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Research Paper

FLEXURAL BEHAVIOR OF FLY ASH BASED REINFORCED GEOPOLYMER CONCRETE BEAMS

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The present experimental program is conducted to study the structural behavior of reinforced Geopolymer concrete beams under two points loading. Geoploymer concrete mixtures are prepared by varying the percentage of fly ash content and experimental study carried on strength parameters, the best suited mixtures based on the optimal strength of compression and flexure was selected for manufacture of beam. Investigation is confined to find Moment of resistance of the beam and compared with the conventional concrete beam analysis as per IS 456-2000 code of practice. Deflections, stiffness and crack patterns are also studied in the investigations. Experimental investigations of moment of resistance of the beams are validated over the analysis results. The defalcation, stiffness and crack patterns are found similar to conventional concrete beam.

Keywords: Structural behavior, Geopolymer Concrete beams, Fly ash

INTRODUCTION

Geopolymer are inorganic polymer binder with chemical composition similar to zeolite but with amorphous microstructure. This technology was first introduced by Dr. Joseph Devidovit and he coined the name GEO-POLYMERS. The Geopolymer concrete is not containing any cement and it is manufactured by using activated pozzolanic materials and aggregates. Unlike ordinary Portland cement Geopolymer donot form calcium silicate hydrates for matrix formation but it forms by polycondensation of aluminium and silica activated by alkali materials. Significant research work has been carried to study the behavior of the geopolymer concrete under structural application and the results of which shows the effective durability and strength over

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conventional ordinary Portland cements concrete. The behavior of the concrete depends upon the source materials or pozzolanas and activator solution or alkaline solution. This research work is carried to study the flexural behavior of beam under the application of load and substantiate the previous research significations.

BASIC MATERIALS

Following are the basic materials used for the preparation of Geopolymer concrete

a) Fly ash (source material)

b) Aggregates (Coarse and Fine aggregate)

c) Alkaline solution (Activators)

d) Steel fibers

e) Water

f) Plasticizers

FLY ASH

In the present experimental work, low calcium, Class F fly ash taken from Raichur thermal power station, RTPCL, Karnataka state, Southern India.

The physical and chemical properties of the fly ash presented in Table 1

Aggregates

Coarse Aggregate

Locally available crushed (angular) granite coarse aggregate passing through 12.5 mm sieve size and retained on 10 mm sieve are used .The Coarse aggregate tested confirms to the size of 12.5 mm graded aggregate of nominal size as per IS 383 – 1970 code of practice.

Specific gravity and water absorption of the aggregates were 2.62 and 0.3%, respectively.

Table 1: Physical and Chemical Properties of Fly Ash

S. No.	Description	Values	Requirement as per IS:3812:2003
Physical Property			
1	Specific gravity	2.05	–
2	Fineness (Blain's air permeability-m^2 /kg)	333	320
Chemical Properties			
3	SiO_2 (% by mass)	62.92	35
4	Al_2O_3 (% by mass)	30.96	–
5	$SiO_2 + Al_2O_3 + Fe_2O_3$ (% by mass)	93.88	70
6	Mg O (% by mass)	0.74	5
8	Total sulphur as sulphur trioxide SO_3(% by mass)	0.23	3
9	Loss of ignition (% by mass)	0.59	5

Fine Aggregate

Locally available river sand is used as fine aggregate. The sieve analysis is conducted .The fine aggregate test conforms to Zone-II as per IS: 383-1970. Fineness modules and Specific gravity of fine aggregate were 2.61 and 2.64, respectively

Void Content of Combined Aggregates

Minimum void test was conducted for combined aggregate (Fine and coarse) by varying the percentage of Coarse and fine aggregate the maximum bulk density obtained 1.855 kg/L at 56:44(CA: FA) with least void of 28.78%. The same source of material and same combined percentages was used throughout experiment.

Alkaline Solution

A combination of sodium silicate solution and sodium hydroxide solution was used to react with the aluminium and the silica in the fly ash. Flake form sodium hydroxide with 97% purity and sodium silicate from local supplier was used for the present study. The chemical composition of sodium silicate solution are Na_2O=14.74%, SiO_2=31.45%, and water content equal to 33.75% by mass. The molarity of the solution is kept 16 M for throughout experimental work.

Water

Cleanpotable water is used for solution preparation. The total water in the solution is considered as added water plus the water content in the sodium silicate

Super Plasticizers

Poly carboxylic ether based high performance super plasticizers of the brand name Glenium B233 confirmed with IS 9103: 1999, from BASF construction chemicals was used for all the experimental mix. The dosage applied in the range of 1% to 2% of cementitious material (fly ash) by mass for better workability.

Mix Proportioning

Table 2: Details of Mixture Proportion

Mixtures	Fly Ash %	Fly ash kg/m^3	Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	NaOH kg/m^3	Na_2SiO_3 kg/m^3	Plasticizer kg/m^3
FGC-M1	15	312.86	992.82	780.08	89.78	224.46	3.13
FGC-M2	17	354.58	969.46	761.72	89.77	224.45	3.54
FGC-M3	19	396.29	946.10	743.37	89.77	224.45	3.96
FGC-M4	21	438.01	922.74	725.01	89.77	224.45	4.38
FGC-M5	23	479.73	899.38	706.66	89.77	224.45	4.80
FGC-M6	25	521.44	876.02	688.30	89.76	224.44	5.21
FGC-M7	27	563.16	852.66	669.94	89.76	224.44	5.63
FGC-M8	29	604.87	829.30	651.59	89.76	224.44	6.05
FGC-M9	31	646.59	805.94	633.23	89.75	224.43	6.46

The mixtures named as FGC-M (Fly ash based Geopolymer concrete mixture) were prepared by varying fly ash content from 15% to 31% of total particulate matter with increments of 2%. The ratio of sodium silicate to sodium hydroxide kept constant at 2.5 for all series of mixture. The mixtures were prepared with water content of 130 L per cubic meter of concrete. The detail of mixture proportions are presented in Table 2. Based on strength compressive strength, flexural strength tests results the selection of mixture was decided for manufacturing of beams.

Compressive Strength of the Concrete

Compressive Strength Test

The compressive strength test is conducted 150x150x150 mm concrete cubes. Three no of cubes prepared on each mixtures specified in Table 2 and tested through compressive testing machine. Table 3 shows the compressive strength of the specimens.

Flexural Strength Test

The Geopolymer concrete mixtures FGC3-M6, FGC3-M7, FGC3-M8 (Optimal compressive strength mixtures) were used for the flexural strength. Tests carried on 100 X 100 X 500 mm specimens according to IS: 516-1959, the tests results are shown in Table 4.

Based on test data the higher values of compressive and flexure strength found at FGC-M7, are selected to manufacture the beam specimens to study the flexure behavior of beams. Three Number of beams are manufactured in each tensile reinforcement ratio shown in Table 5.

Geometry and Reinforcement

The reinforcement fabrications for beam size of 100x150x1200 mm beam with end face cover of 75 mm and top, bottom and side cover of 15 mm were prepared as shown in Figure 1.

Casting, Curing and Testing of Beams

The coarse aggregates and fine aggregate were first mixed in 100 L capacity laboratory tilting mixer for about 2-3 min and then fly ash is added and continued the mixing about 2 min. After the dry mixing, the alkaline solutions together with the super plasticizer were added to the dry materials and the mixing continued for another four minutes. Immediately after mixing, the fresh concrete was cast into the moulds. All beams were cast horizontally in wooden moulds in three layers. Each layer was compacted using a tamping rod. The beam specimen was kept 3 days in the mould in the room temperature for initial setting and hardening. Then all the beams specimens with mould were placed in Hot air curing chamber (Davidovits, 1991) for curing the specimens at the temperature of 65^0 C to 70^0C up to 24 h.

After the curing period the beams are removed from the mould. All the specimens were kept 24 h in normal room temperature.

Method of Test and Test Setup

All beams were tested under two point loading system. The beams are simply supported over a span of 1050 mm and tested in a loading frame with capacity of 500 kN. Two steel rollers of 30 mm diameter were placed symmetrically over the beam on at the distance of 1/3rd of span from left and right side of the support. The steel beam ISMB 250 is provided over the roller to transfer the load on the beam

Table 3: Compressive Strength of Cube Specimen

Mixtures	% of fly ash	Density (KN/m^3)	Load (kN)	Compressive Strength f_{ck}(N/mm^2)	Average Compressive Strength (N/mm^2)
FGC-M1	15	23.53	405	18	17.48
		23.37	385	17.11	
		23.45	390	17.33	
FGC-M2	17	23.49	440	19.56	19.92
		23.37	475	21.11	
		23.33	430	19.11	
FGC-M3	19	23.46	610	27.11	26.59
		23.57	590	26.22	
		23.54	595	26.44	
FGC-M4	21	23.58	630	28.00	28.44
		23.66	655	29.11	
		23.64	635	28.22	
FGC-M5	23	23.67	695	30.89	31.55
		23.63	725	32.22	
		23.59	710	31.56	
FGC-M6	25	23.67	785	34.89	35.25
		23.59	805	35.78	
		23.53	790	35.11	
FGC-M7	27	23.63	805	35.78	37.11
		23.56	835	37.11	
		23.69	865	38.44	
FGC-M8	29	23.46	745	33.11	33.55
		23.38	785	34.89	
		23.68	735	32.67	
FGC-M9	31	23.49	640	28.44	28.07
		23.35	660	29.33	
		23.58	595	26.44	

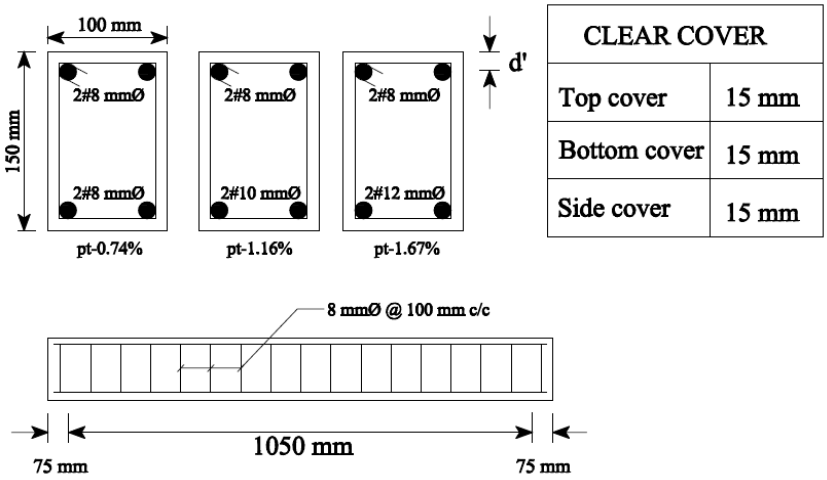
Table 4: Flexural Strength of Specimens

Mixtures	Load P(kN)	Distance From fracture to Nearer Support (mm)	Flexural Strength $f_{cr}=PL/bd^2$(N/mm^2)	Average Flexural Strength (N/mm^2)
FGC-M6	10	178	4.0	4.26
	11.5	135	4.6	
	10.5	183	4.2	
FGC-M7	11	165	4.4	4.46
	10.5	167	4.2	
	12	178	4.8	
FGC-M8	9.5	174	3.8	4.13
	10.5	166	4.2	
	11	168	4.4	

Table 5: Reinforcement Detail

Beam	Beam Dimension	Reinforcement Tensile		Reinforcement ratio, pt(%)
		Compression	Tension	
FGC-B1	100X150X1200	2 # 8	2 # 08	0.74
FGC-B2	100X150X1200	2 # 8	2 # 10	1.16
FGC-B3	100X150X1200	2 # 8	2 # 12	1.67

Figure 1: Reinforcement Arrangement



CLEAR COVER	
Top cover	15 mm
Bottom cover	15 mm
Side cover	15 mm

through rollers. Hydraulic jack with capacity of 500 kN is placed centrally over the beam and channel. Three number of digital dial gauge used to measure the deflection. One placed at mid section of the beam and two were placed at 1/6th span from left and right side of the support. The test configuration is shown in Figures 2 and 3.

General Behavior of Beam

As the load increases beam starts to deflect in the direction of load and cracks are developed along the tension face of the beam specimens, eventually all the beam specimens failed in a typical flexure mode. The load-deflection curves indicate distinct events that were taking place during the test. These events are identified as first cracking, yield of the tensile reinforcement, crushing of concrete at the compression face associated with Spalling of concrete cover and disintegration of the compression zone.

Figure 2: Schematic Diagram for Flexure Test on Beam

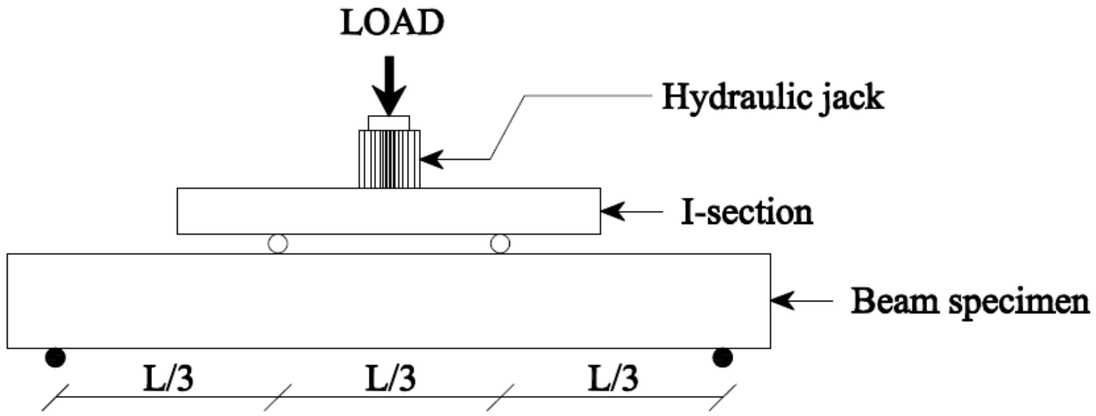


Figure 3: Arrangement Prior to Flexure Test of the Beam Specimen

Crack Patterns and Mode of Failure

All the beam specimens were failed in same mode, as the load increases the flexure cracks initiates in the pure bending zone. As the load increases, existing cracks propagated and new cracks developed along the span. The cracks at the mid-span opened widely near failure, the beams deflected significantly, thus indicating that the tensile steel must have yielded at failure. The final failure of the beams occurred when the concrete in the compression zone crushed, accompanied by buckling of the compressive steel bars. The failure mode was typical of that of an under-reinforced concrete beam. Figures 4, 5 and 6 shows the crack patterns and failure modes of the beam specimens.

Flexural Capacity

The Theoretical ultimate moment calculated according to IS 456:2000 for doubly reinforced section based on corresponding tensile and compression reinforcement are compared with the experimental ultimate moment. The test results shows the experimental ultimate moment is within the range as mentioned in IS code. Tested ultimate moments of the beams were presented in the Table 6.

Figure 4: Crack Patterns and Failure Mode of FGC-B1 Beams

Figure 5: Crack Patterns and Failure Mode of FGC-B2 Beams

Figure 6: Crack Patterns and Failure Mode of FGC-B3 Beams

Figure 7 show the effect of tensile reinforcement on the flexural capacity of beams. The graph shows that there is slight increase in the tested flexural capacity compared to the theoretical ultimate moment of beams. Also we can see that ultimate moment increases with increase in tensile reinforcement ratio. When the ratio of tensile reinforcement increases from 0.74 to 1.16 the increase in ultimate moment is 24.67% further increase in tensile reinforcement to 1.67 will increase the ultimate moment to 38.52%.

Cracking Moment

The load at which the first flexural crack was visibly observed was recorded. From the available test data theoretical cracking moments were determined according to the IS: 456-2000. Both the experimental and theoretical test results were compared, the test result shows the experimental first crack moment is much higher than the theoretical cracking moment. The results are given in

Table 6: Flexural capacity of test Beams

Beam	% of Tensile Reinforcement	Compressive Strength f_{ck} (N/mm^2)	Mid Span Deflection at Failure (mm)	Theoretical Ultimate Moment M_{uc}	Tested Ultimate Moment M_{ut}	Ratio M_{ut}/M_{uc}
FGC-B1	0.74	37.11	17.061	4.326	7.58	1.752
FGC-B2	1.16	37.11	16.604	7.406	9.45	1.276
FGC-B3	1.67	37.11	15.606	10.352	10.5	1.014

Figure 7: Effect of Tensile Reinforcement Ratio on the Ultimate Moment of Beams

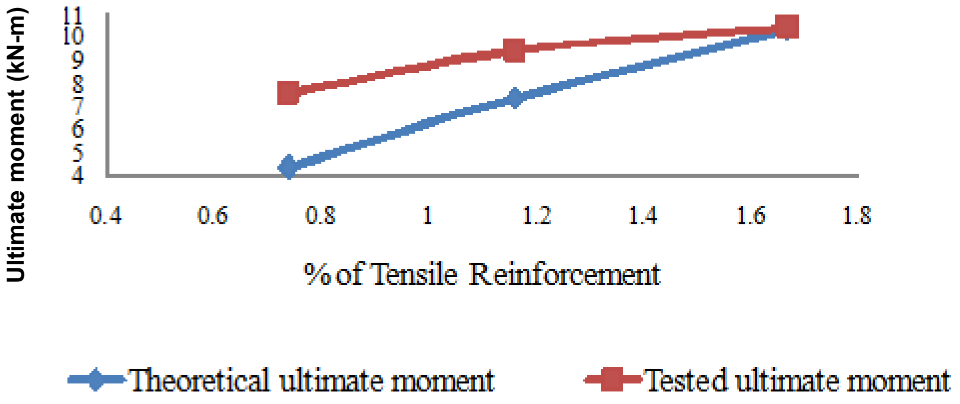


Table 7 and Figure 8 shows the variation of moment at first crack with % of tensile reinforcement.

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The results are given in Table 7 and Figure 8 shows the variation of moment at first crack

Table 7: Cracking Moment of Test Beams

Beam	% of Tensile Reinforcement	Compressive Strength f_{ck} (N/mm^2)	Modulus of Rupture (N/mm^2)	Moment at First Crack M_c(kN-m)	Theoretical Cracking Moment $M_r=(f_{cr} \times I_{gr}/Y_t)$	Ratio M_c/M_r
FGC-B1	0.74	37.11	4.26	5.13	1.59	3.23
FGC-B2	1.16	37.11	4.26	6.65	1.59	4.18
FGC-B3	1.67	37.11	4.26	7.35	1.59	4.62

Figure 8: Effect of Tensile Reinforcement Ratio on the Cracking Moment of Beams

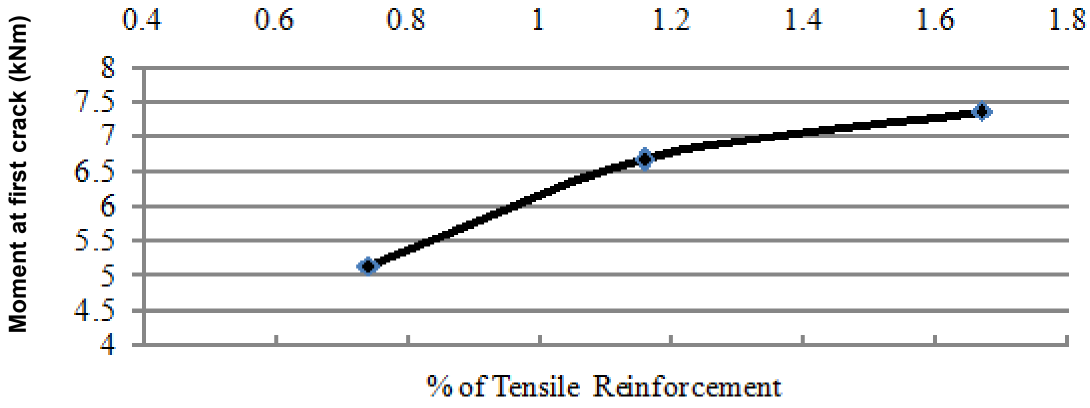
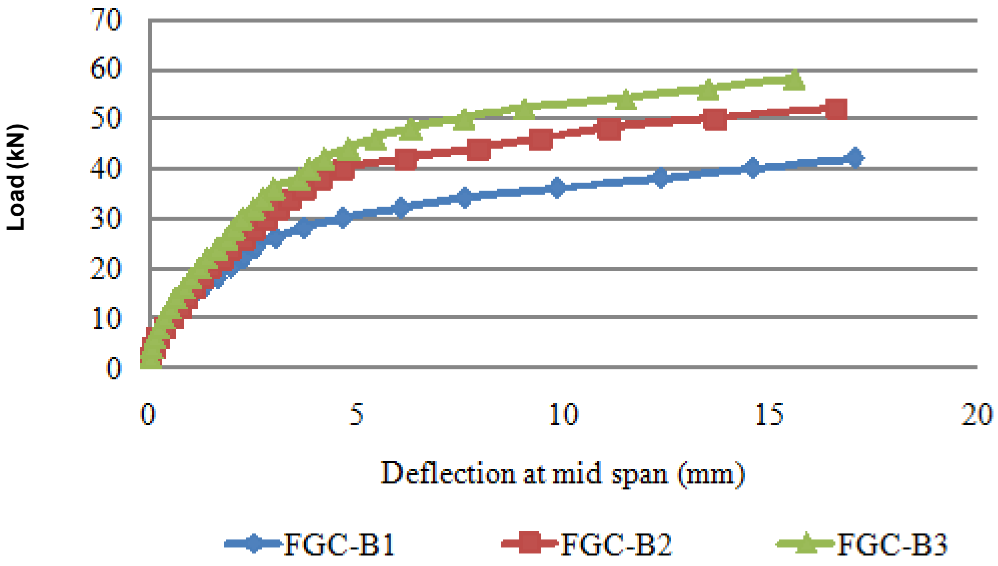


Figure 9: Load Verses Deflection Curve



with % of tensile reinforcement. The Figure 8 shows the Moment at first crack increases with increase in % of tensile reinforcement as the percentage of tensile reinforcement increases from 0.74 to 1.16 the increase in cracking moment is 29.63%, further increase in tensile reinforcement from 1.16 to 1.67 the increase in cracking moment is about 10.53%.

Deflections

The deflections were measured at mid span and at 1/6th of span from both sides. The deflections were recorded up to failure load and compared with test values. The Load versus mid-span deflection curves of the test beams are presented in Figure 9 shows average mid span deflections.

CONCLUSION

The flexural strength of fly ash-based Geopolymer concrete is a fraction of the compressive strength, as in the case of Portland cement concrete. The measured values are higher than recommended values in IS: 456-2000. As compressive strength increases the flexural strength also increases in Geopolymer concrete. This behavior is similar to the OPC concrete.

All the beams were failed in flexural mode, the cracks are initiated in the tension face of the beam and cracks are propagate towards compression face as the load increases, followed by the crushing of concrete in compression face. As the tensile reinforcement ratio increases the first crack load is also increases. The cracking moment is calculated according to the IS: 456-2000 and compared with the tested results it shows the all the results are within the range specified in the codal provisions.

The flexural capacity of the beam increases with the increase in longitudinal tensile reinforcement ratio, the tested ultimate moment capacity of beams were found 1.35 times more than theoretical ultimate moment capacity. The measured service load deflections of test beams were compared with the values calculated with the IS: 456-2000. All the measured deflection were within the permissible limit. Stiffness of the beam increase with increase in percentage of tensile reinforcement, this behavior is similar to the reinforced OPC concrete beams.

REFERENCES

1. Davidovits J (1991), “Geopolymers: inorganic polymeric new materials”, *Journal of thermal analysis*, Vol. 37, pp. 1633-1656.
2. Davidovits J (1994), “Properties of geopolymer cements”, Proceedings in first international conference on alkaline Cements and concretes, Scientific Research institute on binders and Materials (1994), Ukraine, pp. 131-149.
3. Hardjito D and Rangan B V (2005), “Development and Properties of low calcium fly ash based geopolymer concrete.” Research report GC 1, Curtin university of technology Perth, Australia.
4. Kumar.S, Pradeepa J and Ravindra P M (2012), “Experimental investigations on optimal strength parameters of fly ash based Geopolymer concrete”, *International journal of Structural and Civil engineering Research,* Vol. 2, No. 2.
5. Pradeepa J, Kumar S and Ravindra P M (2012), “Cost Effective Curing Arrangement for Geopolymer Concrete Specimens”, *International Journal of Emerging Trends on Engineering and Development,* RS Publications, No. 2, Vol. 7, pp. 227-223.
6. Ranganath R V and Mohammed Saleh (October-2008), “Some optimal values in geopolymer concrete incorporating fly ash”, *The Indian concrete journal*, pp. 26-35.
7. Sumajouw M D J and Rangan B V (2006), “Low calcium fly ash based Geopolymer concrete: Reinforced beams and columns”, Research report GC3, Curtin University of technology Perth, Australia.