4.0 FLEXURAL STRESS STRAIN BEHAVIOR OF CONCRETE AND STEEL

Among the most widely used and easily available aggregates , Granite holds the first place having Young's Modulus varying from 10 – 70 GPa - far above the values of sand stone rocks i.e 1- 20 GPa . When Manufactured sand of granite origin as fine aggregate mixed with coarse aggregates of granite origin , with fly ash : slag at 70:30 the resulting composite of granite based geopolymer concrete develops better structural properties. The relations between compressive strength and flexural strength, modulus of elasticity i.e., for fly ash:slab at 70:30 closely follow the expressions $f_{cr}=0.7\sqrt{fck}$ [2] and $E_c= 5000\sqrt{fck}$ after 28 days of ambient curing.[18],[19]

All slabs are analyzed using conventional elastic theory for the applied loads and provided boundary condition using geometrical & material properties like compressive strength, steel strength etc. listed in Table 2. The flexural stress strain relations of top compressive concrete follow distinct stages similar to OPC based RCC flexural components. The basic flexural compressive stress strain relations proposed by popovics with modified curve fitting factor suggested by Ganesan [5] used to predict the flexural behavior of compression concrete. The failure loads corresponding to first appearance of tension crack in concrete, yielding of tension steel and peak compressive stress corresponding to 0.67fck and 0.85fck are determined

Typical Slab analysis and structural design output after numerical computations are described in following graphs using load deflection curves, stress and strains developed at top edge of compressive concrete, stress and strains developed in steel .

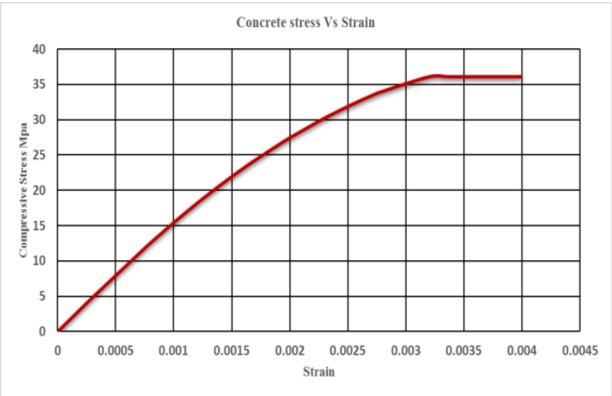


Fig 2 a) Stress Vs Strain in Compressive Concrete-Slab No.6

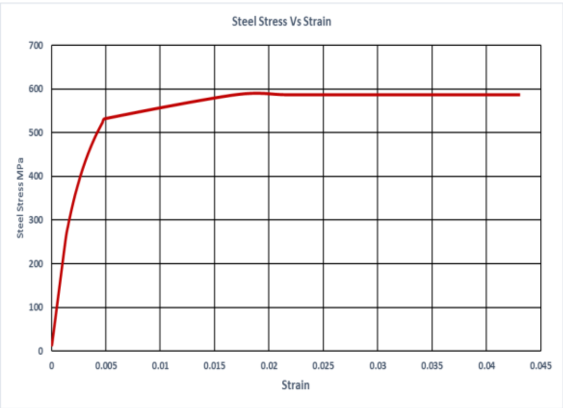


Fig 2 b) Stress Vs Strain in Tension steel - Slab No. 6

5.0 STRENGTH AND DEFORMATION BEHAVIOR

The measured Load vs Deflection relations at center bottom of slabs are represented in figure (3) to (8).The flexural stiffness of RGPC decreases with the gradual increase in applied loads similar to OPC based RCC flexural elements. Till the appearance of first crack in tension concrete, whole section including reinforcements are effective in producing linear elastic behavior with noticeably low profile deflections.

The appearance of first crack and further loading will noticeably reduce the effective depth and will increase the crack depth and width making concrete in tension less effective and therefore tension resistance offered by concrete is ignored. However the membrane action developed is taken into account by considering effective moment of inertia recommended by Indian RC designer.

The composite continues to be in linear elastic stage till yielding of tension steel. Numerical computations indicate significant shift in neutral axis once the tension steel yields. The deflections based on new effective section indicate the loss of flexural stiffness similar to OPC based sections. The close agreement between measured and calculated deflections indicate a healthy bond strength between reinforcement and tension concrete justifying the negligence of tensile strength in concrete .

The specimen is said to have failed structurally when compression concrete reaches 0.67fck while it has already crossed yield strength of tension steel as all slabs were under reinforced. Further loading at post failure stage develop significant deflections which are slightly deviating from calculated ones based on effective moment of inertia.

The numerical computations for flexural deflections do not include shear deflections which are estimated to be less than 0.5% of flexural deflections.

All the specimens behaved to produce strain hardening flexural deflections.

Comparison of load Vs deflection for CPL and UDL from Fig (3) to Fig (8) , it is observed that the calculated deflections for Central Point Loads differ more than the measured ones while for UDL there is marginal difference. Thus confirming the sensitiveness of Geopolymer Concrete for point loads

6.0 DUCTILITY INDICES

The performance of structural elements is well appreciated , when their ability to absorb and dissipate energy by post elastic deformations subjected to several cycles of loading are naturally imbedded at low cost. Reinforced Geopolymer Concrete (RGPC) develop significant ductility along with steel reinforcement.

Ductility indices of flexurally deflected RGPC elements are compared with calculated ones. The Ductility Index**(*calculated*)** = Δ_u / Δ_y where Δ_u & Δ_y are measured deflections corresponding to computed yield load $\mathbf{F_y}$ & ultimate load $\mathbf{F_u}$.

Similarly Ductility Index **(*measured*)** = Δ_{um} / Δ_y , Δ_{um} is the maximum deflection the component under maximum applied load $\mathbf{F_{um}}$. Ductility Index(calculated) represents the minimum ductility the GPC will develop and Ductility Index (measured) represents maximum ductility the GPC will develop.

The Average Displacement Ductility is the average ductility between these two values which is more probable to develop under Normal Quality Control during GPC production.

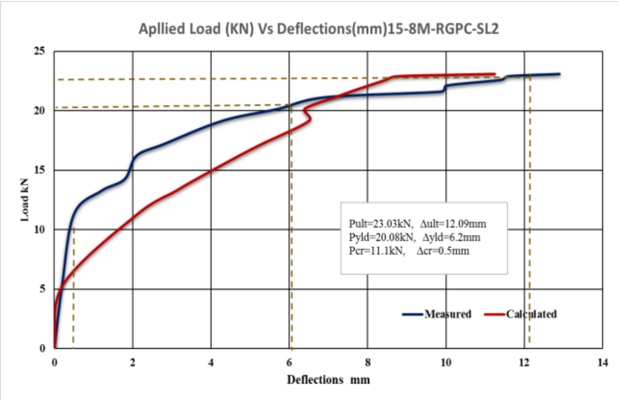


Fig 3a): Load Vs Deflections Curves of Slab 1 Under CPL
(Measured & Calculated)

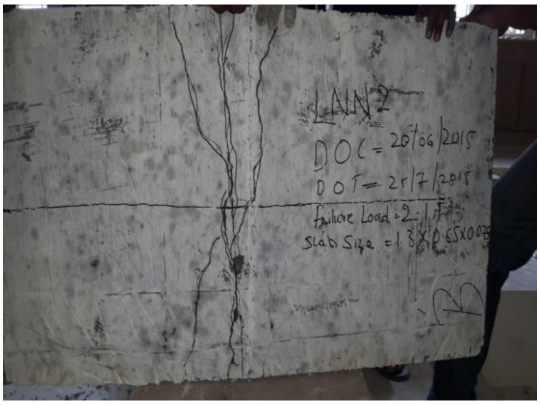


Fig 3b): Crack Patterns slab 1

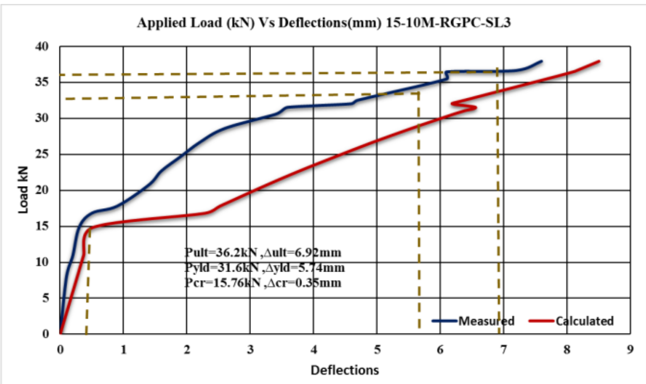
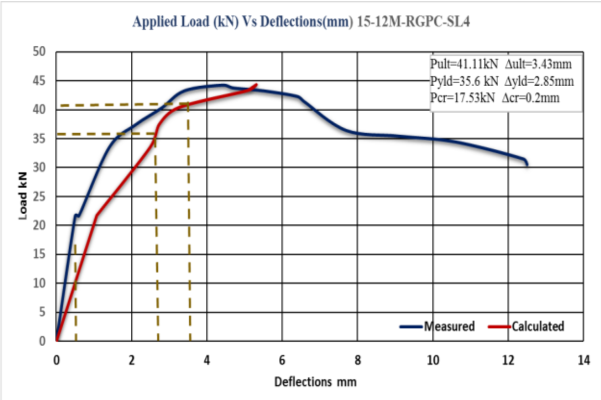


Fig 4a): Load Vs Deflections Curves of Slab 2Under CPL
(Measured & Calculated)

Fig 4b): Crack Patterns slab 2



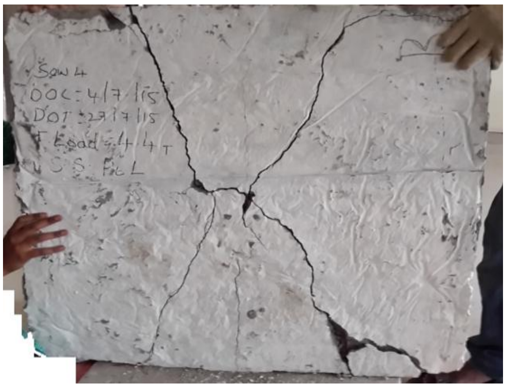


Fig 5a): Load Vs Deflections Curves of Slab 3 Under CPL (Measured & Calculated)

Fig 5b): Crack Patterns slab 3

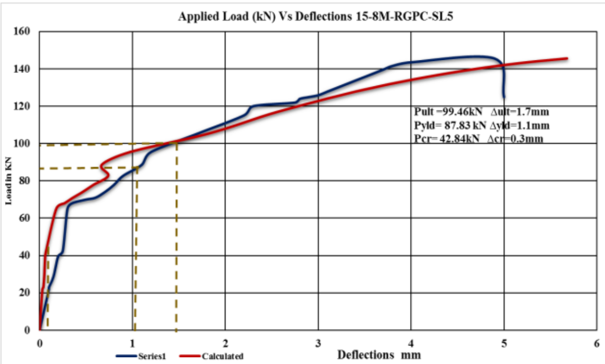
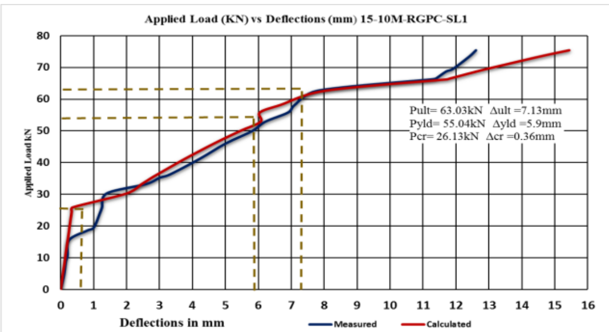


Fig 6a): Load Vs Deflections Curves of Slab 4 Under UDL (Measured & Calculated)

Fig 6b): Crack Patterns slab 4



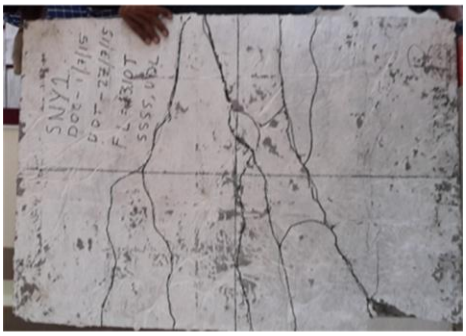


Fig 7a): Load Vs Deflections Curves of Slab 5 Under UDL (Measured & Calculated)

Fig 7b): Crack Patterns slab 5

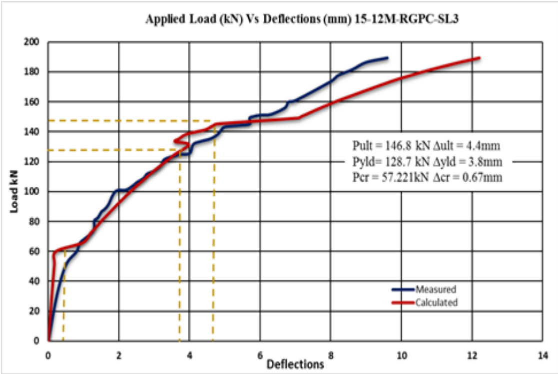


Fig 8a): Load Vs Deflections Curves of slab 6 Under UDL (Measured & Calculated)

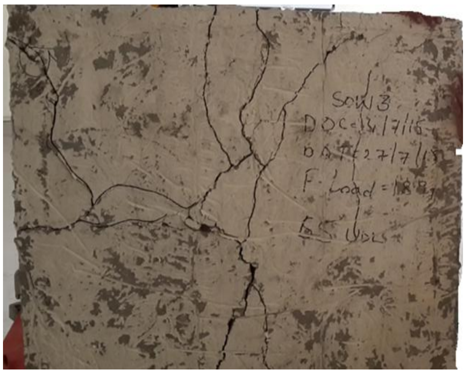


Fig 8b): Crack Patterns of slab 6

Table 2: Structural Details of Specimen Tested				
S.No.	Details	Slab 1& 4	Slab 2 & 5	Slab 3 & 6
1	Span Side Length	1.3m	0.975m	0.8m
2	Size : L mm X B mm X D mm	1300 x 650 x 75	975 x 650 x 75	800 x 800 x 75
3	L/D	17.33	13.00	10.67
4	Self weight in kg	147.65 & 147.25	110.4 & 110.1	111.25 & 111.75
5	Aspect Ratio	2	1.5	1
6	Molarity	8M	10M	12M
7	Curing days	36	26	22
8	fck	57.87 N/mm^2	45.96 N/mm^2	41.7 N/mm^2
9	Reinforcement Parallel to Shorter & Longer Sides	8mm-4# & 7#	8mm - 4# & 6 #	8mm - 5# & 5#
10	Reinforcement	0.507%	0.507%	0.515%
11	Yield Stress & Ultimate Stress	533.94 - 587.33	533.94 - 587.33	533.94 - 587.33
12	Test Results - Central Point Load	S1	S2	S3
	Support Conditions	2SSS	2SSS	2SSS
	First cracking load & deflection	11.1 kN - 0.5 mm	15.76 kN - 0.35 mm	17.53 kN - 0.20 mm
	Steel Yielding load &deflection	20.07 kN - 6.2 mm	31.6 kN - 5.74 mm	35.6 kN - 2.85 mm
	Ultimate load &deflection	23.0 kN - 12.09 mm	36.2 kN - 6.92 mm	41.11 kN - 3.43 mm
	Max.applied load & delfection	23.07 kN - 27.6 mm	37.9 kN - 7.6 mm	44.29 kN - 4.4 mm
	Crack width at ultimate load	3.7 mm	1.5 mm	1.5mm
	Ductility - Cal - Measured - Average	1.55 - 3.09 - 2.32	1.21 - 1.94 - 1.57	1.16 - 2.66 - 1.91
13	Test Results - UDL	S4	S5	S6
	Support Conditions	4SSS	2SSS	2SSR
	First cracking load & deflection	42.84 kN-0.3 mm	26.13 kN - 0.36 mm	57.22 kN - 0.67 mm
	Steel Yielding load &deflection	87.83 kN - 1.1 mm	55.04 kN -5.9 mm	128.7 kN - 3.8 mm
	Ultimate load &deflection	99.46 kN - 1.7 mm	63.03 kN - 7.13 mm	146.8 kN - 4.4 mm
	Max.applied load & delfection	125.86 kN - 3.4 mm	77.39 kN - 13.80 mm	189.27 kN - 9.6 mm
	Crack width at ultimate load	1.9 mm	1.3 mm	1.2 mm
	Ductility - Cal - Measured - Average	1.20 - 4.45 - 3.26	1.69 - 2.11 - 1.90	1.20 - 1.54 - 1.37
14	***Average Ductility of all Specimens***	***Calculated = 1.483***	***Measured = 2.633***	***Avearge = 2.058***
Notations Used:4SSS- All 4 Sides Simply Supported ,2SSS- Two Shorter Sides Simply Supported and Other Edges free,2SSR- Two Short Edges Partially Restrained and remanining edges free, UDL- Uniformely Distributed Loading , CPL- Central Point load, M-NaoH Molarity				

7.0 CRACK WIDTHS AND PATTERNS .

Developed crack widths within the range of strains in tension steel up to 0.87fy/Es (0.0023 for Fe415 steel having yield stress 533.87 N/mm^2) are within the acceptable limits and are in agreement with calculated ones based on Indian and BS RC Designers. Crack patterns follow load type and boundary conditions used and are in consistency with similar OPC based RC elements. Crack widths beyond strain in steel 0.87fy/Es are in excess of calculated ones.

8.0 RESULTS AND DISCUSSIONS

In this research work GPC is prepared by manual mixing and cured at room temperature 16 to 28 degrees celsius. Manual mixing up to 20 to 30 minutes increases workability for further concreting activities. Manual mixing and compaction needs careful observation to ensure normal quality control to enhance the basic strength properties of concrete similar to OPC based concreting.

Since all slabs were under reinforced , tension failure of the specimens were noticed. The appearance of first crack was little earlier than the calculated ones indicating slightly less flexural strength of concrete compared to IS Code i.e fcr=0.7√fck. The average peak strain in concrete at 0.67fck stress gives 0.002 to 0.0025 for parabolic stress block suggested by Indian RC code and for 0.85fck stress it gives 0.003 to 0.0035 for rectangular stress block.

The flexural behaviour of all tested elements show distinct stages of behaviour similar to OPC based RCC flexural elements like appearance of first crack, yielding of tension steel and peak stress failure of compressive concrete as seen from the Fig (3) to Fig (8) .

The stress strain behavior of compression concrete in Reinforced Geopolymer Concrete Sections under increasing flexural stresses are in line with popovics model with slight modification to curve fitting factor.

Load Vs Deflections of measured ones with calculated values based on effective moment of inertia are found to differ within acceptable limits. Shear deflections being very less do not show noticeable deflection profile

From fig (9) & fig (10) , it is observed that the developed crack widths co relate with calculated crack widths based on IS 456-2000 code. Crack widths are found to be within acceptable limits at service loads.

9.0 CONCLUSIONS

Following conclusions are drawn based on the above research work

- *Geopolymer concrete manufactured using low calcium based fly ash with slag can be used for in situ applications of reinforced geopolymer concrete flexural applications.*
- *The flexural behavior of Reinforced Geopolymer Concrete is similar to Conventional RCC using OPC. Indian Code 456-2000 can be used to predict all structural design related output. Especially this seems to be more valid for fly ash: slag at 70:30 proportions.*
- *Low calcium fly ash and slag **(70:30)** based geopolymer concrete , with coarse aggregates & M - sand of granite origin , With **Fe500** grade reinforcement, Displacement Ductility of RGPC could be in the range **1.50 to 2.70**. And The average displacement ductility of RGPC could be around **2.10***

ACKNOWLEDGEMENTS:

The Authors wish to thank Management of Alliance University Bangalore And The Oxford College of Engineering - Bangalore for their kind support while investigating this research work.

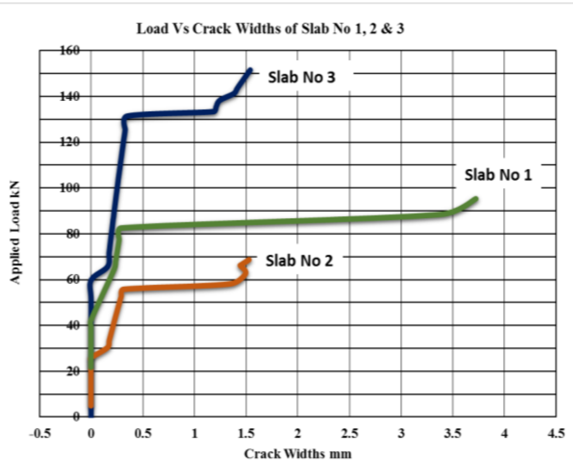


Fig 9) Load Vs Crack widths - Central Point Loads

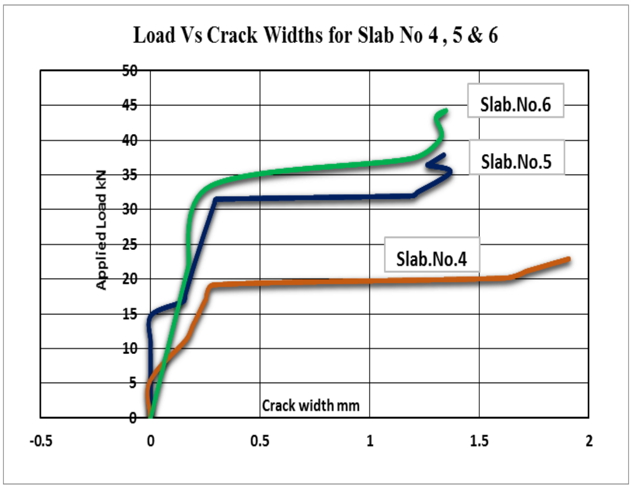


Fig 10) Load Vs Crack widths : for UDL

10.0 REFERENCES

1) Rajamane ‘et al’,” Flexural behavior of reinforced geopolymer concrete beams”, International Journal of Civil and structural Engineering,Vol 2, No 1, 2011
2) Radhakrishna et al 2014,” Strength Characteristics of Open Air Cured Geopolymer Concrete”, TRANSACTIONS OF THE INDIAN CERAMIC SOCIETY,FEB 2014
3) Pradip Nath, Prabir Kumar Sarker (2014), “Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition.” Department of Civil Engineering, Curtin University of Technology, Australia
4) Vijay Rangan et al ,”Early Age Properties of low calcium fly ash geopolymer concrete suitable for ambient curing”, The 5th International Conference of Euro Asia Civil Engineering Forum,(EACEF-5),Sept 2015.
5) N Ganesan ‘et al’,” Development of stress block parameters for geopolymer concrete “,The Indian Concrete Journal, September 2015, vol 89,Issue 9,pp 47-56.
6) Rangan B V ‘ et al”,” Modified Guide lines for Geopolymer Concrete Mix Design Using Indian Standard “. Asian Journal of Civil Engineering(Building And Housing) Vol 13,No3(2012).
7) Prakash Desai & K U Muthu,” A brief review on strength, deflection and cracking of rectangular ,skew and circular reinforced concrete slabs”, Indian Institute of Science , Mar-Apr 1988,91-108
8) Robert Park & Thomas Paulay,” Reinforced Concrete Structures”, John Wiley & sons,INC.UK 2013
9) INDIAN STANDARD 456-2000.
10) Djwantoro Hardjito,” Studies on Fly Ash based Geopolymer Concrete”, Thesis Report, Curtain University of Technology , November 2005.
11) Charles E Reynolds & James C Steedman, ”Reinforced Concrete Designer’s Hand Book”,10th Edition
12) Magdy I. Salma “ Analysis of slabs spanning in two directions under concentrated load”, HBRC Journal (2012) 8,212-216
13) Mahantesh et al,” Study on Flexural Behaviour of Fly Ash based reinforced rectangular Geopolymer Concrete slabs “,International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 4 Issue 09, September-2015
14) Mahantesh et al, ”Infleunce of Ambient Curing on Reinforced Geopolymer Concrete Structural Elements “,International Journal of Engineering Trends and Technology, Volume 28,Number 4,October 2015

15) Daguang Han,"Experimental and Theoretical Invetsigation of the crack behavior of RC Slabs subjected to biaxial bending", Institute of Structural Engineering for structural concrete, University of Armed Forces Munich, December 2011.
16) Said M.Allan," Evaluation of Tension Stiffening effect on the crack width calculation of flexural RC member",1110-016,2013FacultyofEngineering,AlexandriaUniversity.Production and hosting by Elsevier B.V http://dx.doi.org/10.1016/j.aej.2012.12.005
17) Rajamane N P & Jayalakshmi R ,"Quantities of Sodium Hydroxide Solids And water to prepare sodium hydroxide solution of given molarity for geopolymer concrete mixes ",ICI technical paper
18) Kadirnaikar 'et al', "Stress strain Characteristics for Geopolymer Concrete-An Experimental Approach CACE Volume 2, Issue 2 Apr. 2014 PP. 44-47,American V-King Scientific Publishing,2014
19) Vijay Rangan," Geopolymer Concrete for Environmental Protection", The Indian Concrete Journal, April 2014.

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