FLEXURAL BEHAVIOUR OF REINFORCED GEOPOLYMER CONCRETE BEAMS USING FLY ASH PARTIALLY REPLACED WITH GGBS

M.K. Thangamani Bindhu[1],Dr.D.S.Ramachandra Murthy[2]

[1](Research Scholar, St.Peter's University, Chennai, Tamil Nadu, India)[2](Director (R&D), St.Peter'sUniversity, Chennai, Tamil Nadu, India)

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1. INTRODUCTION

Portland cement is the most energy–intensive construction material after aluminium and steel. Hence research efforts are undertaken for alternate materials to replace the cement used in the concrete.Flyash and GGBS can be used as binders in concrete but needs to be activated.Davidovit coined the term geopolymer in 1978 to describe the alkali-activated material from geological origin by- product materials such as flyash and rice husk ash. The formulation showed rapid strength and fast setting.

This paper presents the information about the materials and mix proportions of flyash based reinforced geopolymer concrete. The performance of RGPC beams such as load carrying capacity, moments, deflection and crack width at different stages were studied. A total of 7 beams having different mix proportions of flyash and GGBS for different percentage of steel reinforcement were tested after ambient temperature curing.The compressive strength ranged from 15.5 to 43.8 MPa.

2. LITERATURE REVIEW

Dattatreya J K , Rajamane NP , Sabitha D , Ambily PS Nataraja MC (2011) Conducted investigation on flexural behaviour of reinforced Geopolymer concrete beams and observed that the load carrying capacity of most of the GPC beams was in most cases marginally more than that of the corresponding conventional OPCC beams. The deflections at different stages including service load and peak load stages were higher for GPC beams.

Kumaravel S and ThirugnanasambandamS(2013) Based on their research work on flexural behaviour of low calcium flyash based geopolymer concrete beams, concluded that the experimental results are higher when compared with numerical results by 6.5% and the beams failed initially by yielding of the tensile steel followed by the crushing of concrete in the compression face.

Madheswaran C K, Ambily P S, Rajamane N P

Arun G (2014) Conducted investigation on flexural behaviour of reinforced geopolymer concrete beams with light weight aggregatesand concluded thatthe flexural capacity of the beams was influenced by the percentage of tensile reinforcement. As the percentage of tensile reinforcement increased, the flexural capacity of the beams increased significantly.

Sangeetha S.P, JoannaP.S. (2014) Conducted investigationon flexural behaviour of reinforced concrete beams with partial replacement of GGBS. The ultimate moment capacity of GGBS was less than that of the controlbeam when tested at 28 days, but it increases by 21% at 56 days.

3. EXPREMENTAL INVESTIGATION

3.1 Materials

Fly ash: Flyash used in this study was obtained from National Thermal Power Corporation,Ennore.The specific gravity of flyash is 2.14.

Ground granulated blast furnace slag: Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. GGBS is a glossy, granular, non-metallic material consisting essentially of silicates and aluminates of calcium and other bases. The specific gravity of GGBS is 2.9.

Fine Aggregate: The locally available manufactured sand of zone III was used as fine aggregate in the present investigation and the specific gravity is 2.6.

Coarse Aggregate: Natural coarse aggregate was used as the coarse aggregate in the concrete mixtures. Locally available crushed granite of maximum size 20mm was used as the natural coarse aggregate.Specific gravity of 20mm coarse aggregate is 2.76.

Alkaline activator: The alkaline activator liquid used was a combination of sodium silicate solution and sodium hydroxide. An analytical grade sodium hydroxide in flakes form (NaOH with 98% purity) was used. To avoid effects of unknown contaminants in laboratory tap water, distilled water was used for preparing activating solution. The activator solution was prepared at least one day prior to its use in specimen casting.

Water: Distilled Water and Potable water which is free from chemicals and organic materials was used for the study.

Super plasticizer: Ceraplast 300 was used in this study (Fig.1). Table 1 gives the properties of super plasticiser.

Table 1: Properties of Super plasticizers

Ceraplast 300
Colour: Brown
Specific gravity = 1.2 +_ 0.3
Chloride Contents: Nil
Manufacturer's recommended dosage= 0.3-1.2% Ceraplast by weight of cement
It is a high grade superplasticizer based on naphthalene,highly recommended for increased workability and high early and ultimate strength of concrete.

Fig-1: Super plasticizer

3.2 Mix Design of Geopolymer concrete

In the design of Geopolymer concrete mix, total aggregate (fine and coarse) is taken as 77% of entire concrete mix by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire concrete mix by mass. Fine aggregate was taken as 30% of the total aggregates. From the available literature, it is observed that the average density of flyash-based Geopolymer concrete is similar to that of OPC concrete (2400 kg/m^3). Knowing the density of concrete, the combined mass of alkaline liquid

and fly ash can be arrived. By assuming the ratios of alkaline liquid to flyash as 0.35, mass of flyash and mass of alkaline liquid were obtained. Three types of mixes were used for the present study namely with 100% flyash (FA), 75% fly ash and 25% GGBS (FAGB), and 50% fly ash and 50% GGBS (FGGB).

Table 2:GPC Mix Proportions using Flyash

Materials		FA1	FA2	FA3
Coarse aggregate kg/m^3	20mm	840.84	840.84	840.84
	12.5mm	452.76	452.76	452.76
Fine aggregate,kg/m^3		554	554	554
Fly ash, kg/m^3		408	408	408
GGBS, kg/m^3		-	-	-
Sodium hydroxide, kg/m^3		41	41	41
Sodium Silicate Solution, kg/m^3		103	103	103
Super plasticizer, lit/m^3		4.9	4.9	4.9
Extra water, lit/m^3		20.0	20.0	20.0

Table 3:GPC Mix Proportions Using Flyash and GGBS

Materials		FAGB1	FAGB2	FAGB3	FGGB3
Coarse aggre gate kg/m^3	20m m	840.84	840.84	840.84	840.84
	12.5 mm	452.76	452.76	452.76	452.76
Fine aggregate kg/m^3		554	554	554	554
Fly ash, kg/m^3		306	306	306	204
GGBS, kg/m^3		102	102	102	204
Sodium hydroxide,kg/m^3		41	41	41	41
Sodium Silicate Solution, kg/m^3		103	103	103	103
Super plasticizer, lit/m^3		4.9	4.9	4.9	4.9
Extra water, lit/m^3		20.0	20.0	20.0	20.0

3.3 Preparation, Casting and Curing of Geopolymer Concrete.

Davidovits (2002) suggested that it is preferable to mix the sodium silicate solution and the sodium hydroxide solution together at least one day before adding the liquid to the solid constituents. Hence mixing of sodium hydroxide solution and sodium silicate solution together was done one day prior to adding the liquid to the dry materials. GPC can be manufactured by adopting the conventional technique used in the manufacture of Portland cement concrete. The fly ash and the aggregates were mixed together dry on pan for about 4 minutes. The solution is then added and super plasticizer was added to the materials and the mixing continued for another 5 minutes for each mixture. Pan mixer was used for mixing the materials. Table vibrator was used for compacting the specimens.The addition ofsodium silicate is to enhance the process of geopolymerisation. For the present study, concentration of sodium hydroxide is taken as 10M and ratio of alkaline solution as 2.5. After casting, the specimens were cured in ambient temperature. The demoulding procedure is similar to that of conventional concrete.The cube specimens were tested as per IS 516:1959 and strengths were calculated.

3.4 Preparation of BeamSpecimens

Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the hardening c oncrete. GPC

was mixed in a tilting drum mixer machine. Thesteel reinforcement as per the design was placed over the 25mm cover block. Concrete was placed in the mould in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted (Fig.3). Along with beam casting, three numbers of150mm size cubes were cast to determine the compressive strength of concrete.Specimens were demoulded after 24hours.The GPC beams were cured in ambient temperature in the laboratory for a period of 28 days after casting (Fig.4).The cube specimens were tested for compressive strength.

Reinforcement details for beam specimens: Seven beams of size100 mm x 150 mm x 1800mm were cast. Reinforcement details are given in Table 4

Fig- 2: Reinforcement details of beam specimens

Fig- 3: Casting of beam specimens – Wet concrete in the mould

Table 4: Reinforcement details of GPC beams

Beam ID	Area of steel (mm^2)	
	Top	Bottom
FA-1	100.48	100.48
FA-2	100.48	157.00
FA-3	100.48	226.08
FAGB-1	100.48	100.48
FAGB-2	100.48	157.00
FAGB-3	100.48	226.08
FGGB-3	100.48	226.08

Fig- 4: Seven Beam Specimens

4. TEST AND RESULTS

4.1 Test set up

The test set up for flexure test is shown in Fig. 5. The test specimen is mounted in a beam testing frame of 500kN capacity. The beams are simply supported over a span of 1600mm and subjected to two concentrated loads placed symmetrically on the span. The load is applied on two points each 533.3 mm away using a steel distribution beam. A data acquisition unit is used to collect the load and deflection data during test. Linear Variable Data Transformer (LVDT) is placed at mid span and under the load points of beam for measuring deflection. The load is applied in stages gradually till failure. The 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 first crack loads are obtained by visual examination. Fig.6 shows beam after test.

Fig -5: Test Setup

4.2 Results

Test results are shown in Table 5.The theoretical and experimental maximum load, maximum deflection and crack width for various beams are given in the table. Load vs. Maximum deflection curves for various beams are shown in Chart. 1 to 7.

Fig- 6: Beam after Failure

Table 5: Load carried at various stages by GPC beams

Beam ID	Crack load (kN)	Experimental Service Load (kN)	Theoretical Ultimate Load (kN)	Experimental Ultimate Load (kN)
FA1	6	8.67	11.7	13
FAGB1	6	14	14.38	21
FA2	8	16.67	18.17	25
FAGB2	9	16.67	21.91	25
FA3	10	18	22.07	27
FAGB3	12	23.33	28.55	35
FGGB3	10	16	29.86	24

Table 6: Test results for GPC beams

Beam ID	Theoretical Ultimate Moment (kNm)	Experimental Ultimate Moment (kNm)	Ultimate Deflection (mm)
FA1	3.13	3.466	44.1
FAGB1	3.84	5.600	18.8
FA2	4.849	6.666	24
FAGB2	5.843	6.666	20.3
FA3	5.886	7.200	20.6
FAGB3	7.615	9.332	29.1
FGGB3	7.965	6.400	17.3

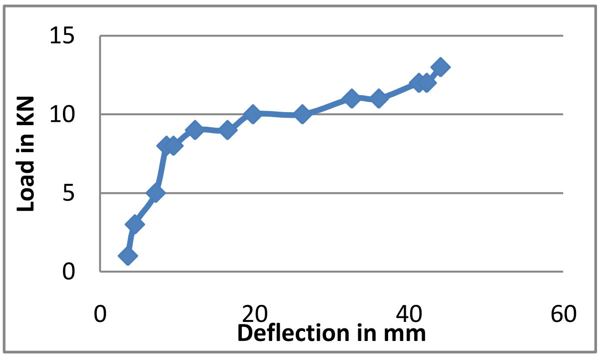

Chart-1: Load versus Mid Span Deflection of FA1

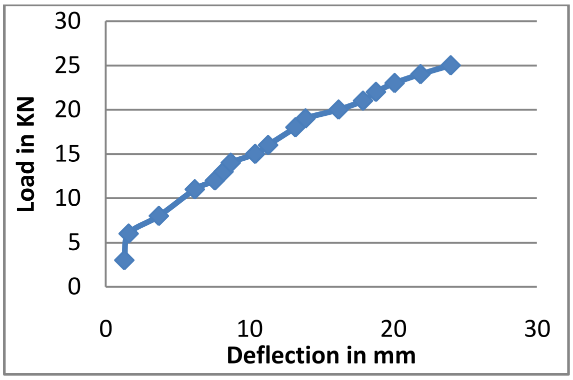

Chart-2: Load versus Mid Span Deflection of FA2

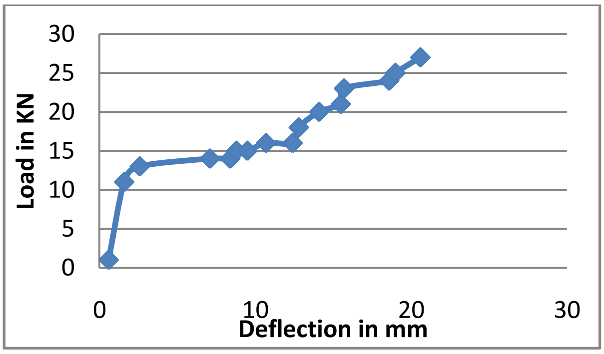

Chart-3: Load versus Mid Span Deflection of FA3

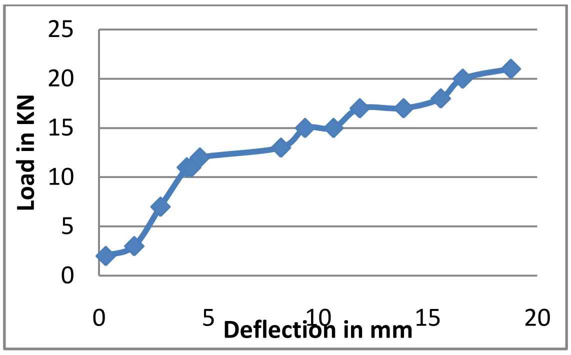

Chart-4: Load versus Mid Span Deflection of FAGB1

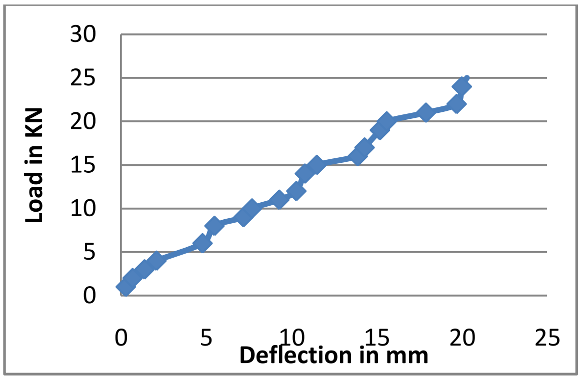

Chart-5: Load versus Mid Span Deflection of FAGB2

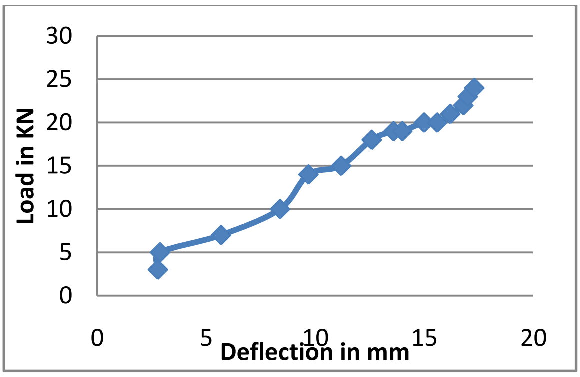

Chart-7: Load versus Mid Span Deflection of FGGB3

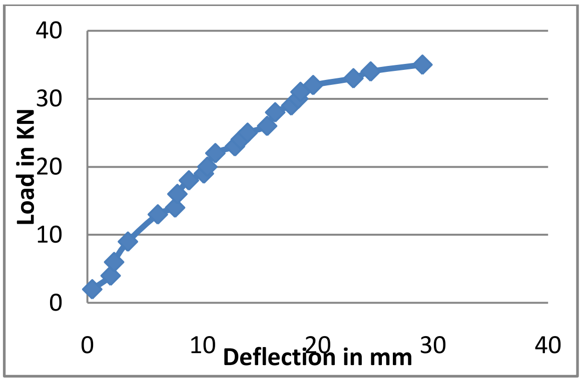

Chart-6: Load versus Mid Span Deflection of FAGB3

Table 7: Service load carried by the variousbeams

Beam ID	Binder composition Flyash/ GGBS	% of Tensile reinforcement	Experimental Deflection at Service Load (mm)	Theoretical Deflection at Service Load (mm)
FA1	100% FA	0.66	16.5	3.88
FAGB 1	75% FA / 25% GGBS	0.66	9.4	5.75
FA2	100% FA	1.05	14.2	6.04
FAGB 2	75% FA / 25% GGBS	1.05	13.1	5.03
FA3	100% FA	1.51	13.6	5.24
FAGB 3	75% FA / 25% GGBS	1.51	12.8	6.05
FGGB 3	50% FA / 50% GGBS	1.51	11.2	3.75

4.3 Compressive Strength

Cubes of size 150mmx150mmx150mm were cast along with the beam and cured in ambient temperature. The mix proportion of the cube is same that for beams. The cubes are tested at the age of 28 days (Fig-7).The compressive strengths for all specimens are shown in Fig.8. The FGGB-1 mix (with 50% fly ash and 50% GGBS) gavemaximum compressive strength of 43.82 MPa.

Fig-7: Testing of cube

Fig- 8: Failure of cube

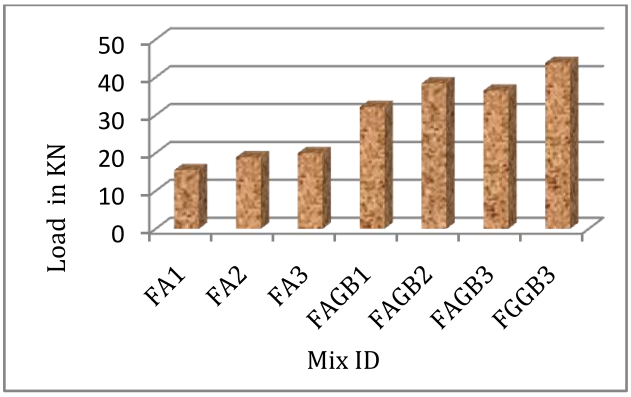

Chart-8: Compressive strength of geopolymer concrete cubes at 28 days

5. CONCLUSIONS

1. Addition of GGBS is found to give increased compressive strength of Geopolymer concrete as seen from the results of cube tests.

2. Ultimate loads for GPC beams with 75% fly ash and 25% GGBS (FAGB series) were found to be higher than the ultimate loads for GPC beams with fly ash only irrespective of the quantity of tensile reinforcement. Load carrying capacity was found to be high in the beam FAGB-3 which had higher percentage of tensile reinforcement.

3. It was generally observed that GPC beams having more tensile reinforcement withstood greater ultimate loads. This is similar to the behaviour of conventional under-reinforced cement concrete beams. Also, experimental loads were more than theoretical loads for all the beams.

4. The crack width was found to be less for GPC beam FGGB3 with 50% fly ash and 50% GGBS.

5. Workability of mix FGGB3 was low and not easy compared with other mixes.

6. Minimum crack width was observed in the beam FGGB3 even though ultimate load was less when compared to FAGB3. Also, minimum deflection was observed in the beam FGGB3.

7. Load – deflection behaviour indicates stiffness of the beams. It was observed that GPC beams with 75% fly ash and 25% GGBS had greater ultimate load/deflection ratio and hence greater stiffness compared to other beams.

8. Hence it can be generally concluded that the overall behaviour of GPC beams with 75% fly ash and 25% GGBS is better than GPC beams with fly ash only.

REFERENCES

[1]Dattatreya J.K., Ambily P.S., Madheswaran C.K., Sabitha D., Neelamegam M. (2011),"Experimental Studies on Shear Behaviour of Reinforced Geopolymer Concrete Beams", SERC Research Report No. RR-2, June.

[2] Dattatreya J.K., Rajamane N.P., and Ambily P.S., (2009), "Structural Behaviour of Reinforced Geopolymer Concrete Beams and Columns", SERC Research Report.

[3] Hardjito D., and Rangan B.V., (2005), "Development and properties of low calcium fly ash based geopolymerconcrete",Curtin University of Technology, Perth, Australia.

[4] IS456:2000, Indian Standard Code for Plain and reinforced Concrete-Code of practice, BIS, New Delhi.

[5] IS 516:1959. Methods of tests for strength of concrete.

[6] IS 12089: 1987, Specification for granulated slag for the manufacture of Poland slag cement.

[7] Kumaravel.S, Thirugnanasambandam.S., (2013), "Flexural behaviour of low calcium fly ash based Geopolymer Concrete Beams", Annamalai University, Annamalainagar

[8]GanapatiNaidu.P, A.S.S.N.Prasad, S.Adiseshu, P.V.V.Satayanarayana(2012) "Study on Strength Properties of Geopolymer Concrete with Addition of G.G.B.S"

[9] Madheswaran C.K, Ambily P S, RajamaneN.P

Arun G,(2014), "Studies on flexural behaviour of reinforced geopolymer concrete beams with light weight aggregates". Tamilnadu College of Engineering, Coimbatore.

[10] S.P.Sangeetha, P.S Joanna, (2014) "Flexural Behaviour of Reinforced Concrete Beams with Partial Replacement of GGBS", Hindustan University, Chennai.