Experimental study on Torsional behavior of Silica Fume based Geopolymer concrete beam

A. Nishanth[1], A. Joshua Daniel[2]

[1]*M. Tech, Department of Civil Engineering, SRM University, Tamil Nadu, India*
[2]*Assistant Professor, Department of Civil Engineering, SRM University, Tamil Nadu, India*

Abstract - *This research investigates and evaluates the results of geopolymer concrete beams subjected to torsion and compared with conventional concrete beams. Eight beams, four with geopolymer concrete and four with conventional concrete were fabricated and tested. Study includes the general cracking characteristics, pre cracking behaviour, post cracking behaviour, crack width stiffness and ductility. From the compression and split tensile tests, the optimum replacement of silica fume is found to be 40%. The ultimate torque resistances of geopolymer concrete is less in comparison to that of conventional concrete. Further, with increase in reinforcement percentage, the ductility of geopolymer concrete increase.*

Key Words: *Geopolymer Concrete, Silica Fume, Torsion, Reinforcement, Cracks.*

1.INTRODUCTION

The increasing worldwide production of cement to meet the future development in the infrastructure industry indicates that concrete is the most important ingredient in the modern construction materials. It is well evident that production of Ordinary Portland Cement (OPC) not only consumes larger quantity of natural resources but also emits larger quantity of carbon dioxide gas to the atmosphere. Effort were made to reduce the emission of carbon dioxide gas and also to produce an eco-friendly material in the development of inorganic alumino silicate polymer called geopolymer. Utilization of direct alkaline activation of industrial wastes, such as Silica Fume (SF), Fly Ash and ground granulated blast furnace slag, can be employed to produce Geopolymer cements which can be utilized to manufacture novel concrete for constructions [3] & [4].

Geopolymer Concrete (GPC) is a type of inorganic polymer composite, which has the potential to used as a substantial element in construction industry by replacing/supplementing the conventional concretes. GPC can be designated as a high strength concrete with good resistance to chloride penetration, acid attack. Sulphate attack, etc. Because of possible realization of even superior chemical and mechanical properties compared to Ordinary Portland cement (OPC) based concrete mixes. GPC mixes are being discussed for their potential application in concrete industry including structural concreting, precast panels and ready-mixes [11].

An attempt was made in the present study to know the behaviour of the Silica Fume based Geopolymer concrete in comparison with the conventional concrete under torsion.

2. MATERIALS

Cement of grade 53 was used in this study. River sand passing through 4.75mm IS sieve was used as fine aggregate. Crushed stone aggregate passing through 20mm IS sieve was used as coarse aggregate.

Silica fume is a by-product in the production of ferrosilicon industry and also of silicon metal. Silica fume of size <1µm was supplied by Astrra chemicals, Chennai. Silica and alumina constitutes around 80 to 85%. In the present study 40% of cement has been replaced with silica fume.

Conplast SP 430 super plasticizer is added to improve the workability of the silica fume based geopolymer concrete which supplied by FOSROC Constructive Solutions Company and it is used in the present study.

The sodium or potassium based alkaline liquid is soluble alkali metals. A combination of Sodium hydroxide (NaOH) and Sodium silicate (Na_2SiO_3) were used as alkaline liquids. A solution of 16 M of sodium hydroxide is prepared by dissolving 640 g of sodium hydroxide pellets in a liter of water and stored separately. Mix the two solutions in the beaker one day before casting of specimens. The ratios of Na_2SiO_3 to NaOH selected were 0.5 and Alkaline Liquid (AL) to Silica Fume (SF) ratio were taken as 0.25 [13].

Silica fume were mixed with sand, aggregates and the alkaline liquid (combination of sodium silicate and sodium hydroxide) were poured to dry mix and mixed thoroughly to form homogenous mixture. Once the mixing process gets over the mould was filled with concrete in three layers and compacted in vibrating table. The specimens were thermal cured at a temperature of 100°C for 6 hours.

3. EXPERIMENTAL WORK

A total of six beams were cast with the mix proportion of 1:1.52:2.61 with an w/c ratio of 0.45 based on IS 10262 [10]. Three beams were casted with conventional concrete (CC1–CC3) and three beams with geopolymer concrete(GPC1–GPC3). The specification for those are given in Table -1.

Table -1: Details of Longitudinal reinforcements

Beams	Beam section		Cantilever section	
CC1 & GPC1	Top	2-8mmØ	Top	3-8mmØ
	Bottom	2-8mmØ	Bottom	2-8mmØ
CC2 & GPC2	Top	2-8mmØ	Top	3-8mmØ
	Bottom	2-10mmØ	Bottom	2-10mmØ
CC3 & GPC3	Top	2-10mmØ	Top	2-12mmØ
	Bottom	2-12mmØ	Bottom	2-10mmØ

Geopolymer concrete beams were casted with optimum replacement percentage of Silica fume obtained from compression testing and split tensile tests, shown in Table -2 and Table -3.

The cross sectional dimension of beam was taken as 150x200mm and the length of the beam was taken as 1200mm centre to centre for both CC and GPC beams as shown in Fig -1.

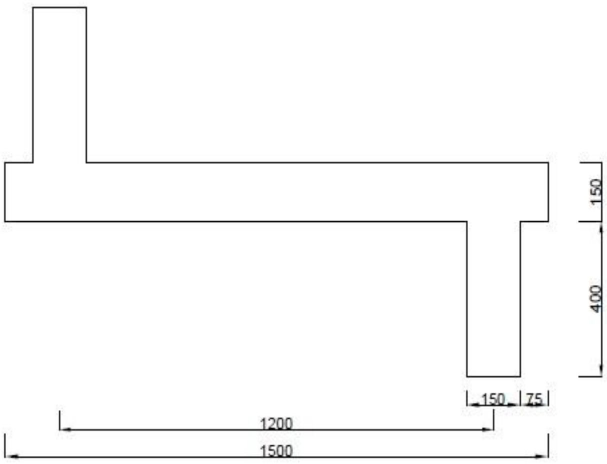

Fig -1: Plan View of Beam Specimen

In this study, transverse reinforcement i.e. 2 legged stirrups of 8mm at 100 mm centre to centre is kept constant and the longitudinal reinforcement are shown in table -1. The beam specimens were designed based on American Concrete Institute Committee 318-Building code [1] & [2].

4. RESULTS AND DISCUSSIONS

4.1 Test for Compression

The size of the specimens used for the present study is 150x150x150mm cubes and 150x300mm cylinders as per IS 516 [8]. The compression test values are shown in Table -2.

Table -2: Compressive Strength of Geopolymer concrete

Mix	Cubes (N/mm^2)		Cylinder (N/mm^2)
	7 days	28 days	28 days
(0%SF+ 100%CM)	18.26	29.32	21.5
(20%SF+ 80%CM)	10.52	20.43	14.72
(40%SF+ 60%CM)	18.75	30.1	22.46
(60%SF+ 40%CM)	14.75	23.56	16.2

4.2 Test for Split Tensile

As per IS 5816 [9], the size of the specimen used for this study is 150x300mm cylinders. The values of split tensile are shown in Table -3.

Table -3: Split Tensile of Geopolymer concrete

Mix	Cylinder (N/mm^2)
	28 days
(0%SF+ 100%CM)	3.312
(20%SF+ 80%CM)	2.307
(40%SF+ 60%CM)	3.397
(60%SF+ 40%CM)	2.63

From the results obtained from the compression and split tensile tests, the optimum replacement percentage of silica fume is found out to be 40%.

4.3 Test for Torsion

Specimens were tested by using a setup consisting of 40T loading frame, 50T capacity hydraulic jack and 40T capacity proving ring. The testing setup was shown in Fig -2. Two deflectometers were used to measure the twist. Torsional loading is given to the beam using an ISMB section. Crack patterns and crack widths were measured using visual observations and hand-held microscope with an optical magnification of 40X and a sensitivity of 0.01 mm.

The beam to be tested was lifted using a hydraulic crane of capacity 2T and kept inside the loading platform of the frame where the steel saddles were made ready by placing 12mm mild steel bars in between the saddles and also by applying grease to carry the beams on both edges to allow the twist when torque is applied. An ISMB was placed diagonally over the two cantilever portions of the beam to transfer the torque equally to the two legs. A hydraulic jack was placed over the ISMB section at the middle over which a proving ring was placed. The jack and the proving ring was adjusted to the middle of beam using a plum bob.

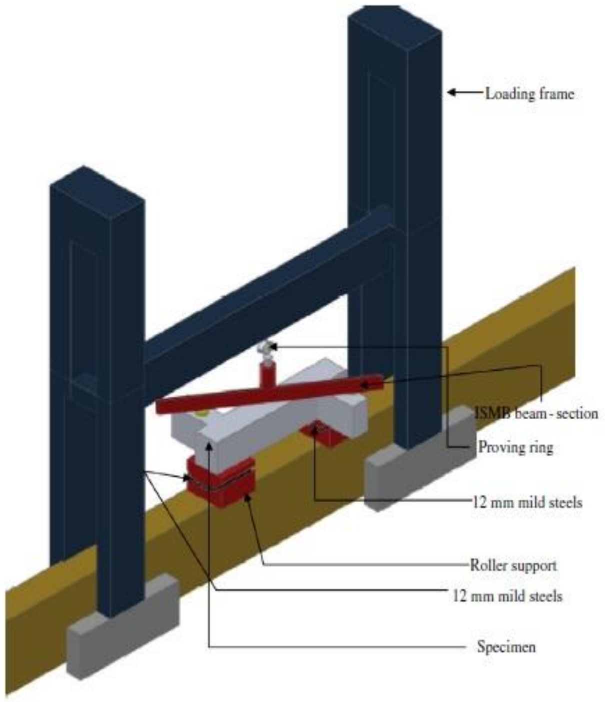

Fig -2: Schematic Diagram of Experimental Setup

Up to the cracking, all specimens were elastic and all the torsion was resisted by the concrete itself. From this, it can be noted that up to the cracking both the conventional and geopolymer concrete were elastic. After the cracking, it can be seen from the Charts -1, Charts -2 and Charts -3, that the torque vs twist relationship is nonlinear. Cracks were formed at 45° with the horizontal, which shows that the loading is purely torsion and not accompanied by any bending or shear effects. The ultimate load carrying capacity of all the specimens were nearly equal and vary very little. Loading was given at intervals of 0.4T up to the cracking stage later which the interval was reduced to 0.2T.

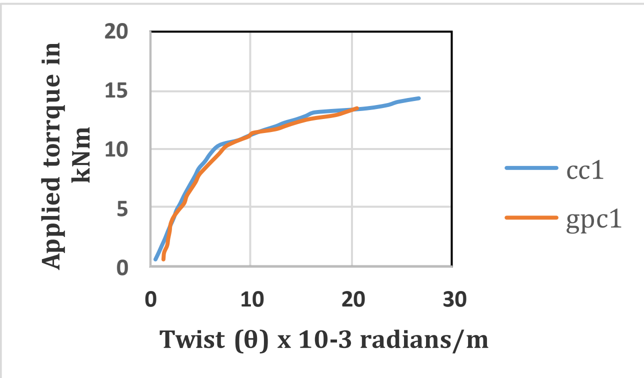

Chart -1: Torque versus Twist for CC1 & GPC1 beams.

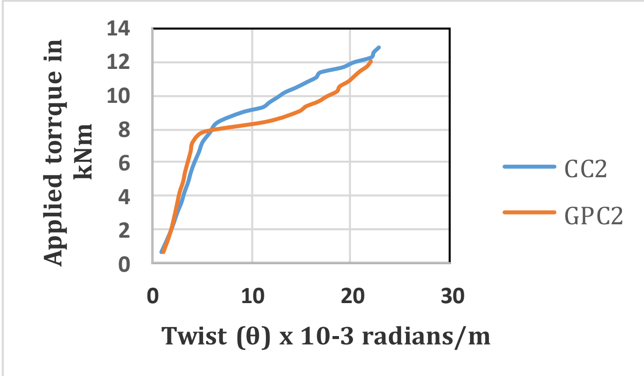

Chart -2: Torque versus Twist for CC2 & GPC2 beams.

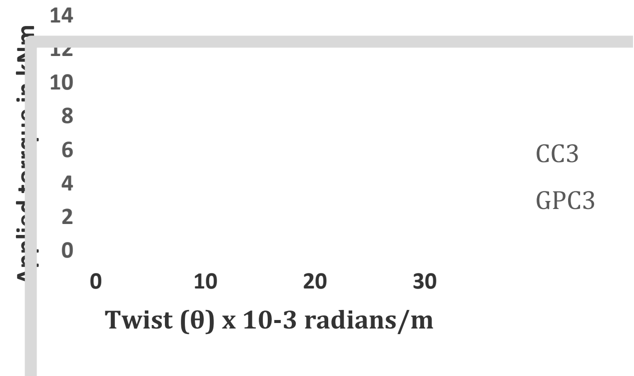

Chart -3: Torque versus Twist for CC3 & GPC3 beams.

4.4 Ductility

Ductility is also an important parameter as it gives warning of the imminent failure of a structure. The ductility of a beam subjected to torsion is defined as the deformable capacities which can be taken as the angle of twist corresponding to 90% of ultimate torque [12], which are presented in Table -4. Compared to CC1 and GPC1, the ductility of CC1 increases about 8.8% compared to GPC1. Likewise, compared to CC2 and GPC2, the ductility of GPC2 increases about 11.22% compared to CC2. Similarly, compared to CC3 and GPC3, the ductility of GPC3 increases about 14.5% compared to CC3.

Table -4: Ductility comparisons.

Beam specimen	twist at 90% of ultimate torque (rad/m)x10^{-3}
CC1	15.44
GPC1	14.08
CC2	17.63
GPC2	19.86
CC3	16.74
GPC3	19.58

4.5 Crack width

Crack widths were measured at the time of initial cracking torque and also at ultimate torque applied on each specimen using a hand-held microscope with an optical magnification of 40X and a sensitivity of 0.01 mm. It can be seen that the width at initial cracking torque for GPC1 is better than CC1, whereas GPC2 and GPC3 shows an inferior behaviour than CC2 and CC3. At ultimate cracking torque, the crack width in GPC beams is higher in comparison to CC beams for their corresponding reinforcement ratios. The measured crack widths are tabulated and are shown in Table -5.

Table -5: Torque at Initial and Final Cracking

Specimens	Initials		Final	
	Torque (kNm)	Crack (mm)	Ultimate torque (kNm)	Crack (mm)
CC1	10.5	0.03	14.4	1.9
GPC1	9.6	0.02	13.5	2.1
CC2	9.3	0.02	12.9	2.6
GPC2	8.1	0.03	12	3.1
CC3	8.1	0.01	12.6	2.4
GPC3	7.2	0.02	12.3	2.9

4.6 Stiffness

Stiffness of both CC and GPC specimen were calculated as the ratio of ultimate torque to angle of twist from the corresponding experimental results. The values of stiffness are listed in Table -6.

Table -6: Stiffness comparisons.

Beam specimens	Ultimate Torque, T_u (kNm)	Twist, θ (rad/m) x10^{-3}	Stiffness (T_u/ θ) (kNm)
CC1	14.4	26.62	540.95
GPC1	13.5	20.62	654.70
CC2	12.9	22.75	567.03
GPC2	12	22.12	542.50
CC3	12.6	25.21	499.8
GPC3	12.3	23.10	532.47

5. CONCLUSIONS

- The behaviour of both conventional and geopolymer concrete before cracking was elastic.
- The ultimate load carrying capacity of the conventional concrete was about 9.6T, 8.6T & 8.4T and of the geopolymer concrete is 9T, 8T and 8.2T respectively with corresponding reinforcement ratios.
- Compared to CC1 and GPC1, the ductility of CC1 increases about 8.8% compared to GPC1. Likewise, compared to CC2 and GPC2, the ductility of GPC2 increases about 11.22% compared to CC2. Similarly, compared to CC3 and GPC3, the ductility of GPC3 increases about 14.5% compared to CC3.
- Crack width at initial cracking torque for GPC1 is better than CC1, whereas GPC2 and GPC3 shows an inferior behaviour than CC2 and CC3.
- The crack width of the final crack for geopolymer concrete specimens were higher than conventional concrete.
- The Stiffness of GPC1 increases about 17.37% compared to CCC1. Likewise, the Stiffness of CC2 increases about 4.32% compared to GPC2. Similarly, compared to CC3 and GPC3, the Stiffness of CC3 increases about 6.14% compared to GPC3.

REFERENCES

[1] ACI Committee 318, “Building code requirements for reinforced concrete and commentary” Farmington Hills, United States of America: American Concrete Institute; 1989.

[2] ACI Committee 318, “Building code requirements for structural concrete and commentary” Farmington Hills, United States of America: American Concrete Institute; 1995.

[3] Bharat Bhushan Jindal, Kamal Khetarpal, (2015), **“Geopolymer Concrete - A Review”,** ‘SSRG International Journal of Civil Engineering’.

[4] Davidovits J. (1991), “**Geopolymers: inorganic polymeric new materials”,** ‘Journal of Thermal Analysis’, page 1633–1656.

[5] H.A. Praveen Tissera, Imtiaz Pasha, Oran Mark, Gowri U.N, M.R. Prakash, Prabakaran R, (2012), **“Experimental Investigation on Torsional Behaviour of Reinforced Normal Strength Concrete”.**

[6] Hsu TTC, Hwang CS, **“Torsional limit design of spandrel beams**”, ‘ACI Struct J’ 1977;74(2):71–9.

[7] IS 10262 (1982), **“Guide Lines for Concrete Mix Design”**, ‘Bureau of IndianStandards’, New Delhi.

[8] IS 516 (1959),**“Method of Tests for Strength of Concrete**”, ‘Bureau of IndianStandards’, New Delhi.

[9] IS 5816 (1999), **“Method of Test Splitting Tensile Strength of Concrete”**, ‘Bureau of IndianStandards’, New Delhi.
[10] Macgregor JG, Ghoneim MG, “Design for torsion”, ‘ACI Struct J’ 1995;92(2):211–8.
[11] More Pratap Kishanrao,**”Design of Geopolymer Concrete”**,’ International Journal of Innovative Research in Science, Engineering and Technology’,Vol. 2, Issue 5, ISSN: 2319-8753, May (2013).
[12] Punmia BC, Jain Ashok Kumar, Jain Arun Kumar. Limit state design of reinforced concrete. New Delhi, Laxmi Publications (P) Ltd.; (2011) p. 194.
[13] A.Rajerajeswari, G. Dhinakaran and Mohamed Ershad, (2013),**“Compressive Strength of Silica Fume Based Geopolymer Concrete”,**‘Asian Journal of Applied Science’, ISSN 1996-3343.