Shear Behaviour of High Strength GPC/TVC Beams

R.Mourougane, C.G. Puttappa, C. Sashidhar and K.U. Muthu

Abstract--- *Geopolymer concrete is a new construction material with significant potential. This type of concrete is produced without Portland cement as a binder. Instead, the base material such as fly ash, which is rich in Silicon and Aluminium is used to produce binder. The objective of this paper is to present the results of study on the shear behavior and strength of geopolymer concrete (GPC) beam and traditionally vibrated concrete (TVC) beams. A total of twelve beams (Six GPC and Six TVC) specimens were cast and tested. The test results included the crack patterns, load carrying capacity, the load-deflection characteristics, and the failure modes of the beams. The experimental results are checked for IS 456:2000 codal provisions. The analytical work consisted of computing ultimate strengths of test beams using the methods currently available in the literature. In addition, the design provisions contained in the American Concrete Institute Building Code ACI 318-2010, AS 3600 and Bentz Software are used to calculate the strength of all the beams.*

Keywords--- *Beams, Crack, Deflection, Failure, GPC, Shear Strength, TVC*

I. Introduction

IN recent years, attempts are being made to develop environment friendly concrete to reduce the use of traditional concrete made with portland cement which is not environment friendly as each tonne of cement manufacture will emit equal amount of carbon-di-oxide which pollutes the environment. Several efforts are in progress to supplement the use of portland cement in concrete. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice husk ash and metakaolin, and the development of alternative binders to portland cement. In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the portland cement (Duxson et al, 2007). Geopolymer and alkaline activation technology has been known in the construction industry for nearly five decades. Glukhovsky and his associates in Ukarine, proposed a general mechanism for alkali activation materials primarily of materials comprising silica and alumina. Geopolymer is used as a binder, instead of cement paste to produce concrete. The geopolymer paste binds the loose coarse aggregates, fine aggregates and other unreactive materials together to form geopolymer concrete. The manufacture of geopolymer concrete is carried out using usual concrete technology. The alkali activation of fly ash is a simple procedure in which the powdery grey materials is mixed with an alkaline solution (alkaline activators) and then cured at 60°C in steam curing chamber to produce solids. In the present study, an experimental programs has been planned to study the shear behavior of high strength GPC and TVC beams

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II. Objective of the Work

The main objective of the present study are:

1. To investigate the shear behaviour of reinforced GPC beams, crack patterns and deflection, under two points loading and comparing it with high strength TVC beams of same grade.
2. To compare the experimental results with prediction methods currently available in literatures for TVC structural members, and to evaluate the suitability of these methods for GPC

III. Literature Review

There is a need for the development of alternative binders to make concrete and the use of fly ash in concrete. The studies on reinforced fly ash-based geopolymer concrete members are extremely limited. Palomo et.al (2004) investigated the mechanical characteristics of fly ash based geopolymer concrete. It was found that the characteristics of the material were mostly determined by curing methods especially the curing time and curing temperature. Their study also reported some limited number of tests carried out on reinforced geopolymer concrete sleeper specimens. Another study related to the application of geopolymer concrete to structural members was conducted by Brooke et al. al (2005). It was reported that the behaviour of geopolymer concrete beam column joints was similar to that of members made of Portland cement concrete. The behaviour and strength of reinforced geopolymer concrete slender columns and the flexural behaviour of reinforced geopolymer concrete beams have been studied by Sumajouw and Rangan (2006). It is reported that the behaviour, failure mode and load carrying capacity of columns and flexural members are similar to those of TVC. Effective utilization of Fly ash in structural concrete has been demonstrated in this work

IV. EXPERIMENTAL WORK

The work involves production of high strength traditionally vibrated concrete and geopolymer concrete .The shear strength, crack pattern and deflection of geopolymer and traditionally vibrated concrete were studied and reported

A. Methodology

The Mix Proportions Were Arrived by Trail Mixes are Shown in Table 1.

In the preparation of GPC fly ash, GGBS and aggregates were dry mixed in the pan mixer for about 3 minutes. The alkaline solution, i.e sodium silicate solution, the sodium hydroxide solution that was prepared one day prior to usage along with, added water and the super plasticizer were premixed then added to the solids. The wet mixing was confirmed for another 2 minutes. While preparing the TVC cement, silica fume and aggregate were dry mixed in the pan mixer for about 3 minutes. Super plasticizer and water was added into the blend and mixed for about 2 minutes. The workability of both geopolymer and traditionally vibrated fresh concrete was measured by means of conventional slump cone. The fresh concrete was used to make the beam specimens of size 125mm × 250mm × 2000mm with the varying reinforcement for both GPC and TVC beams are shown in Table 2. Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the cured concrete. The geopolymer beam specimens were steam cured in a curing chamber for 24 hours at a temperature of 60°C. The specimens were then allowed to cool in air. Similarly, TVC beams were cured for 28 days using wet gunny bags.

Table 1: Concrete Mix Details

kg/m^3	Cement	Flyash	GGBS	SF	CA	FA	NaOH	Na_2SiO_3	Water	SP
GPC	-	366	40	-	1295	555	41	103	16.2	3
TVC	375	-	-	42	1050	716	-	-	150	2.5

Table 2: Details of Beam Reinforcements

	Series-1			Series-2		
Tension Steel	2#8 Ø & 2#10 Ø			4#12 Ø		
Hanger bar	2#8Ø					
Stirrups 2L#8 Ø	150 c/c	200 c/c	230 c/c	150 c/c	200 c/c	230 c/c

Test Setup

The beams were tested for shear at the end of 28 days with the test arrangement as shown in fig 1. On the day prior to the testing, the beams were white washed to facilitate the marking of cracks. The beams were simply supported having an effective span of 1600mm and loaded symmetrically at 400mm from the supports to maintain the a/d ratio more than 1and less than 2.5 to ensure the failure of the beam in shear. The load was applied at intervals of 4 kN until the first crack thereafter increments were of 8 kN. Measurements of deflection, surface strain, and crack width were noted at various load intervals. On the same day of testing the beam, auxiliary specimens of cubes were tested to determine the compressive strength

Figure 1: Test Setup of a Typical Beam

V. RESULTS AND DISCUSSIONS

The initial cracks developed near the flexure zone and after considerable increments of the load, the cracks at the flexural zone stopped propagating. Whereas, the cracks in the shear span of the beam grew towards the loading point, along which first two TVC beams failed in flexure and rest of TVC and GPC beams failed in shear.

Ultimate and shear strength of all GPC and TVC beams are shown in the Table 3 to 6. They are calculated using various codal equations and compared with the experimental values. The fig 2 shows the comparison of ultimate shear of GPC and TVC beams, it is observed that the all five beams of GPC are taking more ultimate shear than TVC beams. Fig 3 and 4 shows a plot of ultimate load versus stirrup spacing, from this it is very clear that as the tensile reinforcement ratio increases, the ultimate load also increases for both GPC and TVC beams. The fig 5 shows typical crack patterns of GPC and TVC beams.

Table 3: Ratios of P_u by $P_{u,expt}$ of GPC Beams

Beam	Expt. Load kN	$P_u/P_{u,expt}$			
		ACI 318	IS 456	AS 3600	Bentz
GPC-1	150	1.5	1.14	1.05	1.31
GPC-2	180	1.05	0.76	0.69	1.1
GPC-3	180	0.96	0.69	0.62	1.1
GPC-4	230	0.99	0.77	0.71	1.3
GPC-5	230	0.83	0.63	0.57	1.32
GPC-6	200	0.9	0.66	0.6	1.56
	Mean	1.04	0.77	0.7	1.28
	SD	0.24	0.19	0.18	0.17
	Cv	23.19	24.36	25.01	13.32

Table 4: Ratios of P_u by $P_{u,expt}$ of TVC Beams

Beam	Expt. Load kN	$P_u/P_{u,expt}$			
		ACI 318	IS 456	AS 3600	Bentz
TVC-1	140	1.66	1.22	1.1	1.15
TVC-2	160	1.25	0.86	0.78	1.03
TVC-3	146	1.23	0.85	0.78	1.1
TVC-4	214	1.12	0.83	0.75	1.06
TVC-5	220	0.89	0.65	0.59	0.96
TVC-6	214	0.89	0.61	0.58	0.96
	Mean	1.17	0.84	0.76	1.04
	SD	0.28	0.22	0.19	0.08
	Cv	24.3	25.75	24.62	7.42

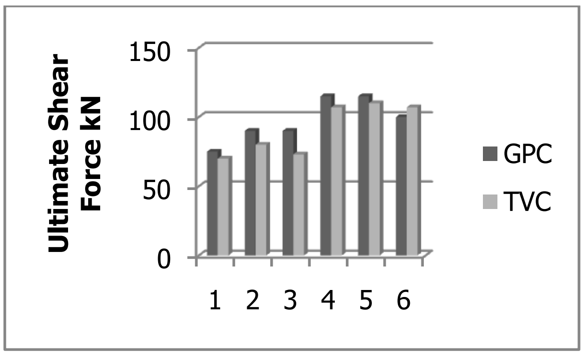

Figure 2: Comparison of V_u of GPC & TVC Beams

Table 5: Ratio of $V_{u\ cal}$ and $V_{u\ expt}$ of GPC Beams

Beam	$V_{u,\ expt.}$ kN	$V_{u,\ cal}/V_{u,\ expt}$			
		ACI 318	IS 456	AS 3600	Bentz
GPC 1	75	1.5	1.14	1.05	1.31
GPC 2	90	1.05	0.76	0.69	1.1
GPC 3	90	0.96	0.69	0.62	1.1
GPC 4	115	0.99	0.77	0.71	1.3
GPC 5	115	0.83	0.63	0.57	1.32
GPC 6	100	0.9	0.66	0.6	1.56
	Mean	1.04	0.77	0.7	1.28
	SD	0.24	0.19	0.18	0.17
	C_v	23.19	24.36	25.01	13.32

Table 6: Ratio of $V_{u\ cal}$ and $V_{u\ expt}$ of TVC Beams

Beam	$V_{u,\ expt.}$ kN	$V_{u,\ cal}/V_{u,\ expt}$			
		ACI 318	IS 456	AS 3600	Bentz
TVC 1	70	1.66	1.22	1.1	1.15
TVC 2	80	1.25	0.86	0.78	1.03
TVC 3	73	1.23	0.85	0.78	1.1
TVC 4	107	1.12	0.83	0.75	1.06
TVC 5	110	0.89	0.65	0.59	0.96
TVC 6	107	0.89	0.61	0.58	0.96
	Mean	1.17	0.84	0.76	1.04
	SD	0.28	0.22	0.19	0.08
	C_v	24.3	25.75	24.62	7.42

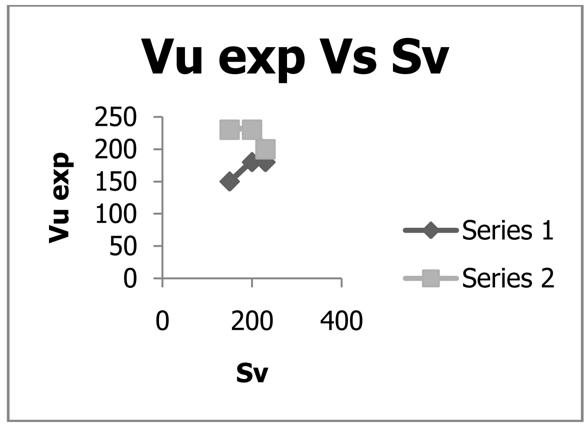

Figure 3: $V_{u\ expt.}$ Vs S_v of GPC Beams

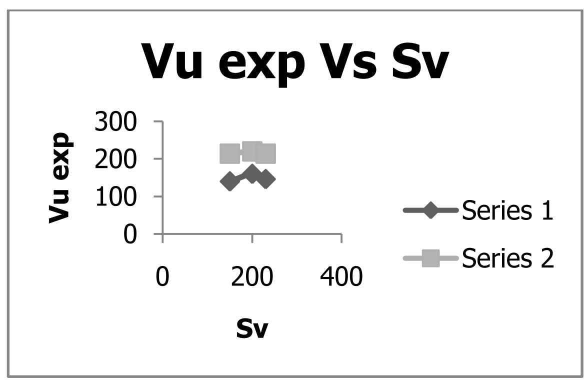

Figure 4: $V_{u\ expt.}$ Vs S_v of TVC Beams

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Figure 5: Crack Patterns of Beams GPC 3 and TVC 3

VI. Conclusion

The paper presents shear behavior of Steam-cured fly ash-based geopolymer concrete. Low-calcium fly ash (ASTM Class F) is used as the source material, as a substitute of the Portland cement, to make geopolymer concrete.

Geopolymer beams are cast in two series of tension reinforcement with stirrups spacing of 150mm, 200mm and 230mm. Each beam is tested for shear under two point loading and compared with beams of TVC of same concrete grade.

The following conclusions are drawn from the above experimental work:

Beams TVC 1 and 2 failed in flexure and all TVC and GPC beams failed in shear. For the beams which failed in flexure, concrete spalling was observed in the compression zone. For the beams which failed in shear, the shear cracks kept propagating from the middle of shear zone toward the support and the loading point, and sudden failure of the beams was observed.

- It was observed that for all the beams, cracks were developed initially near the soffit of the beams. Generally, in all the beams, flexure cracks appeared first at the initial stages of the loadings. However as the load increased, the shear cracks were noticed in the shear plane. For all the beams the cracking load was found to be within the range of 30kN and 90kN.
- Using different codal equations and Response 2000 software, shear strength of all the 12 beams were calculated and compared with the experimental shear strength. The ratio of $V_{u, cal}/V_{u, exp}$ was calculated and the mean, standard deviation and the coefficient of variation also calculated for GPC and TVC beams respectively. ACI-318-10, predicts the shear value better when compared with the other equations with a mean of 1.04 and coefficient of variation of 23.19% for GPC beams. The Response 2000 predicts the shear value better when compared with the other equations with a mean of 1.04 and coefficient of variation of 7.42% for TVC beams
- The Ultimate experimental load V_u-Stirrup spacing S_v of GPC and TVC beams were compared. The Ultimate load V_u of GPC beams were comparatively more when compared with the TVC beams.

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