Experimental Investigation of GGBS based Geopolymer Concrete with Steel Fibers

G. Srinivasa Rao, B. Sarath Chandra Kumar

Abstract: Concrete is the most popular material used in the construction works in which cement is the main composite. The manufacturing of cement involves the emission of greenhouse gases into the atmosphere which are responsible for global warming. Hence the researches are currently focused on various materials to replace and reducing the usage of cement. In this study Geopolymer concrete is prepared with Ground Granulated Blast furnace Slag (GGBS) with the addition of steel fibers. GGBS is the by-product produced from steel industry. Steel fibers are added to increase the tensile strength of concrete. In this experimental investigation geopolymer concrete containing GGBS and steel fiber (0.5%) with 8 Molar and 10 Molar alkaline activators are used. The ratio of these alkali activators is 1:2.5. The results showed that fiber can significantly enhance the Mechanical properties. The enhancement also increases with the increasing fiber volume fraction.

Index terms: Alkaline Activator Solution, Geopolymer, Ground Granulated Blast Furnace Slag, Molarity, Steel Fibers.

I. INTRODUCTION

The world's construction rate is increasing day by day and the nation's economy is dependent on the construction industries. The waste disposal from the industries was also in a large scale. Utilization of these industrial wastes in a safe manner is required and Utilization of these waste in the construction field for cost reduction [1].

Geopolymer concrete is made by fly ash, GGBS with alkali activation and special concrete is prepared[2], [3] The energy required for the manufacture of cement based concrete is very large than the energy required for the manufacture of geopolymer cement, this is effecting the environment [3].Where the normal concrete i.e. ordinary Portland cement concrete (OPCC) is not suitable at that conditions special concrete with good durability aspect is preferred, such alternative concrete like geopolymer concrete is in needed.

The cement production emits toxic chemicals and carbon dioxide into the environment on the other hand the materials for the preparation of concrete are depleting i.e. natural resources like fine aggregate and coarse aggregate. From the Last few years the requirement of cement is increasing in a population increases the demand for electricity also rapid manner due to the population increase. As the increased due to this reason electricity production by thermal power stations are also in large scale.

From these power stations simultaneously the fly ash disposal increases and this disposal in to the environment is a problem [4]. As the structures are reinforced with steel lot of steel demand is there, due to this iron production industries is more, from this industries slag is disposed and the slag is converted to ground granulated blast furnace slag (GGBS). As a civil engineer we know the problem of cement manufacture emits carbon dioxide in to the environment which is almost equal to its production. For the production of the cement lot of energy consumption is required i.e. lot of fossil fuels are consumed [5]. When cement is partially replaced by fly ash in the presence of H_2O and this mix is cured under ambient conditions, fly ash reacts with the calcium hydroxide during the hydration process to form the C-S-H gel. With the help of literature review fly ash is replaced up to 60% by mass of concrete [4].

Where research works were carried out from several years to conform geopolymer concrete is a good material for construction purpose. In India like country alternative concrete like geopolymer concrete have a great acceptance realizing the geopolymer concept CSIR-structural engineering research Centre carried research on different parameters of geopolymer concrete for more than a decade [1, 2, 3, 4]. Mainly for chemical resistant structures the geopolyemer concrete is used and it is increasing slowly. In some countries like Australia and Spain had done considerable amount of research, these research have proposed some suitable materials for the preparation of geopolymer concrete and also mix design and durability aspects [11, 12, 13].

Durability of geopolymer concrete is more because of inorganic binder with silica and alumina. Like conventional concrete is reinforced the geopolymer concrete should also reinforced for the structural applications [2].

In this present study the flexural behavior of reinforced geopolymer concrete in addition of steel fibers and without steel fibers are carried out, and these beams made up of 8 and 10 molarity. The compressive strengths of the specimens made with steel fibers and without steel fibers and also split tensile strength were studied. Flexural studies were also carried out on beams.

Geopolymer is an addition of binder in OPC. Currently the binder material is used in OPC as an option and the innovation of this technique applied by the cement industries. The geo polymer cement was suggested by Davidovitsin 1978. From the manufacturing of cement from the industries increases the global warming due to gradually stretching the releasing amount of Co2 is 80% and other

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harmful gases in climate to the atmosphere. The binding material can be produced when the source material i.e. having rich in silica and alumina added by high alkaline solution and this methodology is known as Geopolymerisation. Revenue generated by construction industry in India is huge and waste generated by power industries and steel industries are more. So these are considered as industrial bi products and by using it in construction industry may reduce the cost and the produced waste can be used in reducing usage of construction material. By using GGBS in cement, leads path to some of these new concretes other than Ordinary Portland cement based concrete and we require adopting some new concretes where OPCC are weak. Extreme research been carried out to find the potential of GPC. By developing alternate concretes in India which is a great move in reducing the industrial waste being generated by relied industries. The use of GPC is slowly being accepted, mostly in chemical resistance structures and research been taken some momentum to extend the usage. When industrial waste like GPC got some inorganic binders like silicon and aluminum, found to have high durability. In most of the civil engineering GPC been reinforced with steel bars which increases the application of GPC and this made a thought of developing research for reinforced GPC.

II. MATERIALS AND MIXING PROCEDURE

A. Materials

Fine aggregates, coarse aggregates and distilled water were used for the control OPCC test specimens. The geopolymer concrete was prepared by mixing of GGBS, fine aggregates, coarse aggregates and alkaline activator solution (AAS) with different molarity.

Alkaline activator are commonly used in a combination of sodium hydroxide (NaOH) and sodium silicate .The type and concentration of alkali solution effect the dissolution of GGBS.Generally al3+ and si4+ ions are high with NaOH. Alkali concentration is a major important factor for the polymerization process,GGBS particles and mechanical properties of hardened geopolymer are controlled from the filtering of silica and alumina.

A compound sodium metasilicate is the common name for sodium silicate (Na_2SiO_3). It is available in liquid form and solid form. Sodium silicate solution is used in manufacturing of cement and automobiles. Silicon dioxide and sodium carbonate react in molten state to form sodium silicate as well as carbon dioxide.

The formation of alkaline liquid was done by fusion of sodium silicate and sodium hydroxide solution. In process of polymerization the alkaline solution plays a vital role. The molarities used for NaOH is 8 M and 10 M. It means 8 and 10 parts of sodium hydroxide pellets are to be mixing in to 1 Liter solution prepare distilled water.

GGBS is a byproduct from the blast furnace used for iron manufacturing, about 1500 degrees centigrade iron ore, coke and limestone are fed into the furnace. Where the iron ore becomes iron and the remaining materials forms like molten slag and floats on the top surface of the iron in the furnace and this slag is taken out from the furnace and rapid quenching with water after that it forms like granulated slag and this slag is grinded after this process ground granulated blast furnace slag is formed. This GGBS is available in 50 Kg bags, collected from JSW Cements conforming to IS 12089:1987were used.

River sand available in Vijayawada from river Krishna was used as fine aggregates. They were tested as per IS 2386: 1963. Solution was prepared 24 hours before casting.

Locally available granite crushed stone aggregates of maximum size 20 mm and down was used and tests were carried out as per IS: 2386-1963. The properties of the materials used are shown in Tables I to IV. Distilled water was used for the geopolymer concretes. Steel bars, grade Fe 500 with diameter of 8 mm,10 mm,12 mm were used as reinforcement in beams as shown in Table-V, Fig. 1 and Fig. 2 are used in the present study.

Steel fiber having geometry of cylindrical with hooked ends was used. The length and diameter of fibers are 50 mm and 1mm respectively. The aspect ratio (L/d) is 50 are used. The use of fibers in concrete is to resistance against cracking and crack propagation. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fiber composite and its ability to with stand repeatedly applied shock or impact loading. The properties of steel fiber are shown in Table I.

Table I: Properties of GGBS

Parameters	JSW GGBS
Cao	37.34%
Sio_2	37.73%
Al_2O_3	14.42%
Fe_2O_3	1.11%
Glassy content	99.90%
Loss of ignition	1.41%

B. Mix proportion

The geopolymer concrete was developed as a special mix of GGBS, coarse aggregates, fine aggregates and alkaline activator solution. We all know that for GPC there is no specific code for mix design as like OPC.

The main salient feature of concrete is durability by the earliest studies observe that there is no improvement of elastic modulus and compressive strength of fly ash concrete, because in the binder of GPC have to involve with more components such as GGBS, sodium silicate, sodium hydroxide and fibers. Then the composition of substance and interactions are strong binded with source material and gives best results. In this present study for this solid components mixing of GGBS based geopolymer have to be dry without adding of fibers and alkaline activators solution.

In the wet mix the 0.5 % proportion of steel fibers are added by the volume of concrete. The 8 and 10 molarities of NaOH is used for the mixing proportions and the solution should be settled down for 24 hours. Because when the NaOH pellets added with water, there will be a cause of exothermic reaction and sever heat is evolved. The NaOH flakes were taken about 40 grams per one molar. Preparation of sodium silicate and NaOH solutions separately and mixed together at the time of casting with the addition of 10% of water. In this study the amount of NaOH is taken as 2.5times of sodium silicate. The physical properties of coarse aggregate are shown in the Table II. The mix proportion of geopolymer concrete is shown in the Table VI.

Table II: Physical Properties of Coarse Aggregate

Sieve size	Requirement as per IS: 383-1970 (20 mm)	Percentage Passing
40 mm	100%	100%
20 mm	85-100%	93%
16 mm	-	-
12.5 mm	-	-
10 mm	0-20%	12%
Specific gravity		2.9

Table III: Physical properties of fine aggregate

Sieve size	Percentage Passing
10 mm	100%
4.75 mm	100%
2.36 mm	99.50%
1.18 mm	86.70%
600 µ	35.80%
300 µ	8.60%
150 µ	0.80%
Zone	II
Fineness modulus	2.7
Specific gravity	2.6

C. Preparation of specimens

The compressive strength of structure can be calculated by the performance and ability of a material when carry the loads on its surface. It can be tested in a compressive testing machine. In the present study 24 no's of 150 mm × 150 mm × 150 mm size cubes were tested.

On the procedure based on IS 5816:1999 Code. Currently 24 no's of 150 mm diameter and 300 mm long size cylinders were casted to find the split tensile strength. Prisms of size 500 mm × 100 mm × 100 mm were casted to find the flexural strength of Geopolymer concrete. The compressive strength, Split tensile strength and flexural strength is calculated after the curing for the period of 7 days and 28 days respectively.

D. Test setup

The beams are tested under the loading frame of capacity 2000 kN with 2 point loading at L/3 distance the 2 load cells are arranged where L is the total length of the beam the load is applied between the two loading cells for the perfect manner I girder is setup between the two loading cells and the load is applied at center of the girder. At the bottom center of the beam linear variable displacement transducer (LVDT) is placed to find at the deflection at different effects of load.

4 no's of simply supported beams with an effective span of 900 mm and 20 mm be the clear cover. The geometry of beam is 1000 mm ×150 mm ×150 mm were casted for the specimens in tension zone the steel bars of diameter is 12 mm and the compression zone in 10 mm. For the shear reinforcement provided 8 mm diameter of 2 legged vertical stirrups with 100 mm center to center spacing. Properties of steel are shown in the Table IV.

To clear of the adhesion with concrete before the casting the mould are gradually suffused by lubricants and the casting of beams can be done in the beams mould by 3 layers and the vibration is to be used to every layer to avoid voids and after 28 Days the specimens are tested for flexural behavior. Specimen reinforcement details were shown in Fig. 1 and Fig. 2.

Table IV: Properties of Fe500 Simhadri TMT steel

S.NO	Diameter of the diameter of the bar (mm)	Yield stress (N/mm^2)	Ultimate stress (N/mm^2)	Percent-age Elongation
1	8 mm	560.03	638.5	22.5%
2	10 mm	570.06	635.51	22%
3	12 mm	568.42	649.05	21.7%

Table V: Properties of Steel Fiber

Diameter	0.6 mm
Length	30 mm
Aspet ratio(L/d)	50
Type	hooked end
Tensile strength	1450 MPa
Yield strength	1000 MPa
Strain at failure	4%

Table VI: Mix Proportion of Geopolymer Concrete

Materials	Quantity(Kg/m^3)
GGBS	414
Fine aggregate	660
Coarse aggregate(20mm)	681.6
Coarse aggregate(10mm)	454.4
Sodium hydroxide	53
Sodium silicate	133
Extra water	10%

Table VII: Combinations of GPC

Mix ID	Combination
M1	GPC without Steel Fibers
M2	GPC with Steel Fibers

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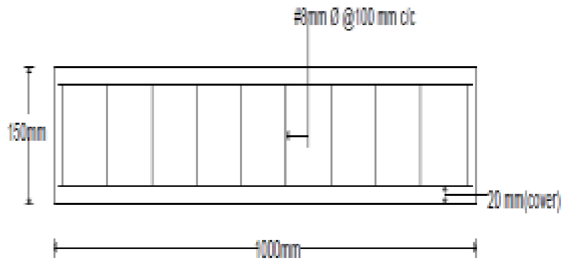

Fig. 1: Reinforcement detailing

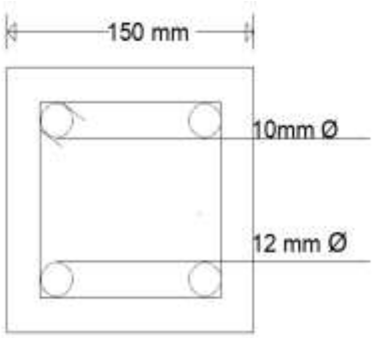

Fig. 2: Cross section of beam

III. TEST RESULTS AND DISCUSSIONS

A. Compressive strength

Fig. 4 represents the compressive strength of GGBS based geopolymer concrete with and without steel fibers of 8M and 10M for 7 days and 28 days respectively. The testing of cubes have to be done by using compression testing machine. The test was done on the compressive testing machine of capacity 3000 kN and the test specimens was about 150 mm x 150 mm x 150 mm size.

The compressive strength of GGBS based geopolymer concrete at the age of 7 days having with and without of 8 Molar was about 73 N/mm^2 , 45.31 N/mm^2 and strength for 10 M having with and without steel fibers were 79.63 N/mm2 and 53.80 N/mm^2. At the age of 28 days the geopolymer concrete having with and without steel fibers of 8M were 80 N/mm^2, 48.04 N/mm^2 and for 10M were 81 N/mm^2, 60.03 N/mm^2. Through the addition of GGBS and Steel fibers the compressive strength increases in geopolymer concrete. The test setup for compressive strength is shown in Fig. 3. The results were shown in Table VIII.

B. Split Tensile Strength

From the procedure of code IS 5816:1999 the tensile strength of concrete cylinder of size 150 mm x 300 mm was tested from split tensile strength. The specimens are cured under ambient temperatures. From the Table IX and Fig. 6. The split tensile strength of with and without steel fibers of 8 M for 7 days were 5.19 N/mm^2 and 2.65 N/mm^2. For 10M of with and without steel fibers was about 5.24 N/mm^2 and 3.43 N/mm^2. From the results observed that the percentage of GGBS and Steel fibers is increased the split tensile strength of geo polymer concrete. Though addition of GGBS and Steel fibers, increases the split tensile in geopolymer concrete, GGBS and Steel fibers based geopolymer concrete shows the high split tensile strength. The split tensile test setup was shown in Fig. 5.

Fig. 3:Test setup

Table VIII: Compressive strength of GPC cubes with and without steel fibers

Average Compressive Strength (N/mm^2)				
Mix ID	M1		M2	
Days of Curing	7 Days	28 Days	7 Days	28 Days
8M	73	80	45.31	48.04
10M	79.63	81	53.80	60.03

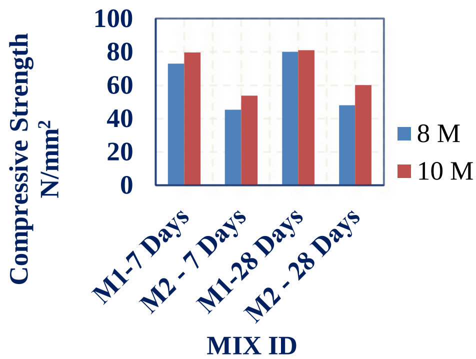

Fig. 4: Average compressive strength of GPC cubes with and without steel fibers

C. Flexural strength

With the reference to Table 10 and Fig.7, at the ambient curing of 7 days the flexural strength of 8M and 10M with steel fibers was about 7.84 N/mm^2 and 7.35 N/mm^2. For the without steel fibers of both 8M and 10M was about 6.53 N/mm^2 and 6.37 N/mm^2. And for the 28 days of both 8M

Fig. 5: Test setup

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Table IX: Split tensile strength of GPC cylinders with and without steel fibers

Average Split Tensile Strength (N/mm^2)				
MIX ID	M1		M2	
Days of Curing	M1-7 Days	M1-28 Days	M2-7 Days	M2-28 Days
8M	5.19	6.46	2.65	2.97
10M	5.24	5.98	3.31	3.43

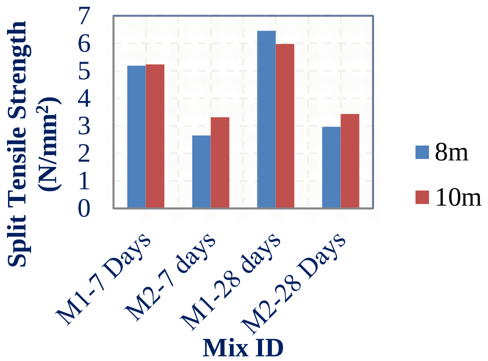

Fig. 6:Average Split Tensile Strength

and 10M having with steel fibers are 9.32 N/mm^2 and 8.67 N/mm^2 and also for without steel fibers was about 6.8 N/mm^2 and 6.65 N/mm^2. It is seen from the results that when the percentage of GGBS and Steel fibers is increased the Flexural strength of the geopolymer concrete. Though addition of GGBS and Steel fibers, increases the Flexural strength in geopolymer concrete, GGBS and Steel fibers base geopolymer concrete shows the high Flexural strength.

Table X: Flexural Strength of GPC Cubes with and without Steel Fibers

Average Flexural Strength N/mm^2				
MIX ID	M1		M2	
Days of Curing	M1-7 Days	M1-28 Days	M2-7 Days	M2-28 Days
8M	7.84	9.32	6.53	6.8
10M	7.35	8.67	6.37	6.65

D. Load Deflection Behavior

The occurring of First visible crack and ultimate load for GPC of with and without fibers was found. The load deflection pattern was similar in case of GPC with steel fiber beams as well as GPC without steel fiber beams except with more specimens which contain more than 70% steel fibers, which had a very low compressive strength. The GPC beams with and without steel fibers and result of load deflection curve at the mid span are shown in fig-. The beam test setup on loading frame is shown in the Fig. 10.

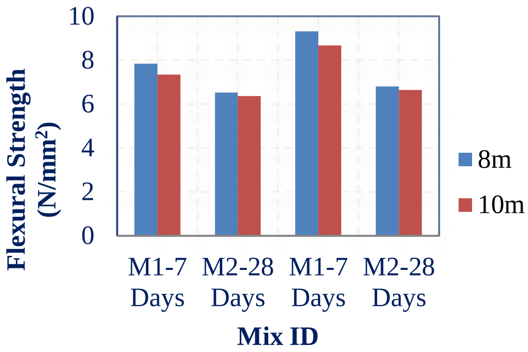

Fig. 9: Average flexural Strength of GPC Prism with and without steel fibres

Fig. 10:Test setup

E. Failure mode and crack pattern

For the GPC beams the failure pattern of the specimens was similar for both with and without fibres significantly all the beams deflected at failure load. In the compression phase the yielding of tensile steel was followed by crushing of concrete in the failure cases. There is no different for crack patterns of geopolymer concrete for with and without steel fibres that is almost unique. The cracking load for the specimens was shown in Table XI.

Table XI: Cracking load and Ultimate load

S. NO	Mix Proportion	First Crack Load (kN)	Ultimate Load (kN)
1	8 M with steel fibers	78.20	110.00
2	8 M without steel fiber	68.00	87.00
3	10 M with steel fiber	86.40	151.00
4	10 M without steel fiber	75.10	120.00

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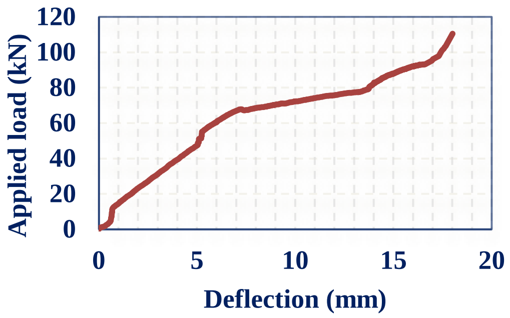


Fig. 10: Load vs. deflection curve with steel fibers 8M

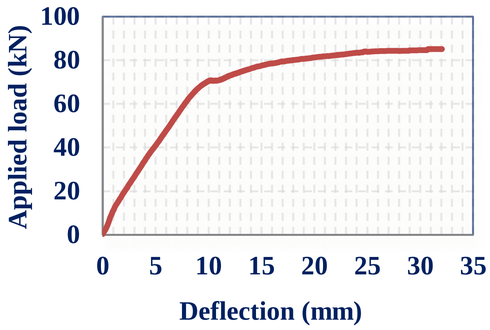


Fig. 11: Load vs. deflection curve without steel fibers 8M

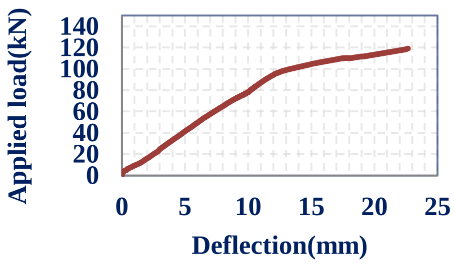
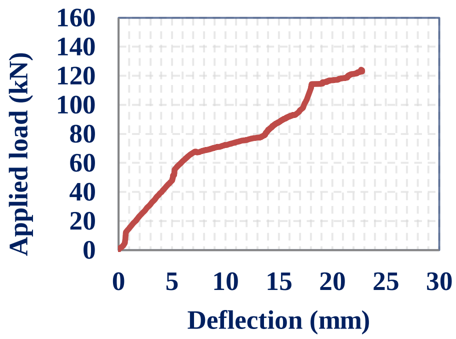


Fig. 12: Load vs. deflection curve with steel fibers 10M



IV. CONCLUSION

The conclusions that can be given by this experimental study are listed below:

- The compressive strength of the geopolymer concrete made with steel fibers are higher than the geopolymer concrete made without steel fibers.
- It was clear that as the NaOH concentration increases the compressive strength also increases.
- The tensile strength of the geopolymer concrete made with steel fibers shows good results.
- Flexural test on prisms with steel fibers under two point loading had shown higher values than geopolymer made without steel fibers.
- It was clear in all tests, as the age of curing increases the strength of the GPC increases.
- The load vs deflection on 8 M and 10 M beam with steel fiber are more than the beam without steel fibers.
- The load carrying capacity of the beams made with steel fibers is higher.

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