Studies on Flexural Behavior of Geopolymer Concrete Beams with GGBS

M. Ratna srinivas, Y. Himath Kumar, B. Sarath Chandra Kumar

Abstract: As CO2 emissions are increasing in the atmosphere and causes global warming with the production of cement, the alternative pozzolanic material is needed. The alternative pozzolanic material for cement in the production of concrete is GGBS. Geopolymer Concrete (GPC) is an alternative material for conventional concrete. Geopolymer concrete is made by mixing GGBS, fine aggregate, coarse aggregate and alkaline activator solution. GGBS is a by-product of the iron industry. This paper shows the results on experimental investigation done on reinforced geopolymer concrete beams to know the flexural behavior. The alkaline activator solution is prepared by sodium hydroxide NaOH and sodium silicate Na2SiO3 in 1:2.5 ratio. The flexural behavior of the beams is examined with different molars of NaOH solution. The GPC beams are compared with conventional reinforced concrete beam of M40 grade concrete. The type of curing adopted in the experimental study is ambient. The size of beam is 1000 mm × 150 mm × 150 mm. The flexural test is done on the loading frame of capacity 200 tons. The ultimate load, cracking load and the maximum deflection and the crack pattern is determined and the load Vs deflection graphs are plotted. This experimental study gives a clear conclusion on the flexural behavior of conventional reinforced concrete beam and reinforced geopolymer concrete beam made with GGBS.

Index terms: Alkaline Activator Solution, Geopolymer, Ground Granulated Blast Furnace Slag, Molarity, Sodium Hydroxide, Sodium Silicate.

I. INTRODUCTION

The construction growth in the world is in a rapid manner and industries are also increasing due to this the waste disposal was in a large scale. Proper utilization of industrial waste in the construction field becomes an important role. And on the other side the global warming is a huge problem, the cause of global warming is mainly by emission of green house gases from industries into the atmosphere. Carbon dioxide is one of the major green house gases, and the cement manufacturing industries also emits CO_2 [1].

In this aspect, geopolymer technology can be used in the concrete as the alternative of OPC. An alkaline activator is required to react with the silica and aluminum in the source material because of this a chemical reaction takes place which is called as polymerization process and "geopolymer" is termed for this kind of binders [2], [3]. These geopolymer concretes are needed where environmental conditions are not suitable for OPC concrete.

The world's population is increasing rapidly and the constructions are also increasing according to the population for various needs, due to this need of cement is more as we all know while cement is manufacturing lot of pollution releases into the environment. Electricity demand increasing as population increases. In India like countries electricity is produced mostly by the thermal power plants and from this power plants lot of waste in the form of fly ash is disposed to the environment this will cause problems in the environment. And in the construction of structures need of steel is main so that the production of steel is also more, while iron is manufacturing ground granulated blast furnace slag(GGBS) is produced which is a by-product. Increasing in quantity of GGBS disposal will cause environmental problems [4].

As the rate of construction increases the use of ordinary Portland cement (OPC) increases. As a civil engineer we know the problems that are related to environmental issues while cement is manufactured. Huge amount of fossil fuels are consumed for the production of cement and also CO_2 is emitted in to the atmosphere which is almost equal to the quantity of cement produced [4], [5].

Lot of research works have been carried out for several years to conform geopolymer concrete as best construction material [2], [3], [5], [6], [7], [8]. There is a need of alternative concrete like geopolymer concrete, where large scale of wastes were disposed from the industries [1]. These geopolymer concretes were used where the environmental conditions are not supporting the OPC concrete structures such as chemical resistant structures geopolymer concrete is used. In India like country the use of geopolymer concrete was increasing in various applications.

Geopolymer concrete is durable, because of silica and alumina were present. As conventional concrete is reinforced the concrete made of geopolymer should also reinforced for its structural applications. By this study the flexural behavior of the geopolymer concrete beams were studied.

This paper deals with reinforced geopolymer concrete beams made with 100% of GGBS under ambient curing. The reinforced geopolymer concrete beams were compared with reinforced beams made with OPC. A total of 6 beams were cast, in that five geopolymer concrete mixes and the remaining 1 is of ordinary Portland cement mix made of M40 grade. Behavior aspects like load carrying capacity and deflection were studied. This paper compares the behavior of reinforced geopolymer concrete beams (RGPC) with beams made of reinforced ordinary Portland cement concrete.

Revised Manuscript Received on April 09, 2019.

M. Ratna srinivas, PG Student, Structural Engineering, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P., India.

Y. Himath Kumar, Assistant Professor, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P., India.

B. Sarath Chandra Kumar, Associate Professor, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P., India.

II. MATERIALS & MIXING PROCEDURE

A. Materials

The different types of materials that were used in this experimental study were ordinary Portland cement which conforms to IS 12269:2013, coarse aggregates, fine aggregates and water for the preparation M40 grade concrete specimens. And another phase of this experimental study is preparation of GPC specimens; these were prepared by mixing of GGBS, alkaline activator solution (AAS) with different molarities, fine aggregates and coarse aggregates.

GGBS is a by-product from the blast furnace used for iron manufacturing, about 1500˚C coke, iron ore and limestone are fed into the furnace. By the above mentioned process molten iron is formed at the bottom of the blast furnace, on the top surface molten iron molten slag is formed and this slag is taken out from the furnace and rapid quenching with water is done after that it forms like granulated slag and this slag is grinded, after this process ground granulated blast furnace slag (GGBS) is formed. This GGBS is available in 50Kg bags; which was collected from JSW Cements.

The Fine aggregate and coarse aggregates that were used in this study are from river Krishna and granite crushed stone which are conforming of 20 mm and 10 mm sizes. The tests were performed on the aggregates as per IS 2386:1963.

Alkaline activator solution (AAS) which was second main component in the geopolymer concrete mix. This solution is prepared by combination of sodium silicate (Na_2SiO_3) with sodium hydroxide (NaOH) [12], [13]. Sodium silicate is commercially available in the form of liquid and sodium hydroxide is in flakes form with 2.5 mm in size. These flakes were dissolved in distill water for the preparation of sodium hydroxide liquid. This solution is prepared in 5 different molarities for 1molar concentration 40 grams of sodium hydroxide is dissolved in 1liter distill water similarly 8 M, 10 M, 12 M, 14 M, 16 M are prepared. The ratio of sodium hydroxide and sodium silicate in this study was 1:2.5.

The various properties of materials that were used in this study were shown in Table I to IV. Distilled water was used in geopolymer concrete and potable water was utilized in OPC. Steel bars made by thermo mechanically treated from Simhadri steels of 500 MPa of 8 mm, 10 mm, 12 mm diameter bars were used as reinforcement in beams and the steel properties were shown in Table V.

The sodium hydroxide solution and sodium silicate solution were separately prepared and this both solutions were mixed together at casting time. When sodium hydroxide was dissolving in distilled water lot of heat is generated, so that this solution was prepared before 24 hours of casting.

B. Mix proportion

As we all know IS 10262:2009 is the code for the mix design of the OPC concrete, but no specific code for mix design of geopolymer concrete. Where as Rangan and Hardjito had given few guidelines for geopolymer, by some trials carried by certain procedures have indicated the strength characteristics and workability of such mixes were not satisfactory. This was due to the different constituents in the binder of geopolymer concrete (viz., GGBS, sodium silicate, sodium hydroxide) [1], [8], [9], [14].

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%

Table II: Coarse Aggregate Physical Properties

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

Table III: Fine Aggregate Physical Properties

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
Specific gravity	2.6
Fineness modulus	2.7

The structure of the geopolymer concrete is still a challenge for the researchers, due to this reason the mix of geopolymer concrete is done under the basis of trial and error. To compare results of geopolymer concrete with conventional concrete, additional conventional concrete mix was prepared with OPC which was designed as per IS 456:2000 [10] and IS 10262: 2009 [11],and the mix proportions were shown in Table VI and Table VII.

C. Mix Design of Geopolymer Concrete

In the control mix the percentage of the aggregates is between 70% to 80% with respect to the total mass of the concrete, in the same way in geopolymer concrete also the percentage of aggregates were same as the control mix. From the previous studies it was clear that the density of the geopolymer concrete is 2400 kg/m^3 [7] which was similar to the normal concrete made by OPC. The sodium hydroxide and the sodium silicate solutions were taken in 1:2.5 [15]. Extra water was added to achieve workability and sodium hydroxide is prepared in five different molarities i.e. 8 M, 10 M, 12 M, 14 M, 16 M for this study.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table IV: Physical Properties of Cement

Description	Cement
Fineness	3.40%
Normal consistency	34%
Initial setting time	75 min
Final setting time	310 min

Table V: Properties of Steel

S. NO	Diameter of the diameter of the bar (mm)	Yield stress (N/mm^2)	Ultimate stress (N/mm^2)	% Elongation
1	8 mm	560.03	638.5	22.50%
2	10 mm	570.06	635.51	22%
3	12 mm	568.42	649.05	21.67%

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%

D. Preparation of Specimens

The beam specimens were 1000 mm length and 150 mm width and depth and the support condition is simply supported. Clear cover of this beam was taken as 20 mm. The geometry and the cross sectional view of the beam specimen is shown in Fig. 1.

Steel bars of 10 mm are used in the compression zone and 12 mm were used in the tension zone of the beam, stirrups made of 8 mm diameter were placed at a distance of 100 mm center to center for the shear reinforcement.

Table VII: Mix Proportion of Cement Concrete

Materials	Quantity (Kg/m^3)
Cement	400
Fine aggregate	687.1
Coarse aggregate (20mm)	817.3
Coarse aggregate (10mm)	544.9
Water	140
w/c	0.35

Lubricant was applied to the moulds before casting to avoid adhesion with the hard concrete. The mix is placed in the beam mould in 3 layers and each layer is subjected to vibration to avoid voids. At the time of beam casting 6 cubes, 6 cylinders were also cast to test their compressive strength, split tensile strength. After 24 hours the specimens were demould. And also an OPC concrete beam is also cast and cured for 28 days and the geopolymer concrete specimens were cured under ambient temperature over a period of 28 days, after that the specimens were tested for compressive strength and flexural behavior. Where as in M 40 is made completely with OPC with 0% GGBS on the other phase geopolymer beams were cast with 0% OPC and 100% GGBS with different molarities. The beams with different mix were named as M 40, 8 M, 10 M, 12 M, 14 M, and 16 M where M denotes molarities for the geopolymer concrete.

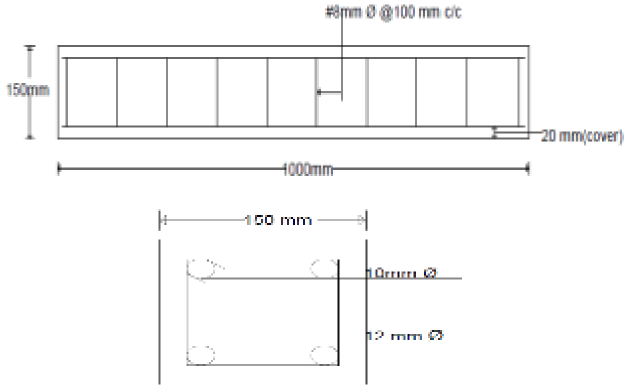

Fig. 1: Reinforcement Detailing of Beam

E. Test Setup

The test specimen for flexural behavior is shown in the Fig 2. The test beams were placed on a loading frame of capacity 2000kN. The support conditions were simply supported and the load is applied on two points. The load cells were placed at two different points at a distance of L/3, where L is total length of the beam. On the two loading cells I girder is placed and at the center of that girder the load is applied. A linear variable displacement transducer (LVDT) is placed at the bottom center of the test beam for knowing deflection at different loading. The beams cast were identified as shown in Table VIII.

Fig. 2: Test Setup

III. TEST RESULTS AND DISCUSSION

A. Strength Characteristics

For the strength parameter compressive tests were performed on different mix i.e. on M40 grade control mix, geopolymer concrete specimens with 8 M, 10 M, 12 M, 14 M and 16 M. The tests were carried out after 7 and 28 days of curing. The test results were shown in the below Fig 4(a) & 4(b). The results obtained were clear and shows that the compressive strength of the geopolymer concrete mix is very much high than the control mix. And also geopolymer

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

concrete made with different molarities is increasing their strengths with respect to the increase in molarity concentration. As the curing time increases the strength is also increasing. The test setup is shown in the Fig. 3.

Fig. 3: Test setup

Where as the flexural strength of different mixes are determined with respect to compressive strength. For calculating flexural strength there was an equation in IS 456:2000 of clause 6.2.2.

$$fcr = 0.7\sqrt{fck} \qquad (1)$$

Where as, f_{cr} is the flexural strength in N/mm^2.

And f_{ck} is the compressive strength of each mix.

The test results were shown in Fig 5(a) & 5(b), the results clearly show flexural strength is in a increasing manner with increase in compressive strength.

Table VIII: Specimen Identification

Mix ID	M1	M2	M3	M4	M5	M6
	M40	8M	10M	12M	14M	16M

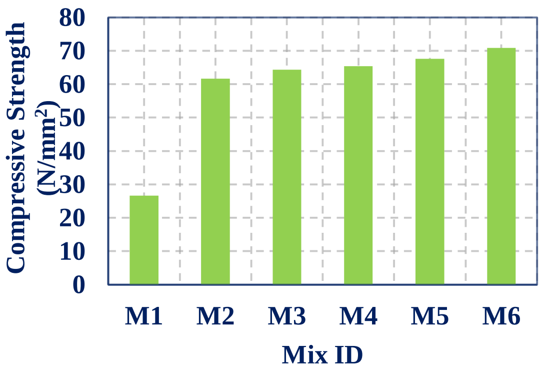

Fig. 4a: Compressive Strength for 7 days (N/mm^2)

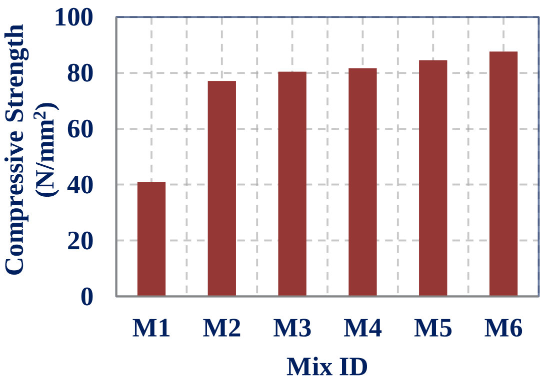

Fig. 4b: Compressive strength for 28days (N/mm^2)

Fig. 7: Test Setup

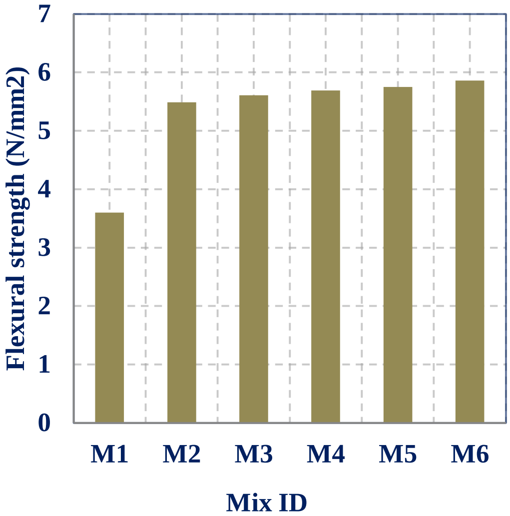

Fig. 5a: Flexural Strength for 7 days (N/mm^2)

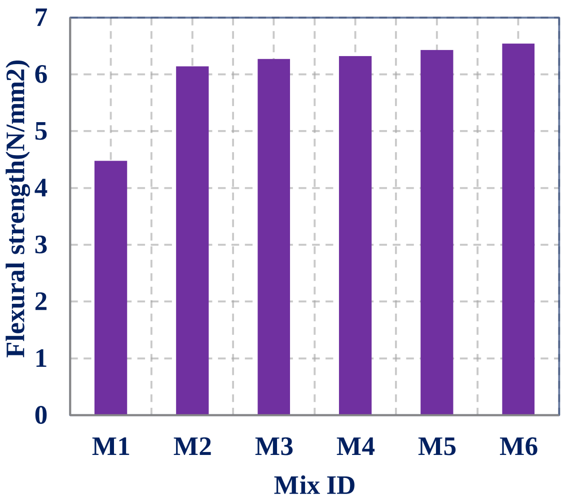

Fig. 5b: Flexural Strength for 7 days (N/mm^2)

B. Split Tensile Strength Test

Testing the tensile strength of concrete is not so easy. But the tensile strength was determined by testing cylinders, with dimensions 300 mm height and 150 mm diameter. This cylinder splits into two parts by placing the cylinder horizontally in the testing machine. It is an indirect method of testing the tensile strength of concrete. M40 grade specimen and the other 5 specimens such as 8 M, 10 M, 12 M, 14 M and 16 M are tested for split tensile test on 7 days and 28 days. Test is performed as per IS 5816:1999 And the test results were listed in below Fig 6(a) & 6(b). In the Fig 7 test set up is shown for the split tensile strength.

C. Load Vs Deflection

This test is performed on the beams that were cast with different molarity and M40 grade concrete beam. The load is applied on the beam and the deflection is noted at the center of the beam. The beam specimens before test and after test were show in the Fig 8(a) & 8(b**).** From the test results the load carrying capacity of the geopolymer concrete beams are higher than the normal concrete beam, as the molarity concentration in the geopolymer increases the load carrying capacity was also increasing. And the load deflection graphs for the specimens were shown from Fig 9 to 14. Cracking load and ultimate load of the beams were shown in Table IX.

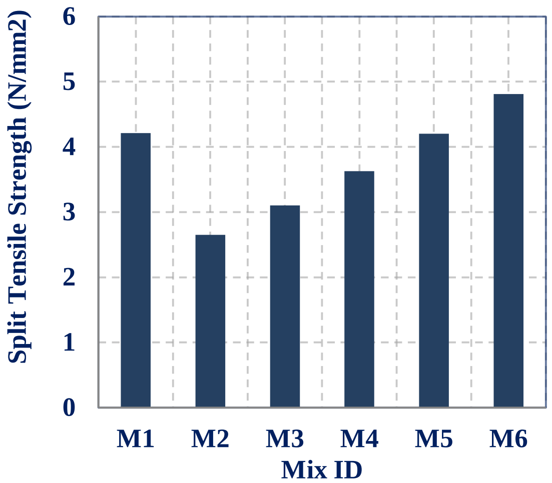

Fig. 6a: Split Tensile Strength for 7 days (N/mm^2)

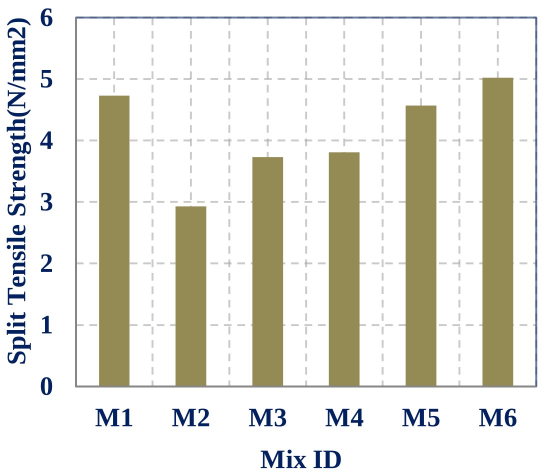

Fig. 6b: Split Tensile Strength for 28 days (N/mm^2)

D. Failure mode and crack patterns

The flexural cracks were standard after the peak load at the mid span of the beam. At failure load, all the beams deflected significantly. In both mixes i.e. control mix and geopolymer mix the crack patterns were similar. The failure that occurred in all the beams made with OPC and GPC was started by yielding of the tensile steel and continued by crushing of concrete in compression zone [1]. And it was clear that, no major difference in failure of the OPC and GPC beams. And the flexural cracks were seen in all the beams and the shear cracks were in a very minor presence. The crack widths are not more than 5 mm to 7 mm. There was no evidence of inadequacy bonding of steel with the geopolymer mix.

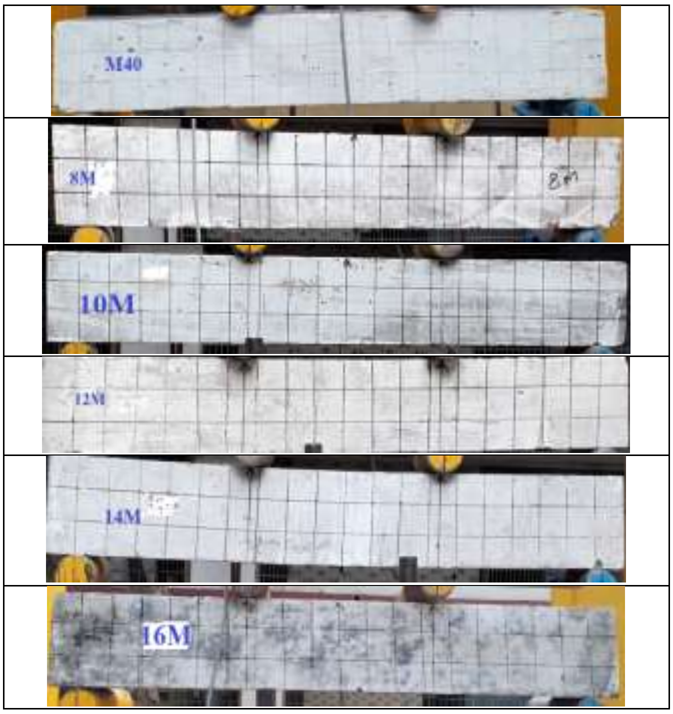

Fig. 8a: Beam Specimens before Test

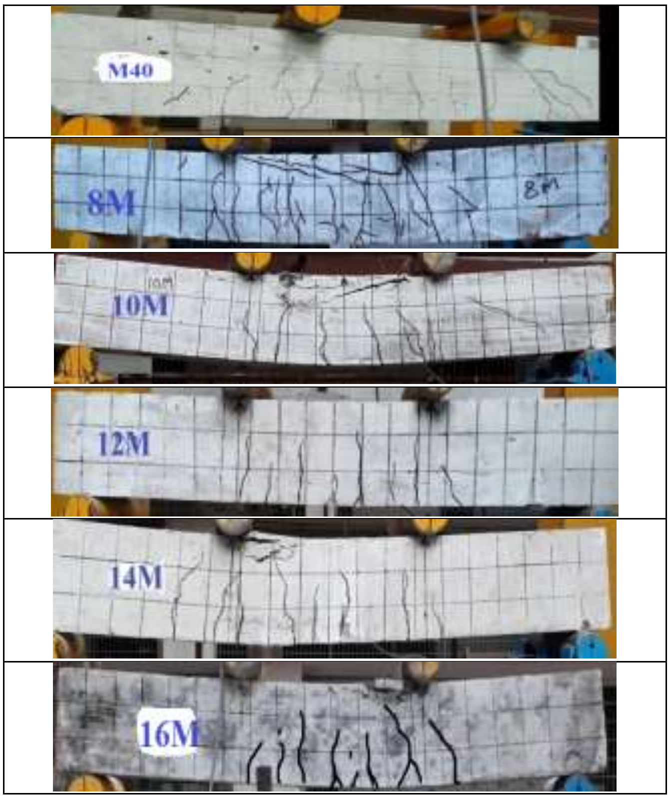

Fig. 8b: Beam Specimens after Test

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

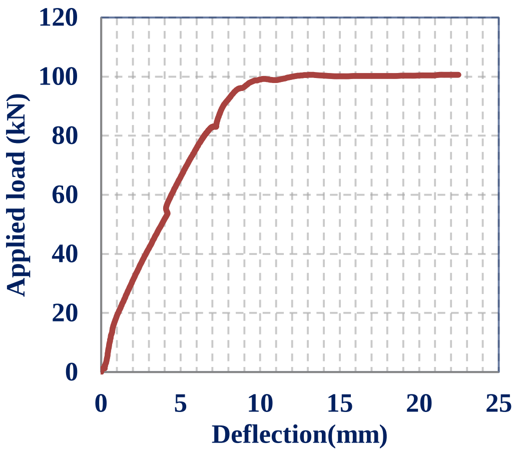

Fig. 9: Load Vs Deflection (M40)

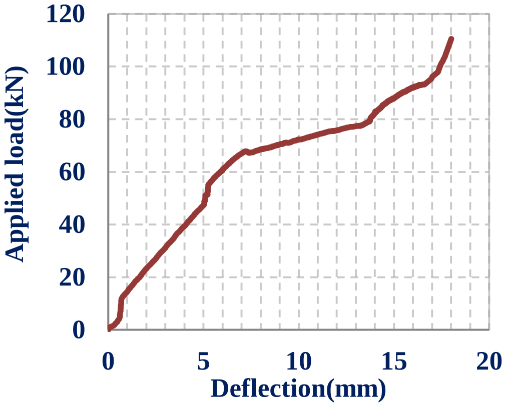

Fig. 10: Load Vs Deflection (8M)

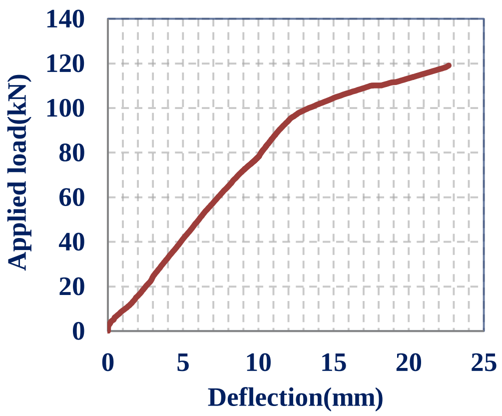

Fig. 11: Load Vs Deflection (10M)

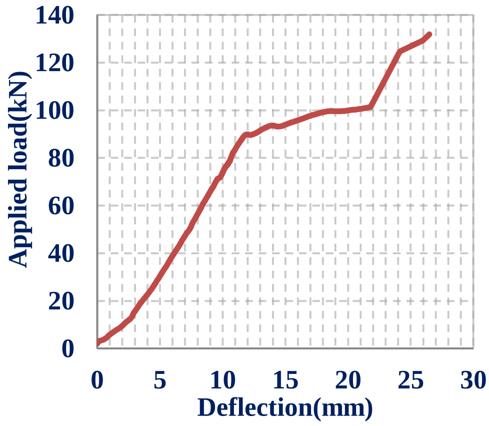

Fig. 12: Load Vs Deflection (12M)

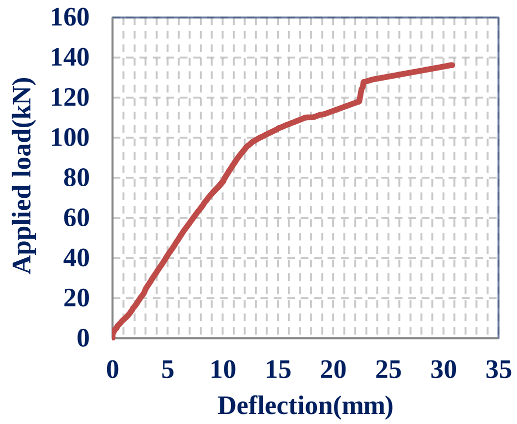

Fig. 13: Load Vs Deflection (14M)

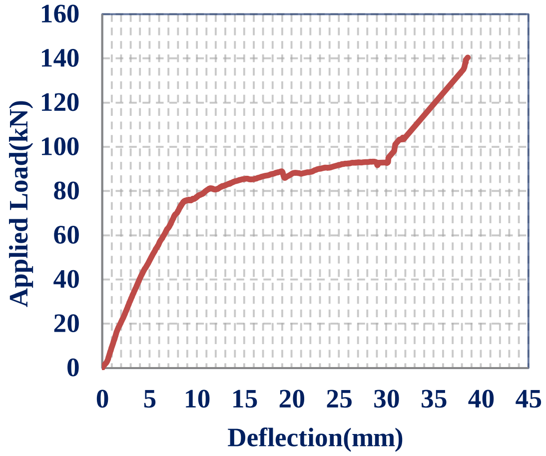

Fig. 14: Load Vs Deflection (16M)

Table IX: Load Details

Mix ID	Cracking Load (kN)	Ultimate load (kN)
M1	72.1	106
M2	74.52	111.5
M3	75.1	119.08
M4	76.08	131.9
M5	78.1	138.84
M6	80.31	140.48

IV. CONCLUSION

Based on experimental studies that were carried out on conventional concrete beam and geopolymer concrete beams it can be concluded that:

a. The strength characteristics of the GPC are higher than the OPC.
b. The load deflection behavior of the GPC is more than the OPC beams.
c. The failure occurred in the beams were in flexural mode. The cracks propagated from the tension zone to the compression zone.
d. The load carrying capacity of the GPC beams increases as the sodium hydroxide concentration increase in terms of molarity.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

ACKNOWLEDGEMENT

The authors wish to gratefully acknowledge the support by the Head of the department and Structural engineering lab staff and Research scholars of Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India, and my fellow students for their support, is acknowledged gratefully.

REFERENCES

1. J. K. Dattatreya and N. P. Rajamane "Flexural Behaviour of Reinforced Geopolymer Concrete Beams," *International journal of civil and structural engineering*, Vol. 2, Issue 1, 2011, pp. 138-159.
2. B. Sarath Chandra Kumar, and K. Ramesh. "Analytical Study on Flexural Behaviour of Reinforced Geopolymer Concrete Beams by ANSYS." *IOP Conference Series: Materials Science and Engineering*. Vol. 455, Issue 1, 2018.
3. B. Vijaya Rangan "Fly Ash-Based Geopolymer Concrete," Proceedings of the International Workshop on Geopolymer Cement and Concrete, Allied Publishers Private Limited, 2010.
4. J. Davidovits "Geopolymers: inorganic polymeric new materials," *Journal of Thermal Analysis*, Vol. 37, 1991, pp. 1633-1656.
5. Duxson, G. C. Lukey "Geopolymer technology: the Current State of The Art," *Journal of Material Science*, Vol. 42, Issue 9, 2006, pp. 2917-2933.
6. B. Sarath Chandra Kumar, K. Ramesh and P. Poluraju. "An Experimental Investigation on Flexural Behavior of GGBS and Metakaolin Based Geopolymer Concrete," *ARPN journal of engineering and applied sciences*, Vol. 12, Issue 7, 2017, pp. 2052-2062.
7. G. Varga, "The Structure of Kaolinite and Metakaolinite," *Epitoanyag*, Vol. 59, Issue 1, 2007, pp. 6-9.
8. D. Hardjito and B. V. Rangan "Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete," *Research Report GC 1,Faculty of Engineering Curtin University of Technology Perth*, 2005.
9. P. VenkataKiran and J. Guru Jawahar "Flexural Studies on Fly Ash and GGBS Blended Reinforced Geopolymer Concrete Beams," *International Journal of Research and Scientific Innovation*, Vol. 4, Issue 8, 2017, pp. 91-95.
10. IS 456-2000, Code of practice for plain and reinforced cement concrete, Bureau of Indian Standards, New Delhi, India.
11. IS 10262-2009, Concrete mix proportioning guidelines, Bureau of Indian Standards, New Delhi, India.
12. Y. Himath Kumar and B. Sarath Chandra "Effect of Sodium Hydroxide and Sodium Silicate Solution on Compressive Strength of Metakaolin and GGBS Geopolymer," *International Journal of Civil Engineering and Technology*, Vol. 8, Issue 4, 2017, pp. 1905-1917.
13. Y. Himath Kumar and B. Sarath Chandra "Effect of Molarity on Compressive Strength of Geopolymer Mortar with GGBS and Metakaoline," *International Journal of Civil Engineering and Technology*, Vol. 8, Issue 4, 2017, pp. 935-944.
14. Y. Himath Kumar and V. Keerty "Experimental Studies on Properties of Geopolymer Concrete With GGBS and Fly Ash," *International Journal of Civil Engineering and Technology*, Vol. 8, Issue 1, 2017, pp. 602-609.
15. Y. Himath Kumar and B. Sarath Chandra Kumar "Study on Strength and Durability Parameters of Geopolymer Concrete With GGBS for 12M and 14M Alkali Activators," *ARPN Journal of Engineering and Applied Sciences*, Vol. 12, Issue 4, 2017, pp. 1202-1212.

AUTHORS PROFILE

M. Ratna Srinivas, received the B. Tech in Civil Engineering from NRI Institute of Technology, affiliated to JNTU Kakinada, Agiripalli, Andhra Pradesh, India in 2017. Pursuing M. Tech in Structural Engineering from Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P., India.

Mr. Y. Himath kumar, working as an Assistant Professor in Deparmaent of Civil Engineering at Koneru Lakshmaiah Education Foundation since November 2012. He completed his B. Tech from RVR & JC College of Engineering, chowdavaram, Guntur district, Andhra Pradesh and M. Tech in Structural Engineering from VIT Vellore, Tamilnadu, India. He published 10 (Ten) research articles in International and National referred Journals.

Dr. B. Sarath Chandra Kumar, working as an Associate Professor in Department of Civil Engineering at Koneru Lakshmaiah Education Foundation since November 2012. In February 2017, He moved to Eritrea Institute of Technology, Eritrea and worked as a Lecturer. He completed his B. Tech in Civil Engineering From G. M. R. Institute of Technology, Rajam, Andhra Pradesh, M. Tech in Structural Engineering from K L University, Guntur, Andhra Pradesh and Ph.D in Civil Engineering from Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P., India. He published 25 (Twenty Five) research articles in international and National referred Journals and 5 (Five) articles in the Conferences. He actively organized conferences, workshops and Guest Lectures in the Department of Civil Engineering from Koneru Lakshmaiah Education Foundation.