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Structural behaviour of high calcium fly ash based geopolymer concrete beam

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Abstract : *This paper presents the experimental and analytical studies of the strength and ductility of high calcium fly ash based geopolymer concrete beam when subjected to ambient curing. The investigations were carried out on geopolymer concrete beams of various grades and sodium hydroxide molarity of 12 M. The beams were designed as under reinforced with tensile reinforcement ratios 1.25% and 1.80 %. The beams were tested under two point static loading. Performance aspects such as load deflection behavior, ductility index, young's modulus and energy absorption capacity were studied. The test results showed that the geopolymer concrete beam exhibits better performance.*

Keywords: *geopolymer, flexure, class C fly ash, ambient curing, ductility.*

I.INTRODUCTION

Concrete is the widely used building material and cement is the main constituent in the manufacturing of concrete. The production of Portland cement consumes considerable energy and at the same time contributes a large volume of CO_2 to the atmosphere [1]. With the intention of overcoming the environmental issues of cement, an effort has been made to find a substitute for cement by using industrial by products such as flyash. Fly ash is the most common source material for making geopolymers. Geopolymers are formed by the alkaline activation of aluminosilicate materials like fly ash [2]. Most well known alkaline solution employed in the geopolymer technology is the mixture of sodium hydroxide with sodium silicate or potassium hydroxide with potassium silicate [3]. Normally, good high strength geopolymers can be made from class F fly ash [4]. However, it has been shown that high calcium fly ash (class C) from lignite can also be used to produce geopolymer mortar with good compressive strength. [5]. Also studies on heat cured geopolymer concrete have shown its suitability for applications only in precast members. Therefore development of geopolymer concrete at ambient temperature will widen its applications to concrete structures practically. Various researches were mainly engaged in identifying suitable source materials for geopolymer concrete, their processing, mix design, mechanical properties, and durability aspects. But, as in conventional reinforced concrete, the geopolymer concrete also needs to be reinforced with steel bars for its large scale utility in civil engineering structural applications. Hence, the investigation on behaviour of reinforced geopolymer concrete was undertaken.

The room temperature cured reinforced class F based geopolymer concrete flexural members had more load carrying capacity and it was inferred that the conventional RC theory could be used for reinforced GPC flexural beams for the computation of moment capacity, deflection, and crack width within reasonable limits. [6]. The flexural capacity of retrofitted geopolymer concrete beams increased with increase in tensile reinforcement [7]. The geopolymer concrete beam of M20 grade with 8M of sodiumhydroxide were steam cured for 24 hours at a temperature of 60oC exhibited good flexural strength [8]. The flexural capacity of flyash based geopolymer concrete was influenced by tensile reinforcement ratio [9].

This paper considers the reinforced geopolymer concrete beams with different grades of 12 M of sodium hydroxide produced by ambient temperature curing. The beams were designed with 1.25 and 1.8 % tension reinforcement. Performance aspects such as load deflection behavior, ductility index, young's modulus and energy absorption capacity were studied.

II. MATERIALS AND SPECIMEN PREPARATION

The materials used were fly ash, fine aggregate, coarse aggregate, alkaline solution and water. High calcium class C fly ash obtained from Neyveli Lignite Corporation in Tamil Nadu was used as the base material for geopolymer concrete. Coarse aggregate of nominal size 20 mm with fineness modulus 6.92 and locally available river sand with fineness modulus 3.16 and conforming to zone II of IS 383 (1970) were used. Alkaline solution comprises a mixture of sodium silicate solution and sodium hydroxide was used. Sodium silicate solution with SiO_2 to Na_2O ratio of 2 (Na_2O=14.7%, SiO_2=29.4% and water=55.9%) by mass was used.

In this series of tests, eight rectangular high calcium fly ash based geopolymer concrete beams were prepared with 12 molarity of sodium hydroxide with an alkaline solution ratio of 2.5. The beams have been designed as under reinforced section. The mix proportions were shown in table 1. All beams were of the same size 150 mm x 150 mm x 700 mm of Fe 500, 3Nos-10 mm diameter bars (GCB 20-10, GCB 30-10, GCB 40-10, GCB 60-10) and 3Nos-12 mm diameter bars (GCB 20-12, GCB 30-12, GCB 40-12, GCB 60-12) were used for flexural reinforcement at the bottom of beam, 2Nos-8 mm at the top of each beam and 6 mm diameter stirrups spaced 200 mm c/c for shear reinforcement. The ultimate strength of the rods was 700 N/mm^2.

The variables considered in this study were the grade of concrete and the tensile reinforcement ratios. The reinforcement ratios were 1.25% and 1.80%. The sodium hydroxide and sodium silicate were prepared a day before since it liberates more heat [10]. The aggregates were first mixed with fly ash and then the alkaline solution was added. All the beams were cast in steel moulds and it was demoulded after 4 hours. Then the beams were left in room temperature for curing.

Table 1: Mix proportions for geopolymer concrete beam

Beam ID	w/f ratio	Fly ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)
GCB 20-10	0.5	383	567	1379	54.51	137
GCB 20-12	0.5	383	567	1379	54.51	137
GCB 30-10	0.45	479	536	1145	54.81	136.29
GCB 30-12	0.45	479	536	1145	54.81	136.29
GCB 40-10	0.40	527	522	1159	53.33	133.33
GCB 40-12	0.40	527	522	1159	53.33	133.33
GCB 60-10	0.31	530	505	1070	51.59	128.59
GCB 60-12	0.31	530	505	1070	51.59	128.59

III. TESTING PROCEDURE

All beams were tested under two point static loading as shown in figure 1. The span of the beam was 750 mm. The loads were applied through load cell using a hydraulic jack. During loading, the mid span deflection was measured using dial gauge having a least count of 0.01 mm. Deflections and the applied load were recorded at every load increment.

Figure 1: Experimental set up

IV. TEST RESULTS AND DISCUSSIONS

4.1 Load Deflection Response

The experimental load deflection responses at mid span of all the GCB beams are shown in Figure 2 to 9**.** All the beams followed the same pattern of load-deflection response. From the test results, it was observed that geopolymer concrete beam GCB-60 had more load carrying capacity compared to other beams. The first crack load and the ultimate load were observed for all the specimens. The flexural capacity of geopolymer concrete beams was influenced by tensile reinforcement ratio. The beam with 1.8 % tensile reinforcement ratio has high load carrying capacity than the beam with 1.25% tensile reinforcement. It was also observed that the load carrying capacity was more for all geopolymer concrete beams.

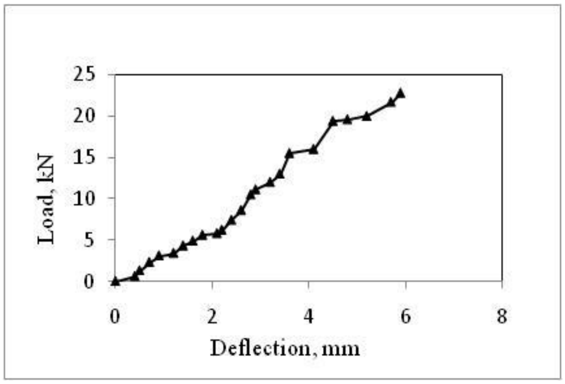

Figure 2 Load-deflection curve for GCB 20-10

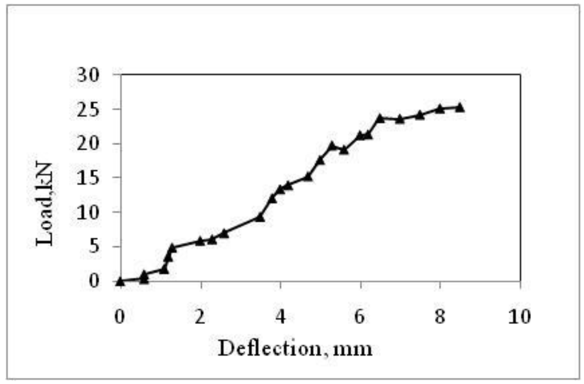

Figure 3 Load-deflection curve for GCB 20-12

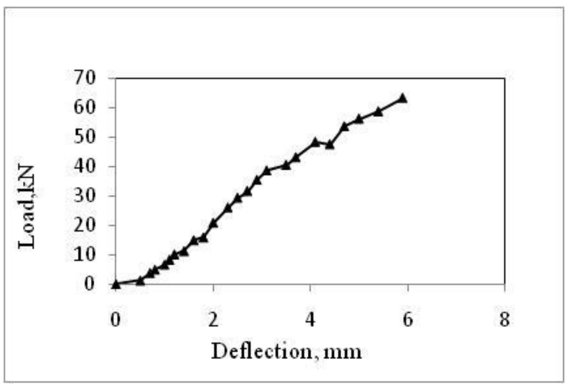

Figure 4 Load-deflection curve for GCB 30-10

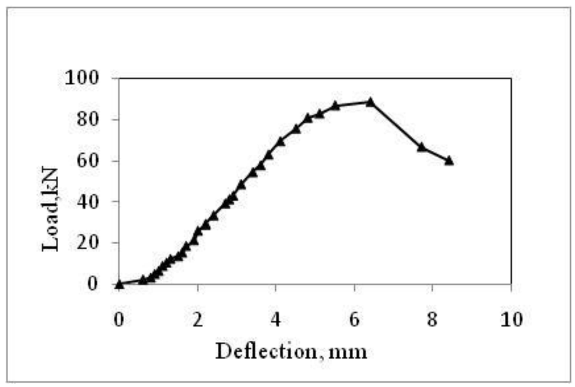

Figure 5 Load-deflection curve for GCB 30-12

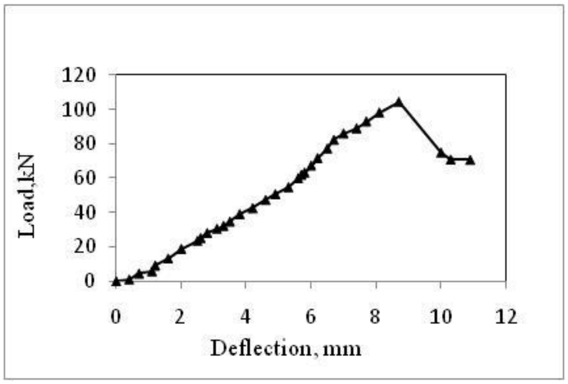

Figure 6 Load-deflection curve for GCB 40-10

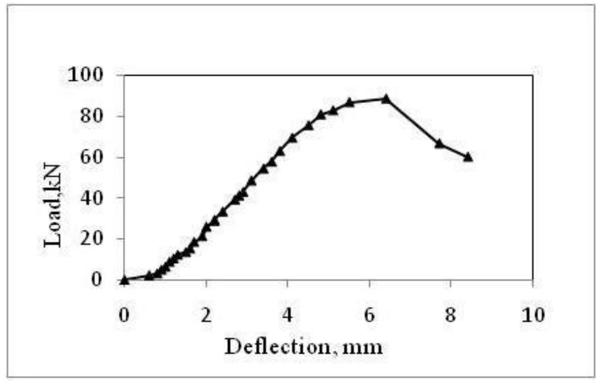

Figure 7 Load-deflection curve for GCB 40-12

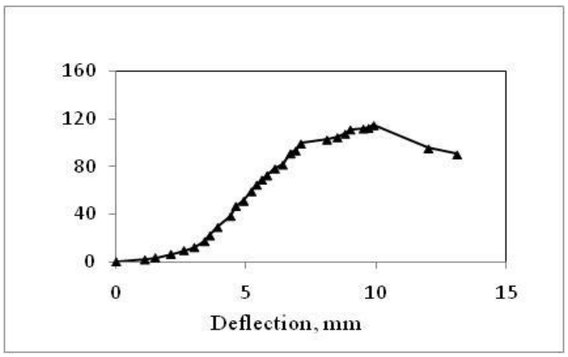

Figure 8 Load-deflection curve for GCB 60-10

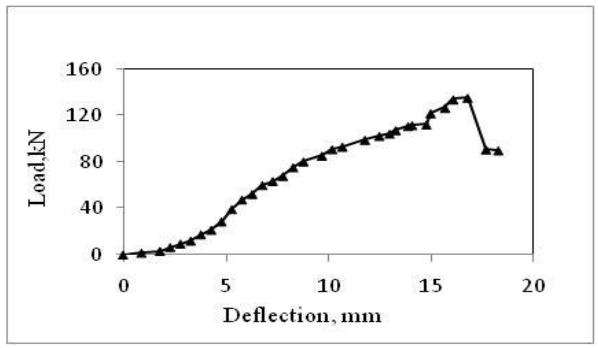

Figure 9 Load-deflection curve for GCB 60-12

4.2 Ductility:

The ductility of the test beams was calculated from the ratio of deflection at ultimate load (δ_u)to the deflection at yield load (δ_y). The ductility ratios have been plotted with various concrete grades for all the beams designed for investigation. Figure 10 shows the variation of ductility ratio with tensile reinforcement ratio of geopolymer concrete. These curves clearly show the downward trend of ductility index as the tensile reinforcement ratio increases. The declining trend of ductility ratios with tensile reinforcement ratio were similar to those observed in the case of reinforced concrete beams tested [11]. Also it can be observed that the ductility index increases with the increase in the grade of geopolymer concrete. The declining trend of ductility ratios from GCB - 20 to GCB - 60 beams showed that the post elastic deformation capacity of the beams gets reduced as the concrete of higher compressive strength is used [12].

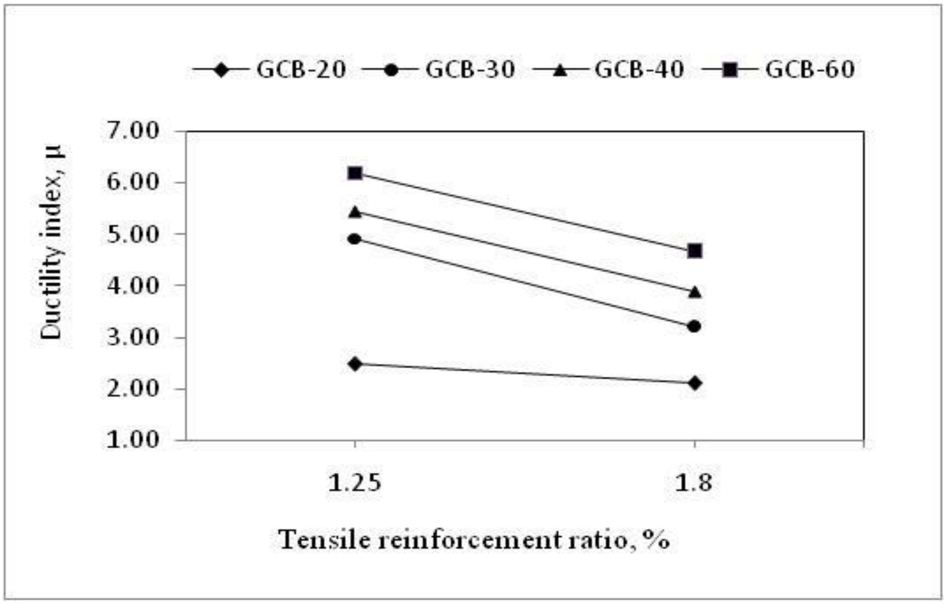

Figure 10 Ductility index for GCB

4.3 Evaluation of Young's Modulus

For a beam subjected to two-point loading, the deflection formula [13], is as follows

$$\delta = \frac{5wl^4}{384\ EI} + \frac{23Wl^3}{648\ EI} \quad (1)$$

where w is self weight of beam in N/mm and W is half the load at failure in N, δ is the deflection in mm, I is the moment of inertia in mm^4, E is the young's modulus in N/mm^2.

The experimental value of mid span deflection of geopolymer concrete was substituted in the above equation for all grades of geopolymer concrete. By substituting proper values of w, W, *l*, and I, E is evaluated and is shown in Table 2. The value of W substituted in the equation is corresponding to first crack.

Table 2 Young's modulus for GCB

Beam ID	Tensile reinforcement p_t (%)	Modulus of Elasticity $E_c \times 10^4$ (MPa)
GCB 20-10	1.25	1.03
GCB 20-12	1.8	1.12
GCB 30-10	1.25	2.53
GCB 30-12	1.8	2.58
GCB 40-10	1.25	2.28
GCB 40-12	1.8	2.30
GCB 60-10	1.25	1.25
GCB 60-12	1.8	1.54

4.4 Energy Absorption Capacity

The area under the load deflection curve indicates the energy absorption capacity. The higher load carrying capacity and the larger deflections undergone by the geopolymer concrete beams increased the energy absorption capacity of the beams. The energy absorption capacity of all geopolymer concrete beams is shown in Table 4.4.

Table 3 Energy absorption capacity of GCB

Beam	Ultimate Load (kN)	Deflection at Ultimate Load (mm)	Energy absorption capacity kN mm
GCB 20-10	22.8	5.2	79.04
GCB 20-12	25.4	8	135.46
GCB 30-10	63.4	5.9	249.37
GCB 30-12	88.4	6.4	377.17
GCB 40-10	104.3	8.7	604.94
GCB 40-12	116.7	14	1089.2
GCB 60-10	114.5	10.7	870.26
GCB 60-12	122	16.1	1228.96

V. CONCLUSIONS

On the basis of experiments conducted on geopolymer concrete beam, the following observations and conclusions are drawn:

- The flexural capacity of beams was influenced by the tensile reinforcement ratio. The beam with 1.8% tensile reinforcement ratio has high ultimate load capacity than the beam with 1.25 % tensile reinforcement ratio.
- Flexural strength of reinforced geopolymer concrete beam of GCB 60-10 is higher than GCB 20-10by 80% whereas GCB 60-12 is higher than GCB 20-12 by 79%.
- Ductility index is found to be in the range between 2.11 to 6.19 for ambient cured geopolymer concrete beams. The ductility index decreased as the tensile reinforcement is increased. The deflection ductility significantly increased for beams with higher grades.
- The modulus of elasticity of geopolymer concrete beam ranges between 1.03 and 2.58 x 104 MPa.

- Energy absorption capacity is increased as the grade of the geopolymer concrete beam increases. The geopolymer concrete beam, GCB 60-10 and GCB 60-12 exceeded the energy absorption capacity of GCB 20-10 and GCB 20-12 by 93% and by 90% respectively.

- When the tensile reinforcement ratio increases from 1.25 % to 1.8 %, the energy absorption capacity of geopolymer concrete beams increased in the range of 13% to 44%.

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