120.

Most GGBS is a by-product from the blast-furnaces used for manufacturing iron. The way of its production is that the blast-furnaces are fed with carefully controlled mixtures of iron-ore, coke and limestone, with temperatures of about 1500^o C. The slag is rapidly put out in volumes of water. The process of putting out improves the cementitious properties and produces granules similar to coarse sand particles. The ‘granulated slag’ is become dry and ground to a fine powder that is called GGBS. It has off-white colour and a bulk density of 1200 kg/m^3. The Chemical compositions of GGBS shown in Table-10.

Table-10. Chemical compositions of GGBS.

Chemical composition	Percentage
Calcium oxide (CaO)	40%
Silica (SiO2)	35%
Alumina (Al2O3)	16%
Magnesia (MgO)	6%
Other- Fe2O3, etc.	3%

PREPARATION OF SELF COMPACTING GEOPOLYMER CONCRETE SODIUM HYDROXIDE

Sodium hydroxide pellets are taken and dissolved in water at various molar concentrations. Sodium hydroxide should be prepared 24 hours prior to use and also if it exceeds 36 hours it terminate to semi solid liquid state. So the prepared solution should be used with in this time. To find the best molarity various calculations where done.The mass of NaOH solids in solution varied depending on the concentration of the solution expressed in terms of molarity (M). Mass of NaOH per Litre shown in Table-11.

Table-11. Mass of NaOH per litre.

NaOH	% of solids	% of water
8M	26.23	73.77
10M	31.37	68.63
12M	36.09	63.91
14M	40.43	59.57

MOLARITY CALCULATION

The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in different molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution.

NaOH solution with a concentration of 12 molar consist of 12x40 = 480grams of NaOH solids per litre of water, were 40 is the molecular weight of NaOH.

This amount of NaOH solids in one litre of water will be large of its volume so it reduces to 361 grams for 12 molar concentrations.

ALKALINE LIQUID

Generally alkaline liquids are prepared by mixing of sodium hydroxide solution and sodium silicate at the room temperature. When the solutions mixed together the both solution start to react with each other there polymerization process take place. It liberate large amount of heat so it is recommended to leave it for about 20 minutes thus the alkaline liquid is ready as binding agent.

PREPARATION, CASTING, AND CURING OFSPECIMENS

For the preparation of fresh SCGC, fine powdered materials (i.e., fly ash, GGBFS, and manufactured sand) were firstly placed in a mixer machine. Afterwards, the coarse aggregate in SSD condition was added to the mixer and mixed mechanically for about 2.5 min. At the end of this dry mixing, a well-shacked premixed liquid mixture, containing of alkaline solution, super plasticizer, and extra water, was added in the mixer. This duration was not less than 3 min.

The Flexure behavior of hardened concrete beams specimens was prepared. The reinforcement bars were place before pouring the concrete in the mould. The fresh concrete was thoroughly mixed by hand and poured into

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beam moulds without compaction, filling all the spaces of moulds by its own weight. The top surface of specimens was scraped to remove the excess material and achieve the smooth.

After casting, without any delay, the specimens along with steel moulds were placed in the oven at a temperature of 60ºC for 48 hours shown in Figure-4. At the end of this oven curing period, test specimens were removed from the moulds and placed in room temperature conditions for the Ambient curing until the test day shown in Figure-5.

Figure-4. Heat curing specimens.

Figure-5. Ambient curing specimens.

MIX DESIGN OF SELF COMPACTING GEOPOLYMER CONCRETE

The mix design in the case of self-compacting geopolymer concrete is totally different of conventional concrete. The design is made by the help of EFNARC guidelines. Typical range of SCC constituents suggested by EFNARC is shown in Table-12.

For this study, five mixtures with fixed value of GGBFS content as 30% and with various replacement of M - sand and R- sand. The water to geopolymer solids (W/G) ratio by mass for all the mixes was maintained at 0.33 and the total powder content was fixed at 450 kg/m^3. To obtain the required workability characteristics of SCGC, a water content of 12% and super plasticizer dosage of 6% by mass for the binder were used. Mix Proportions Based on Replacement of R-Sand and M-Sand shown in Table-13.

Table-12. Typical range of SCC constituents suggested by EFNARC.

Constituent	Typical range by mass (kg/m^3)	Typical range by volume (liters/m^3)
Powder	380 – 600	-
Paste	-	300 - 380
Water	150 – 210	150 - 210
Coarse aggregate	750 – 1000	270 - 360
Fine aggregate (sand)	Content balances the volume of the other constituents, typically 48 - 55% of total aggregate weight.	
Water/Powder ratio by volume		0.85-1.10

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Table-13. Mix proportions based on replacement of R-Sand and M-Sand.

Mix no	Cement	Fly Ash	GGBFS	M sand	R Sand	CA	NaoH	Na_2SiO_3	Molarity	SP	W/G's	H_2O
M1	-	315	135	-	900	1000	57	143	12	6%	0.33	12%
M2	-	315	135	675	225	1000	57	143	12	6%	0.33	12%
M3	-	315	135	450	450	1000	57	143	12	6%	0.33	12%
M4	-	315	135	225	675	1000	57	143	12	6%	0.33	12%
M5	-	315	135	900	-	1000	57	143	12	6%	0.33	12%

FRESH AND HARDERNED PROPERTIES OF SCGC

Fresh properties of SCGC mixes were evaluated based on three key characteristics of SCC: filling ability, passing ability, and resistance to segregation. These characteristics were measured using, test results are shown in Table-14.

- Slump Flow Test
- T_{50cm} Slump Flow
- V-Funnel Test
- L-Box Test
- U-Box Test

Following the European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC) guidelines.

Mix	Slump	T_{50cm}	V-	L-Box	U-
M1	640	7.0	15	0.85	33
M2	650	6.5	14	0.87	32
M3	660	5.5	12	0.93	30
M4	670	5	11.5	0.96	29
M5	680	4.5	10.5	0.95	28

COMPRESSION TEST

Compression test is the most common test conducted on hardened concrete, because it is an easy test to perform and most desirable characteristic properties of concrete are qualitatively related to its compressive strength. The compression test is carried out on specimen in cubical or in cylindrical shape shown in Figure-6. The test was carried out in 150x150x150mm size cubes. The test results were shown in Figure-7.

Compressive strength in Mpa=maximum load /cross section area of the cube.

Figure-6. Compressive tests on self compacting geopolymer concrete cube.

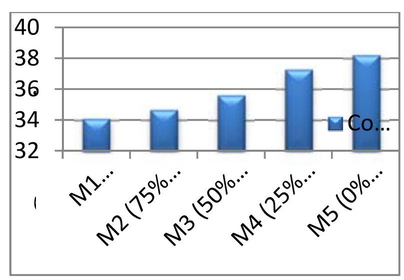

Figure-7. Compressive strength for various mix.

SPLIT TENSILE STRENGTH

The test was carried out on diameter of 150mm and length 300mm in size cylinder. The test results were shown in Figure-8.

Split tensile strength in Mpa = $2P/\pi DL$

Where,

P = compressive load in N

L = length in mm

D = Diameter in mm

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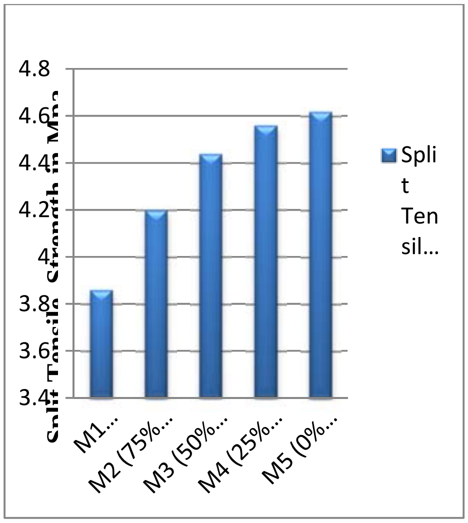

Figure-8. Flexural strength for various mix.

FLEXURAL TEST

Concrete as we know is relatively strong in compression and weak in tension. Tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other results. Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the "pull" applied to the concrete beam rest are found to be measure the flexural strength property of concrete. The test was carried out on 100 x 100 x 500 mm size prism Figure-9 shows the Flexural Test on Self-Compacting Geopolymer Concrete Prism. The test results were shown in Figure-10.

Flexural strength in Mpa = $3PL/bd^2$

Figure-9. Flexural test on self-compacting geopolymer concrete prism.

Experimental set up for beam specimens

All the beams were tested under two point loading. The beam was simply supported on hinged condition at end and a roller support at the other end. The beams were tested in a loading frame of about 1000KN capacity. The flexure load was applied on the test beam through a disturbing steel beam by a hydraulic jack of 500KN capacity. The test specimen was properly instrument for load application and measurement of load and deformations at the mid span. Each beam was tested to failure by applying loads in series of various increments and deflection noted using LVDT and the deflectometer. The experimental set up for beam is shown Figure-10.

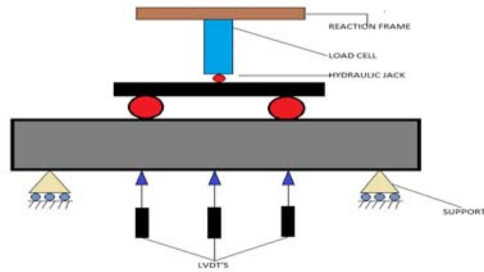

Figure-10. Test set up of beam in loading frame.

Crack Patterns and failure mode

As expected, flexure cracks initiated in the pure bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. In the case of beams with larger tensile reinforcement ratio some of the flexural cracks in the shear span turned into inclined cracks due to the effect of shear force. The width and the spacing of cracks varied along the span. In all, the crack patterns observed for reinforced geopolymer concrete beams were similar to those reported in the literature for reinforced Portland cement concrete beams.

The cracks at the mid-span opened widely near failure. Near peak load, the beams deflected significantly, thus indicating that the tensile steel must have yielded at failure. The final failure of the beams occurred when the concrete in the compression zone crushed, accompanied by buckling of the compressive steel bars. The failure mode was typical of that of an under-reinforced concrete beam. The crack patterns and failure mode of test beams are shown in Figure-11. Table-14 shows the Flexural Test Results of Beams for various Replacement of R-Sand and M-Sand.

Figure-11. Idealized load-deflections curve at mid-span.

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Table-14. Flexural test results of beams for various replacements of R-Sand and M-Sand.

Mix Id	Binder	First crack load in kN	Ultimate load in kN	Ultimate deflection in mm
M1	100% R-Sand, 0%M-Sand	6	18	4.11
M2	75% R-Sand, 25% M-Sand	8	20	4.52
M3	50% R-Sand, 50% M-Sand	8	20	4.73
M4	25% R-Sand, 75% M-Sand	9	22	4.91
M5	0% R-Sand, 100% M-Sand	10	23	5.02

Deflection

The load versus mid-span deflection curves of the test beams are presented in the following figures. Figures 12 to 16 shows the load deflection curve under both type of ambient and heat curing.

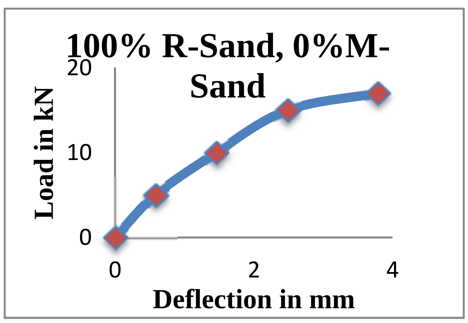

Figure-12. Load deflection curve plot for M1.

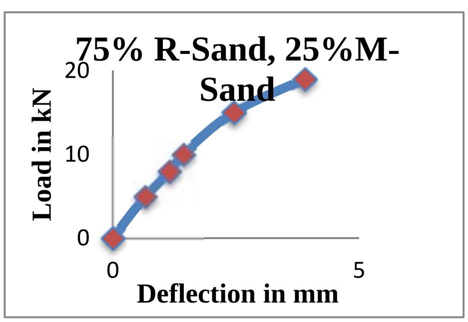

Figure-13. Load deflection curve plot for M2.

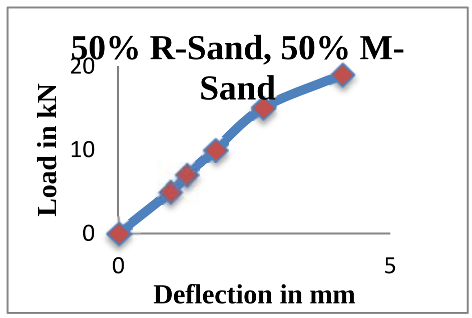

Figure-14. Load deflection curve plot for M3.

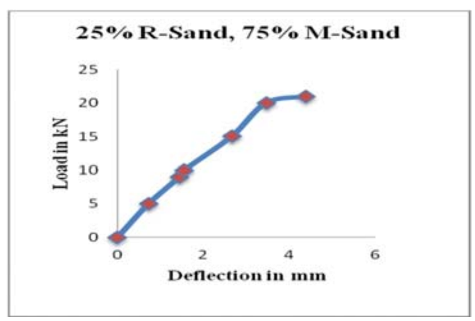

Figure-15. Load deflection curve plot for M4.

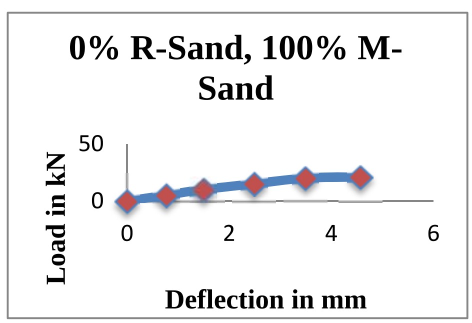

Figure-16. Load deflection curve plot for M5.

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CONCLUSIONS

- The crack patterns observed for self compacting geopolymer concrete beams were similar to those reported in the literature for reinforced Portland cement concrete beams. All beams failed in flexure in a ductile manner accompanied by crushing of the concrete in the compression zone.
- All the beams were cured by heat curing method and then ambient cure till the test day.
- The Mix M5 which has 100% M-sand and 0% R-sand gives the best result. The sharp edges of the particles in manufactured sand provide better bond with geopolymer than the rounded particles of natural sand resulting in higher strength.
- The flexural capacity of test beams was calculated using the flexural design provisions.
- The Mix M1 which has 100% R-sand and 0% M-sand has low workability and gradually increases as the percentage of M-sand increases and Mix 5 with 100% M-sand and 0% R-sand gives high workability.
- The sharp edges of the particles in manufactured sand provide better bond with geopolymer than the rounded particles of natural sand resulting in higher strength. The increase in compressive stress is marginal as compared to flexural.
- The amount of GGBFS replacement is taken as 30% of total flyash content. This is taken with reference to the previous work.
- All the beams agreed well with theoretical values.

REFERENCES

[1] Bilodeau, A. Malhotra, V.M. 2000. “High-volume fly ash system: concrete solution for sustainable development” ACI Materials Journal. Vol. 97, No.1, pp. 41-48.

[2] Bouzoubaa, N. Lachemi, M. 2001. Self-compacting concrete incorporating high volumes of class F fly ash preliminary results” Cement and Concrete Research. Vol. 31, No. 3, pp. 413-420.

[3] Brooks, J.J. Johari, M.A.M. Mazloom, M. 2000. “Effect of admixtures on the setting times of high-strength concrete” Cement and Concrete Composites. Vol. 22, No. 4, pp. 293-301.

[4] Burak Felekoglu, Selcuk Turkel, Bulent Baradan. 2007. Effect of water/cement ratio of the fresh and hardened properties of self-compacting concrete” Building and Environment. Vol. 42, No. 4, pp. 1795-1802.

[5] Dinakar, P. Babu, K.G. Santhanam, M. 2008. Durability properties of high volume fly ash self compacting concretes”. Cement Concrete Composites. Vol. 30 No. 10, pp. 880-886.

[6] EFNARC. 2002. Specification and guidelines for self-compacting concrete. UK, p. 32,

[7] Shri, S. Deepa and R. Thenmozhi. 2012. "An Experimental Investigation on the Flexural Behavior of SCC Ferrocement Slabs incorporating Fibers.”International Journal of Engineering Science and Technology. 4(5).

[8] Fareed Ahmed Memon, MuhdFadhilNuruddin, Samuel Demie and NasirShafiq. 2011. “Effect of Curing Conditions on Strength of Fly ash-based Self-Compacting Geopolymer Concrete”, International Journal of Civil and Environmental Engineering. pp 183-186.

[9] Fareed Ahmed Memon,MuhdFadhilNuruddin, Sadaqatullah Khan, NasirShafiq and Tehmina Ayub. 2013. “Effect of Sodium Hydroxide Concentration on Fresh Properties and Compressive Strength of Self-Compacting Geopolymer Concrete”, Journal of Engineering Science and Technology. Vol. 8 pp. 44-56.

[10] Gesoglu, M. Güneyisi, E. Özbay, E. 2009. Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume” Construction and Building Materials. Vol. 23, No. 5, pp. 1847-1854.

[11] Shri, S. Deepa, R Thenmozhi. 2013. “Prediction of Impact Energy Absorption Using Modified Regression Theory” Life Science Journal. 10(2): 743-749.

[12] Habert, G. Roussel, N. 2009. Study of two concrete mix-design strategies to reach carbon mitigation objectives” Cement and Concrete Composites. Vol. 31, No. 6, pp. 397-402.

[13] Shri, S. Deepa, R. Thenmozhi, and M. Anitha. 2012. "Experimental Validation of a Theoretical Model for Flexural Capacity of Hybrid Ferrocement Slab." European Journal of Scientific Research. 73(4): 512-526.

[14] Khatib, J.M. 2008. "Performance of self-compacting concrete containing fly ash" Construction and Building Materials. Vol. 22, No. 9, pp. 1963-1971.

[15] Khayat, K.H. Lovric, D. Obla, K. Hill, R. 2002. Stability optimization and performance of self-consolidating concrete made with fly ash" Int. Proceedings of 1st North American conference on the design and use of self-consolidating concrete. Chicago, IL: ACI: pp. 215-223.

[16] Sahmaran, M. Yaman, I.O. Tok, M. 2009. Transport and mechanical properties of self consolidating concrete with high volume fly ash", Cement Concrete Composites. Vol. 31, No. 2, pp. 99-106.

[17] Sonebi, M. 2004. "Medium strength self-compacting concrete containing fly ash: modelling using factorial experimental plans" Cement and Concrete Research. Vol. 34, 7, pp. 1199-1208.