ISSN: 2277-9655
Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

An Investigation on Flexural Behaviour of Glass Fibre Reinforced Geopolymer Concrete Beams

S. Srinivasan[*1], A. Karthik[2], DR. S. Nagan[3]
[*1] Research Scholar, Thiagarajar College of Engineering, Madurai, Tamilnadu, India
[2] M.E. Structural Engineering, Thiagarajar College of Engineering, Madurai, Tamilnadu, India
[3] Associate Professor, Thiagarajar College of Engineering, Madurai, Tamilnadu, India
alagarkarthik@gmail.com

Abstract

Geopolymer concrete (GPC) are representing the most promising green and eco-friendly alternative to Ordinary Portland Cement (OPC). Geopolymer Concrete possesses relatively good mechanical properties and desirable thermal stability but they exhibit failure behaviour similar to brittle solids. This limitation may be remedied by fibre reinforcement to improve their flexural strength. This paper presents results of an experimental program on the mechanical properties of Fibre Reinforced Geopolymer Concrete (FRGPC) such as compressive strength, split tensile strength, flexural strength, and flexural behaviour of FRGPC beams. FRGPC contains flyash, alkaline liquids, fine aggregate, coarse aggregate and glass fibre. Alkaline liquid to fly ash ratio was fixed as 0.45 with 100% replacement of OPC. For alkaline liquid combination, ratio of sodium silicate to sodium hydroxide solution was fixed as 2.5. Glass fibre was added to the mix in volume fractions of 0.01%, 0.02%, 0.03% and 0.04% by volume of concrete. Specimens were subjected to 24 hours of Heat curing at 70°C in heat curing chamber. The effect of fibre content on the mechanical properties and flexural behaviour of FRGPC was studied and compared it with ordinary Geopolymer Concrete (GPC)

Keywords: Geopolymer concrete; flyash; alkaline liquids; glass fibre.

Introduction

Concrete is one of the most widely used construction material. It is usually associated with Portland cement as the main component for making concrete. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. Production of Portland cement is currently exceeding 2.6 billion tons per year worldwide and growing at 5 percent annually. Five to eight percent of all human-generated atmospheric carbon-di-oxide worldwide comes from the concrete industry. Among the greenhouse gases, carbon-di-oxide contributes about 65% of global warming. Although the use of Portland cement is still unavoidable until the foreseeable future, many efforts are being made in order to reduce the use of Portland cement in concrete. On the other hand, a huge volume of fly ash is generated around the world. Most of the fly ash is not effectively used, and a large part of it is disposed in landfills which affects aquifers and surface bodies of fresh water. Fibre reinforced cement or concrete is a relatively new composite material in which fibres are introduced in the matrix as micro reinforcement, so as to improve the tensile, cracking and other properties of concrete.

The term, "geopolymer" was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. The extensive research works carried out by several investigators corroborate the potential of Geopolymer Concrete (GPC) as a prospective construction material (Davidovits, 1991: Harjito and Rangan, 2005: Van Jaarsveld et al., 2003) [5,8,11]. Aleem et. al, (2012) [1] mentioned that, Geopolymer Concrete can be used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized. It shall be effectively used for the beam column junction of reinforced concrete structures and infrastructure works. In addition to that the Flyash shall be effectively used and hence no landfills are required to dump the flyash. Anuar et. al, (2011) [3] explained that the higher concentration of sodium hydroxide solution inside the geopolymer concrete will produce higher compressive strength of geopolymer concrete;

because NaOH will make the good bonding between aggregate and paste of the concrete. In this respect, the geopolymer technology proposed by Davidovits shows considerable promise for application in concrete industry as an alternative binder to the Portland cement

Materials

The materials used for making fibre reinforced geopolymer concrete specimens are low-calcium dry fly ash as the source material, fine aggregate, coarse aggregate, glass fibre, alkaline liquids, water and superplasticizer.

Fly Ash

Fly ash is the residue from the combustion of pulverized coal collected by mechanical or electrostatic separators from the flue gases of thermal power plants. One of the important characteristics of fly ash is the spherical form of the particles. This shape of particle improves the flowability and reduces the water demand. It also increases the pozzolanic activity. In this experimental work, low calcium Class F (American Society for Testing and Materials) dry fly ash obtained from the silos of Thermal Power Station, Thoothukudi, was used as the base material. The fly ash is sieved through 50µm standard sieve and collected.

Alkaline Liquid

In this investigation, a combination of Sodium hydroxide solution and Sodium silicate solution was used as alkaline activators for Geopolymerization. Sodium hydroxide is available commercially in flakes or pellets form. For the present study, sodium hydroxide pellets with 98% purity were dissolved in water to make NaOH solution. Sodium hydroxide solution with a concentration of 8M consisted of 8x40 = 320 grams of sodium hydroxide solids (in pellet form) per litre of the solution was used. This solution was prepared one day before the casting of concrete to allow the exothermic process and to reduce heat because it generates more heat while mixing with water. Sodium silicate is available commercially in liquid gel form and hence it can be used as such. The chemical composition of sodium silicate is: Na_2O-14.7%, SiO_2-29.4% and Water- 55.9% by mass.

Aggregates

Locally available coarse aggregate screened and washed to without all the organic and inorganic compounds was used. Coarse aggregates comprising of different sizes 20mm, 12mm, 6mm having fineness modulus of 6.60, bulk density of 1578 kg/m^3 and specific gravity of 2.84 were used. Laboratory tests were conducted on coarse aggregate to determine the different physical properties. Locally available river sand was used as fine aggregate. It was screened and washed to remove all the organic and inorganic compounds that are likely to present in it. Sand has been sieved in 2.36mm (passed) and retained in 600µ. Laboratory tests were conducted on fine aggregate to determine the different physical properties. The results depicted that the river sand conformed to zone III as per IS 383-1970 (Reaffirmed on 1997). Fine aggregates having a specific gravity of 2.63, bulk density of 1721 kg/m^3 and fineness modulus of 2.41 were used.

Glass Fibres

Glass fibres are characteristic for their high strength, good temperature resistance, and corrosion resistance. The glass fibre has a length of 12 mm and nominal diameter of 0.014 mm was used. The unit weight of the glass fibre was 2670 kg/m^3.

Superplasticizer

Use of superplasticizer permits the reduction of water to the extent up to 30 percent without reducing the workability, in contrast to the possible reduction up to 15 percent in case of plasticizers. The use of superplasticizer is mainly to improve the workability in geopolymer concrete. CERA CONCRETE TONIC 350 was used as a superplasticizer in this experiment. It is an admixture of a new generation based on Sulphonated naphthalene polymers.

Experimental Investigations

Mix design details

The basic mixtures proportions used for the trial mixtures was based upon previous research on geopolymer mixture proportions [2] because of the absence of its codal provisions. Alkaline liquids to fly ash ratio by mass was fixed as 0.45. For alkaline liquid combination ratio of Sodium silicate solution to Sodium hydroxide solution was fixed as 2.5. Mix proportions for characteristic strength of 30Mpa (G30) are described in Table 1.

Specimen Details

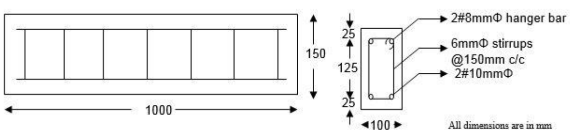
The beam specimens were 100 mm wide and 150 mm deep in cross-section. They were 1000 mm in length and simply supported over an effective span of 750 mm. The clear cover of the beam was 25 mm. The geometry of the beam specimen is shown in Figure 1. Steel bars of diameter 10mm was used as the longitudinal reinforcement in the specimens. The Reinforcement of the Beams is designed according to IS 456:2000 with a tensile reinforcement of 1.05%. The Beam is provided with Main reinforcement of 2 numbers of 10mm diameter bars and hanger bars of 2 numbers of 8mm diameter bars. Two legged vertical stirrups of 6 mm diameter at a spacing of 150 mm centre to centre were provided as shear reinforcement.

Preparation of test specimens and curing:

The solid constituents of geopolymer concrete mix i.e. fly ash, fine and coarse aggregates were dry mixed in pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 4 minutes. Finally extra water along with superplasticizer was added to achieve workable GPC mix. Glass fibre was added to the wet mix in different proportions such as 0.01%, 0.02%, 0.03% and 0.04% by the volume of the concrete [4]. Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the concrete specimens. All specimens were cast horizontally in three layers. Each layer was

Table 1: Mix proportions for G30 geopolymer concrete

Mix ID	Fly ash	Fine aggregate	Coarse aggregate kg/m^3			NaOH Solution	Na_2SiO_3 Solution	Extra water	Super plasti cizer	Glass fibres
			20 mm	12 mm	6 mm					
	kg/m^3	kg/m^3				kg/m^3	kg/m^3	kg/m^3	kg/m^3	%
GPC	378	554	388	543	363	50	124	55.4	7.5	0%
FRGPC1	378	554	388	543	363	50	124	55.4	7.5	0.01%
FRGPC2	378	554	388	543	363	50	124	55.4	7.5	0.02%
FRGPC3	378	554	388	543	363	50	124	55.4	7.5	0.03%
FRGPC4	378	554	388	543	363	50	124	55.4	7.5	0.04%



compacted using a tamping rod. After casting, specimens were placed inside the heat curing chamber and cured at 70°C for 24 hours. After curing, the specimens were removed from the chamber and left to air-dry at room temperature for another 24 hours before demoulding. The test specimens were then left in the laboratory ambient conditions until the day of testing. In this experimental work, a total of numbers of 45 concrete specimens were casted with and without fibres. The specimens considered in this study consisted of 15 numbers of 150 mmx150 mm size cubes, 15 numbers of 150 mm diameter and 300 mm long cylinders, 15 numbers of 100mmx100mmx500mm size prisms and 15 numbers of 100mmx150mmx1000mm size beam specimens.

Testing

Tests for compressive strength and split tensile strength were conducted using a 2000 kN Compression testing machine and the test for flexural strength was conducted using a 500 kN Flexural testing machine. These tests were conducted as per the relevant Indian Standard specification [9,10]. The beams were tested in four point loading technique. This load case was chosen because it gives constant maximum moment and zero shears in the section between the loads, and constant maximum shear force between support and load. The moment was linearly varying between supports and load. The span between the supports is 750 mm and the load is applied at points dividing the length into three equal parts as shown in figure 2.

Deflectometers were used to measure the deflection at mid span and two other one-third points below the point of loading. The experimental loading arrangement is shown in figure 3.

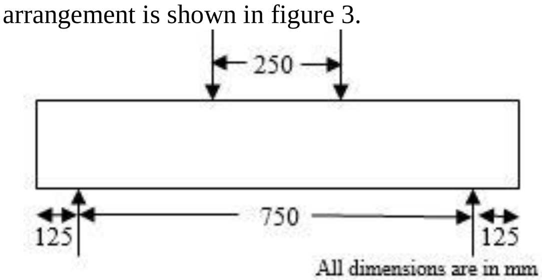


Figure 2: *Test setup*

Figure 3: Experimental loading arrangement

Results and Discussions

In the present study, mechanical properties of Fibre Reinforced Geopolymer Concrete (FRGPC) such as compressive strength, split tensile strength, flexural strength and flexural behaviour of FRGPC beams by using glass fibre at different binder composition of concrete were investigated and compared it with ordinary Geopolymer Concrete (GPC).

Compressive Strength

The average compressive strength of geopolymer concrete with and without fibres for heat curing of 24 hours at 70°C was shown in Table 2. Compressive strength of GPC and FRGPC specimens were compared by plotting graphs as shown in Figure 4. The increase in compressive strength was about

8% and 37% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in compressive strength was about 11% and 16% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.

Table 2: Compressive strength of geopolymer concrete with and without glass fibres

Mix ID	Average Compressive load kN	Average Compressive strength N/mm²	Increase in Compressive strength %
GPC	736.67	32.74	0
FRGPC1	796.67	35.41	8.14
FRGPC2	1010.67	44.92	37.20
FRGPC3	900.24	40.01	22.20
FRGPC4	850.03	37.78	15.39

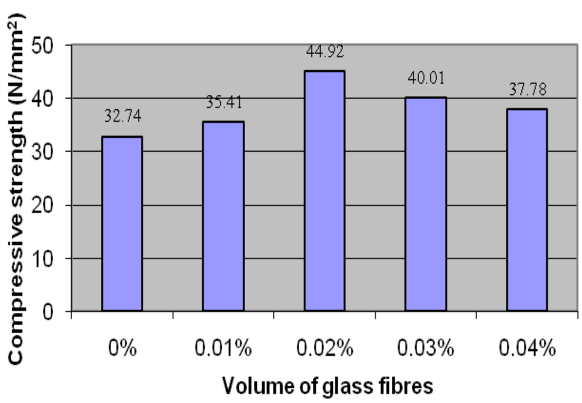


Figure 4: Compressive strength of glass fibre reinforced geopolymer concrete

Split Tensile Strength

The average split tensile strength of geopolymer concrete with and without fibres for heat curing of 24 hours at 70°C was shown in Table 3. Split tensile strength of GPC and FRGPC specimens were compared by plotting graphs as shown in Figure 5. The increase in split tensile strength was about 14% and 48% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in split tensile strength was about 10% and 19% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.

Table 3: Split tensile strength of geopolymer concrete with and without glass fibres

Mix ID	Average Split Tensile load kN	Average Split Tensile strength N/mm²	Increase in Split Tensile strength %
GPC	210	2.97	0
FRGPC1	240	3.39	14.29
FRGPC2	310	4.38	47.62
FRGPC3	280	3.96	33.33
FRGPC4	250	3.54	19.05

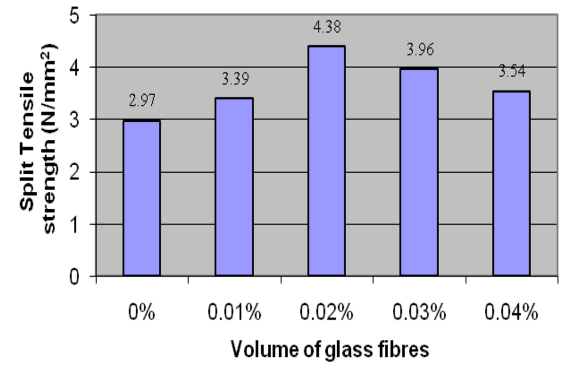


Figure 5: Split tensile strength of glass fibre reinforced geopolymer concrete

Flexural Strength – Prisms

The average flexural strength of geopolymer concrete prism specimens with and without fibres for heat curing of 24 hours at 70°C was shown in Table 4. Flexural strength of GPC and FRGPC specimens were compared by plotting graphs as shown in Figure 6. The increase in flexural strength was about 12% and 35% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in flexural strength was about 9% and 13% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.

Table 4: Flexural strength of geopolymer concrete with and without glass fibres

Mix ID	Average Flexural load kN	Average Flexural strength N/mm²	Increase in Flexural strength %
GPC	17	6.89	0
FRGPC1	19	7.70	11.76
FRGPC2	23	9.32	35.29
FRGPC3	21	8.51	23.53
FRGPC4	20	8.10	17.65

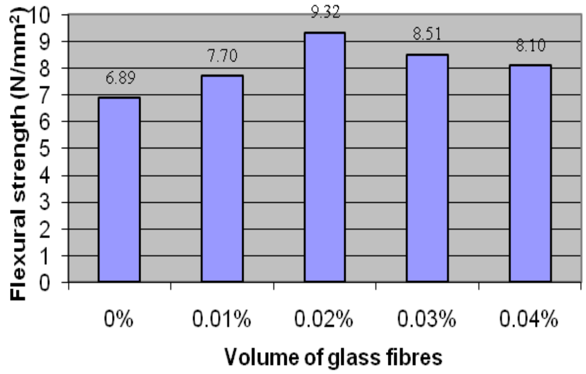


Figure 6: Flexural strength of glass fibre reinforced geopolymer concrete

Flexural Behaviour – Beam Specimens

The average initial cracking load and ultimate load of geopolymer concrete beam specimens with and without fibres for heat curing of 24 hours at 70°C was shown in Table 5. Initial cracking load and ultimate load of GPC and FRGPC specimens were compared by plotting graphs as shown in Figure 7. The load carrying capacity and deflections of FRGPC specimens were more than that of GPC. The initial crack load and ultimate load of FRGPC specimens were 10-30% and 12-35% respectively more than that of GPC.

Table 5: Flexural behaviour of geopolymer concrete beam specimens with and without glass fibres

Mix ID	Average initial Cracking load kN	Average Ultimate Load kN	Increase in Initial cracking load %	Increase in ultimate load %
GPC	48	86	0	0
FRGPC1	53	96	10.42	11.63
FRGPC2	62	116	29.17	34.88
FRGPC3	56	108	16.67	25.58
FRGPC4	54	102	12.50	18.60

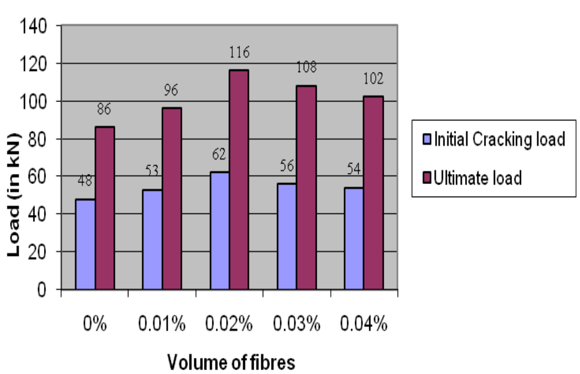


Figure 7: Flexural behaviour of glass fibre reinforced geopolymer concrete beams

Load-Deflection Behaviour:

The load deflection curves for GPC and FRGPC with various fibre content was shown in Figure 8. From the test results it was observed that FRGPC had more load carrying capacity compared to GPC. The first crack load and the ultimate load were observed for all the specimens. First crack load and ultimate load increased with increase in fibre content upto the addition of 0.02% of glass fibres, which is due to the increase in tensile strain carrying capacity of concrete in the neighbourhood of fibres. This has lead to improvement in load carrying capacity. However, the geopolymer concrete beams casted with 0.03% and 0.04% glass fibre content (FRGPC3 and FRGPC4) shows less load-deflection behaviour when compared to FRGPC2. The reason for the reduction of load-deflection behaviour instead of improvement with the addition of glass fibres may be attributed to a greater possibility of these fibres balling together and leaving voids in the matrix [7]. From the table it was also observed that the load carrying capacity was more for all FRGPC specimens than GPC. The initial cracking load for FRGPC1, FRGPC2, FRGPC3 and FRGPC4 specimens are 10%, 29%, 17% and 13% more than that of GPC. The ultimate load for FRGPC1, FRGPC2, FRGPC3 and FRGPC4 specimens are 12%, 35%, 26% and 19% more than that of GPC. The increase in initial cracking load is about 10% and 29% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in initial cracking load was about 43% and 57% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix. The increase in ultimate load is about 12% and 35% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in ultimate load was about 27% and 47% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.

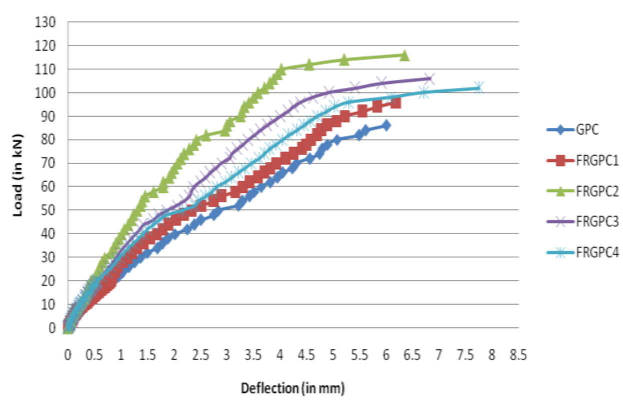


Figure 8: Load-Deflection behaviour of glass fibre reinforced geopolymer concrete beams

Conclusions

1) Geopolymer concrete is an excellent alternative to Ordinary Portland Cement concrete.
2) The increase in compressive strength was about 8% and 37% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in compressive strength is about 11% and 16% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.
3) The increase in split tensile strength was about 14% and 48% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in split tensile strength is about 10% and 19% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.
4) The increase in flexural strength of geopolymer concrete was about 12% and 35% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in flexural strength was about 9% and 13% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix.
5) The load carrying capacity and deflections of all FRGPC beams were more than that of GPC.
6) The initial crack load and ultimate load of FRGPC beams were 10-30% and 12-35% respectively more than that of GPC beams.
7) The increase in initial cracking load is about 10% and 29% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in initial cracking load was about 43% and 57% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2 mix. The increase in ultimate load is about 12% and 35% for FRGPC1 and FRGPC2 respectively with respect to GPC mix and decrease in ultimate load was about 27% and 47% for FRGPC3 and FRGPC4 respectively with respect to FRGPC2.

Acknowledgements

The co-operation and guidance received from the supervisor Dr. S. Nagan, the technical staffs of Materials Testing Lab, Structures Lab and Geopolymer Lab are gratefully acknowledged. The author also acknowledges Jeevanantahan A., Devarajan M. and Lakshmi A.M., B.E. students, Thiagarajar College of Engineering, Madurai for their support to conduct this experiment.

References

[1] Abdul Aleem M. I., Arumairaj P. D., (2012), "Geopolymer Concrete- A REVIEW", International Journal of Engineering Sciences and Emerging Technologies (IJESET), vol-1, Issue 2, PP., 118-122.

[2] Abdul Aleem M.I., Arumairaj P. D., (2012), "Optimum mix for the geopolymer concrete", Indian Journal of Science & Technology, vol-5, No.3, March 2012.

[3] Anuar K.A., Ridzuan A.R.M., Ismail S., (2011), "Strength Characteristic of Geopolymer Concrete Containing Recycled Concrete Aggregate", IJCEE-IJENS vol-11, PP., 81-85.

[4] Bhalchandra S.A., Bhosle A.Y., (2013), " Properties of Glass Fibre Reinforced Geopolymer Concrete", International Journal of Modern Engineering Research (IJMER), Vol-.3, Issue.4, Jul-Aug. 2013, PP., 2007-2010.

[5] Davidovits J., (1991), "Geopolymers: inorganic polymeric new materials", Journal of Thermal Analysis, 37, PP., 1633–1656.

[6] Duxson P., FernándezJiménez A., Provis JL., Lukey GC., Palomo A., Van Deventer, (2007), "Geopolymer technology, The current state of the art", Journal of Material Science,42 (9), PP., 2917–2933.

[7] Dylmar Penteado Dias, Clelio Thaumaturgo, (2005), "Fracture toughness of geopolymeric concretes reinforced with basalt fibers", Cement & Concrete Composites 27 (2005) 49-54.

[8] Harjito D., Rangan B.V., (2005), "Development and properties of low calcium fly- ash based geopolymer concrete", Research report GC1, Curtin University of Technology, Perth, Australia.

[9] I.S: 516-1959 (Reaffirmed 1999), "Methods of Tests for Strength of Concrete", Bureau of Indian Standards, New Delhi.

[10] I.S: 5816-1970, "Methods of Test for Splitting Tensile of Concrete Cylinders",Bureau of Indian Standards, New Delhi.

[11] Van Jaarsveld, J.G.S., Van Deventer J.S.J., Lukey G.C., (2003), "The characterization of source materials in fly ash-based geopolymers", Materials Letters, *57*(7), PP., 1272-1280.