An Experimental Study on Flexural Behaviour of Geopolymer Concrete Beams

A.Lakshmi priya[1] K. Shalini[2] C.Sreenivasulu[3] J. Guru Jawahar[4] K.Narasimhulu[5]
[1]M.Tech Student [2,3]Assistant Professor [4,5]Professor
[1,2,3,4,5]Annamacharya Institute of Technology & Sciences, Tirupati, India

Abstract— Geopolymer binders have been proved to be green building materials that can totally replace OPC by an alkaline reaction between silica and alumina are presented in source material. This paper mainly focused on the Flexural behaviour of geopolymer concrete beams with partial replacement of silica sand as natural sand at different proportions like 100:0, 90:10, 80:20, and 70:30 (natural sand: silica sand). The grade of conventional concrete was made as M40, which is equivalent to grade of geopolymer concrete. The beams were cured for 28 days at ambient room temperature and tested for two point loading. The parameters under flexural behaviour like First crack load, Ultimate load, service load, yield load, Ultimate deflection, bending stresses, Load deflection characteristics, Moment characteristics are presented. The study has given a final conclusion that at 20% replacement level of silica sand as natural sand gives better results at 8M. By increasing the replacement level decreasing the strength, hence the silica sand used as a filler material for well graded geopolymer concrete which is more sustainable.

Key words: Geopolymer Concrete, Silica Sand, Two-Point Loading, Flexural Parameters

I. INTRODUCTION

Geopolymer binder which was introduced by Davidovits1978 is an inorganic polymer binder, rich in silica and aluminium. In the process of polymerization of materials, alkaline substances are to be added [1]. The source material for silica and aluminium are Fly ash (FA), which is produced from thermal power plants as a waste and ground granulated blast furnace slag (GGBS), which is produced from AASTRA Chemicals, Chennai. Alkaline substances used for obtaining Polymerization reaction are alkaline grade sodium silicate solution (Na2Sio3) and sodium hydroxide solution (NaOH) as an alkaline activator, were taken as 8M. Geopolymer concrete made with only fly ash as a source material for silica and aluminium has shown poor results [2]. Geopolymer concrete require curing under ambient room temperature itself. Results are already concluded that GGBS and FA blended GPC mixes attained enhanced mechanical properties at ambient room temperature itself [3-6]. The load deflection characteristic at mid span of the reinforced geopolymer concrete beams and OPC controlled beams were found to be similar and shows slightly more deflections at same load than the reinforced OPCC beams [7]. Research is being conducted on the flexural behaviour of reinforced geopolymer concrete beams (RGPC). The first cracking load and service load of RGPC beams shows slightly high performance when compared to reinforced cement concrete beams [8]. Ultimate load for Geopolymer concrete beams with 75% fly ash and 25% GGBS were found to be higher than the Ultimate loads for reinforced geopolymer concrete beams with only fly ash, irrespective of the quantity of tensile strength [9].

The present investigation is aimed to find the flexural parameters viz. Load deflection characteristics, moment characteristics, cracking load, ultimate load, service load, maximum moment resistance capacity and ultimate deflection under the flexural behaviour of geopolymer concrete beams at different replacement levels of silica sand after 28 days ambient room temperature curing.

II. EXPERIMENTAL STUDY

A. *Materials:*

In this respect, FA, GGBS and silica sand were used as binders whose chemical and physical properties are tabulated in Table1. According to ASTM C 618 (2003) [10], class F fly ash produced from Lanco Industry, srikalahasti, A.P and GGBS produced from AASTRA chemicals, Chennai, A.P were used in the manufacturing of GPC.

Particulars	Class F fly ash	GGBS	Silica sand
Chemical composition			
% Silica(Sio2)	65.6	30.61	81.5
% Alumina(Al2O3)	28.0	16.24	0.64
%Iron Oxide(Fe2O3)	3.0	0.584	0.76
% Lime(Cao)	1.0	34.48	0.14
% Magnesium(Mgo)	1.0	6.79	0.99
%Titanium Oxide(TiO2)	0.5	-	-
%Sulphur Trioxide(So2)	0.2	1.85	-
Loss on Ignition	0.29	2.1	-
Physical properties			
Specific gravity	2.12	2.94	2.60
Fineness(m2/kg)	360	400	-

Table 1: chemical and physical properties of class F flyash, GGBS and silica sand

The alkaline liquid used was a combination of sodium silicate solution (Na2O = 13.7%, SiO2 = 29.4% and water = 55.9%) and sodium hydroxide (NaOH) in pellets form with 97% - 98% purity was purchased from local suppliers. The sodium hydroxide (NaOH) solution was prepared with a concentration of 8M. The sodium silicate solution and sodium hydroxide solution were mixed together one day before prior to use. Crushed granite stones of size 20mm and 10mm used as coarse aggregate, river sand used as fine aggregate and silica sand used as replacement of natural sand at different levels 100:0, 90:10, 80:20 and 70:30. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20mm and 10mm were 2.66 and 0.3% respectively. The bulk specific gravity in oven dry condition and water absorption of the fine aggregate were 2.62 and 1% respectively. The bulk specific gravity in oven dry condition and water absorption of silica sand were 2.60 and 0.4% respectively.

B. *Mix Design:*

Based on the past research on GPC, the mix proportions were selected based on Rangan's method. Geopolymer concrete mix proportions of constituent materials are shown in Table 2.

Materials		Mass(Kg/m^3)			
		100:0	90:10	80:20	70:30
Coarse aggregate	20mm	774	774	774	774
	10mm	516	516	516	516
Fine aggregate		549	494.1	439.2	384.3
silica sand		0	54.9	109.8	164.7
Flyash(Class F)		204.5	204.5	204.5	204.5
GGBS		204.5	204.5	204.5	204.5
Sodium silicate solution		102	102	102	102
Sodium hydroxide solution		41	41	41	41
Extra water		55	55	55	55
Super plasticizer		2.86	2.86	2.86	2.86

Table 2: GPC mix proportions of constituent materials

C. *Experimental Setup:*

Compressive strength test was conducted on the cubical specimens for all the mixes viz., silica sand as replacement at 100:0, 90:10, 80:20 and 70:30 after 7, 28 and 90days of curing as per IS516:1991 [11]. Three cubical specimens of each proportion of size 150mmx150mmx150mm were castes and tested for each age and each mix. The unit weight of hardened concrete (Yc) was determined after 28days of curing prior to compression test.

The dimensions of the beam for flexural test were chosen as 1200mmx150mmx150mm. Two TMT bars of size 12mm diameter (Fe415) were used at the bottom and two bars of size 12mm diameter (Fe415) were used at the top. A clear cover of 20mm was provided. Stirrups having 6 mm diameter were placed at a spacing of 150mm center-to-center(c/c). The beams were white washed so that the cracks can be easily identified. The effective span of the beam was taken as 1000mm. The beams were tested in a manually operated loading frame. The beams were subjected to a two point loading at a distance of L/3 (where L is effective span). linear variable displacement transducers (LVDT's) was set up at L/2 and at L/3 in order to calculate the deflections. The DATA LOGGER was used in order to collect the data as First crack load, Ultimate load and deflections at L/2 and L/3. The load was applied manually by using a hydraulic jack as shown in Figure 1. The flexural failure of the beam after loading is as shown in Figure 2.

Fig. 1: Set up of a GPC beam under two-point

Fig 2: Flexural failure of a beam under two-point loading

III. RESULTS & DISCUSSION

A. *Mechanical Properties:*

From Table 3, we can clearly noticed that there is an increase in the compressive strength of cubes from 31.2 MPa of 100:0 S to 31.3 MPa of 90:10 to 32.9 MPa of 80:20 and decreases at 30.5 MPa of 70:30 for 7days and an increase in compressive strength from 42.3 MPa of 100:0 to 44.97 MPa of 90:10 to 48.2 MPa of 80:20 and decreases at 41.6 MPa of 70:30 for 28days and an increase in compressive strength from 45.42 MPa of 100:0 to 45.91 MPa of 90:10 to 56.53 MPa of 80:20 and decreases at 44.66 MPa of 70:30 for 90days. This increase in performance at 80%S+20%SS is due to increase in silica content present in silica sand but 70:30 , results were poor because there is no reactivity due to increasing silica sand content at 8M.The performance has also been increased from 28days to 90days. The comparison at different replacement levels has been shown in figure 3.

Mix Type	Compressive strength (MPa)		
	7 days	28 days	90 days
100:0	31.2	42.3	45.42
90:10	31.3	44.97	45.91
80:20	32.9	48.2	56.53
70:30	30.5	41.6	44.66

Table 3: Compressive strength of cubes at 7,28 and 90days curing

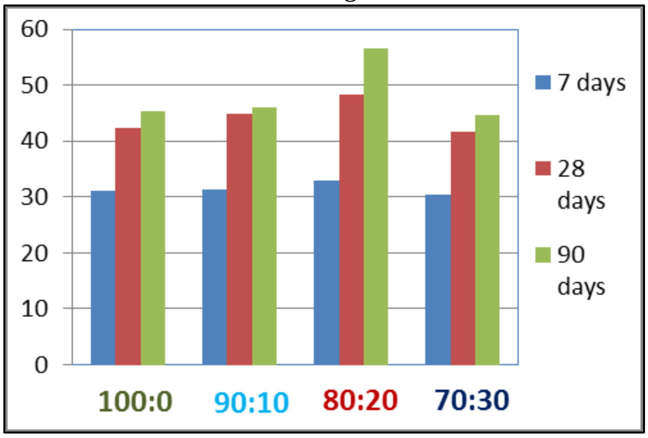

Fig. 3: Comparison of Compressive strength of cubes at 7, 28 and 90days curing

B. *Load Characteristics:*

The load characteristics like First crack load, Ultimate load, Service load and yield load as shown in Table 4. The serviceable load has been calculated by using factor of safety 1.5, taken from IS 456:2000. From the below table, it can be easily noticed that the first crack load increases from 40.54 kN of 100:0 to 54.48kN of 90:10 to 54.92 kN of 80:20 and decrease at 53.59 kN of 70:30 for 28 days. Ultimate Load increases from 92.96 kN of 100:0 to 96.60 kN of 90:10 to 105.34 kN of 80:20 and decreases at 93.86 kN of 70:30 for 28days. Serviceable load increases from 61.97 kN of 100:0 to 64.40 kN of 90:10to 70.22 kN of 80:20 and decreases at 62.57 kN of 70:30 for 28 days. Yield load increases from 75.53 kN of 100:0 to 74.03 kN of 90:10 to 82.10 kN of 80:20 and 80.07 kN of 70:30.

Mix Type	First crack Load (kN)	Ultimate load (kN)	Serviceable load (kN)	Yield load (kN)
100:0	40.54	92.96	61.97	75.53
90:10	54.48	96.60	64.40	74.03
80:20	54.92	105.34	70.22	82.10
70:30	53.59	93.86	62.57	80.07

Table 4: Load characteristics at 28 days of curing

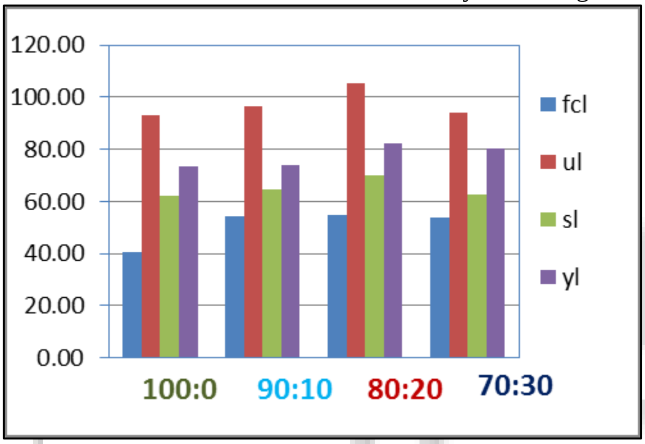

Fig. 4: Comparison of load characteristics at various proportions

C. Moment Characteristics:

The below table shows that predicted cracking moment increases from 6.76 kN-m of 100:0 to 9.08 kN-m of 90:10 to 9.15 kN-m of 80:20 and decreases at 8.93 kN-m of 70:30 for 28 days. The experimental cracking moment increases from 6.86 kN-m of 100:0 to 9.18 k N-m of 90:10 to 9.26 kN-m of 80:20 and decreases at 9.04 kN-m of 70:30 for 28days. The predicted ultimate moment increases from 8.32 kN-m of 100:0 to 8.38 kN-m of 90:10 to 8.45 kN-m of 80:20 and decreases at 8.3 kN-m of 70:30 for 28days. The experimental ultimate moment increases from 15.60kN-m of 100:0 to 16.20 kN-m of 90:10 to 17.66 kN-m of 80:20 and decreases at 15.75 kN-m of 70:30 for 28 days.

Mix Type	Predicted Cracking moment (kN-m)	Experimental Cracking moment (kN-m)	Predicted Ultimate moment(kN-m)	Experimental Ultimate moment (kN-m)
100:0	6.76	6.86	8.32	15.60
90:10	9.08	9.18	8.38	16.20
80:20	9.15	9.26	8.45	17.66
70:30	8.93	9.04	8.3	15.75

Table 5: Moment characteristics at 28 days of curing

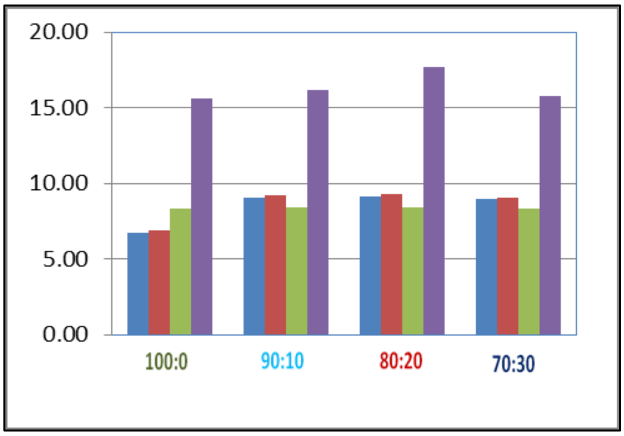

Fig 9: comparison of Moment characteristics at 28 days curing

D. Ultimate Load:

The below table 6, shows the predicted ultimate load increases from the 46.8 kN of 100:0 to48.6 kN of 90:10 to 52.98 kN of 80:20 and decreases at 47.25 kN of 70:30 for 28 days. Experimental ultimate load varies from 92.96 kN of 100:0 to 96.60 kN of 90:10 to 105.34 kN of 80:20 and decreases at 93.86 kN of 70:30 for 28 day.

Mix type	Predicted Ultimate load (kN) at 28days	Experimental Ultimate load (kN)at 28days
100:0	46.8	92.96
90:10	48.6	96.60
80:20	52.98	105.34
70:30	47.25	93.86

Table 6: Ultimate load at 28 days of curing

E. Serviceable Load:

From the below table 7, it can be clearly noticed that the predicted serviceable load increases from 31.2 kN of 100:0 to 32.4 kN of 90:10 to 35.32 kN of 80:20 and decreases at 31.5 kN of 70:30 for 28 days. Experimental serviceable load varies from 61.97 kN of 100:0 to 64.40 kN of 90:10 to 70.22 kN of 80:20 and decreases at 62.57 kN of 70:30 for 28 days.

Mix type	Predicted serviceable load (kN) at 28days	Experimental serviceable load(kN) at 28days
100:0	31.2	61.97
90:10	32.4	64.40
80:20	35.32	70.22
70:30	31.5	62.57

Table 7: Serviceable load at 28 days of curing

F. Cracking Load:

From the below table 8, it can be clearly noticed that the predicted cracking load increases from 20.28 kN of 100:0 to 27.24 kN of 90:10 to 27.45 kN of 80:20 and decreases at 26.79 kN of 70:30 for 28 days. Experimental serviceable load varies from 20.58 kN of 100:0 to 27.54 kN of 90:10 to 27.78 kN of 80:20 and decreases at 27.12 kN of 70:30 for 28 days.

Mix type	Predicted Cracking load (kN) at 28days	Experimental Cracking load(kN) at 28days
100:0	20.28	20.58
90:10	27.24	27.54
80:20	27.45	27.78
70:30	26.79	27.12

Table 8: Cracking load at 28 days of curing

G. Bending Stress:

The below table 9, shows the bending stresses as of increasing 27.73 MPa of 100:0 to 28.81 MPa of 90:10 to 31.40 MPa of 80:20 and decreases at 27.99 MPa of 70:30 for 28 days.

Mix type	Bending stress(MPa) at 28days
100:0	27.73
90:10	28.81
80:20	31.40
70:30	27.99

Table 9: Bending stresses at 28 days of curing

H. Ultimate Deflection:

The below table 10, shows the Ultimate deflection varies as 33.84 mm of 100:0 to 43.7 mm of 90:10 to 45.42 mm of 80:20 and decreases at 40.2mm of 70:30 for 28 days.

Mix Type	Ultimate deflection(mm)
100:0	33.84
90:10	43.7
80:20	45.42
70:30	40.2

Table 9: Ultimate deflection at 28 days of curing

IV. Conclusions

1) The performance of geopolymer concrete beams gives better results at 80:20 replacement level as natural sand at 8M.
2) Though the performance of 70:30 is better, the workability of concrete with this proportion is poor because of there is no reactivity, of increasing silica sand content.
3) The First crack load of the beam at 80:20 is 54.92 KN, which is higher of other replacement levels.
4) The Ultimate load and ultimate moment of beam at 80:20 is105.34 KN and 17.60 Kn-m for 28 days curing.
5) The cracking load and cracking moment of beam at 80:20 is 27.78 KN and 9.26 Kn-m for 28 days curing.
6) The serviceable load and yield load of beam at 80:20 is of 70.22 KN and 82.10 KN of 28 days curing.
7) The bending stress of the beam at 80:20 is 31.40 Mpa at 28 days curing.
8) The ultimate deflection of the beam at 80:20 is 45.42 mm of 28 days curing.

References

[1] Davidovits J. Geo polymers: man-made geosynthesis and the resulting development of very early high strength cement, Journal of materials education, 16(1994)91-139.
[2] J. Guru Jawahar, D. Lavanya, C. Sashidar. “Performance of flyash and ggbs geopolymer concrete in acid environment”, International Journal of Research and scientific Innovation(IJRSI), 3(2016), 101-104.
[3] Guru Jawahar J, mounika G. Strength properties of flyash and GGBs based geopolymer concrete, Asian journal of Civil Engineering, 17(2016) 127-135.
[4] C. Sreenivasulu, J.Guru Jawahar, M.Vijaya Sekhar Reddy and D.Pavan Kumar,”Effect of Fine aggregate Blending on short-term mechanical properties of geo polymer concrete, Asian Journal of Civil Engineering (BHRC), Volume-17,Issue-5(2016),PP-537-550.
[5] C.Sreenivasulu, A.Ramakrishnaiah, and J.Guru Jawahar, Mechanical properties of geo polymer concrete using granite slurry as sand replacement, Intenational Jornal of Advances in Engineering and Technology,April-2015, Volume-8,Issue-2,PP-83-91.
[6] C Sreenivasulu, J Guru Jawahar, C Sashidhar, Study and predicting the stress-strain characteristics of geopolymer concrete under compression, Case Studies in Construction Materials, 8(2018) 172-192.
[7] C.K. Madheswaran , P.S. Ambily, J.K. Dattatreya, Ramesh G. Experimental studies on behaviour of reinforced geopolymer concrete beams subjected to monotonic static loading. International Journal of Innovative Research in science, Engineering and technology, 3(2014), 14473-14482.
[8] M.K. Thangamanibindhu and Dr. D.S. Rama chandramurthy. Flexural behaviour of geopolymer concrete beams replaced with recycled coarse aggregates. International Journal of Civil Engineering and Technology 6(2015), 13-23.
[9] M.K. Thangamanibindhu and DR.D.S. Rama chandramurthy , Flexural behaviour of reinforced geopolymer concrete beams using flyash partially replaced with GGBS, International Journal of Engineering and Technology(IRJET), 3(2016),1839-1851.
[10] ASTM C 618:2003, standard specification for coal flyash and raw or calcined natural pozzolana for use in concrete.