

Flexural Behaviour of Glass Fibre Reinforced Geopolymer Concrete Beam

Mohiyuddin C S¹, Dhruthi L², Akash Babu L A³, Sadath Ali Khan Zai⁴

^{1, 2, 3} Dept of Civil Engineering

⁴Professor, Dept of Civil Engineering

^{1, 2, 3, 4} UVCE, Bangalore University, Bengaluru, Karnataka, India

Abstract- *The present research investigation deals with the study of test beam specimens of M40 grade of concrete integrated with glass fibers (GF) under static loading. A series of four test beam specimens of 1500 x 250 x 150 mm dimensions were considered. The study on the flexural behavior of geopolymer concrete beams explores into the innovative use of alternative materials in construction to enhance structural performance and sustainability. Through a series of experiments, various concrete mixes were tested, including (B-1): Controlled specimen CC M40, (B-2):CC M40+GF, (B-3):GPC M40-10M, (B-4):GPC M40+GF to evaluate their compressive strength, flexural strength, and load-bearing capacities under static loading conditions.*

The experimental investigation deals with the static loading which was carried out under two point loading at mid-point with the help of load cells attached vertically to a hydraulic jack and LVDTs placed at center. Various parameters such as ductility index, toughness index, ultimate deflection, yield deflection and energy absorption capacity are studied. The static tests performed on the beams shows that the ultimate load carrying capacity, ductility index and toughness index of (B-4):GPC M40-10M+GF of beam 150x250x1500 mm is 98.36 kN, 7.07 and 25.065 respectively.

I. INTRODUCTION

As CO₂ emissions are increasing in the atmosphere and causes global warming with the production of cement, the alternative pozzolanic material is needed. The alternative pozzolanic material for cement in the production of concrete is GGBS. Geopolymer Concrete (GPC) is an alternative material for conventional concrete. Geopolymer concrete is made by mixing GGBS, fine aggregate, coarse aggregate and alkaline activator solution. GGBS is a by-product of the iron industry (1). 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(2). The materials used for making glass fibres reinforced geopolymer concrete are Low calcium dry fly ash

as source material, alkaline liquids, coarse & fine aggregates, glass fibres & water(3). The paper focuses on investigating characteristics of Ground Granulated Blast furnace Slag (GGBS) based Geopolymer Concrete with M40 Grade Concrete. This leads to examine the admixtures to improve the performance of the concrete(4).

Fly ash is well-off in silicate and alumina, hence it reacts with alkaline solution to generate alumina silicate gel that binds the aggregate to manufacture a good quality concrete. Literature on the flexural behavior of geopolymer concrete (GPC) beams have been studied and compared with the reference concrete beams of the respective grade. From the literature, It has been observed that the development of flexural cracks are relatively less in geopolymer RCC beams compared to conventional beams, the failure occurred in the beams was in flexural mode and the cracks are generated from the tension zone to the compression zone and also the compressive strength greater than before due to decrease in porosity, as the fineness of fly ash enhanced (5).

II. MATERIALS USED

In the present investigation, various materials were utilized to develop geopolymer concrete with enhanced mechanical and durability characteristics. Ground Granulated Blast Furnace Slag (GGBS), a by-product from iron manufacturing, was used for its cementitious properties. It is obtained by rapidly cooling molten slag with water to form a glassy granulated material, which is then ground into a fine powder. Class F Fly Ash, a low-calcium by-product from coal combustion in thermal power plants, was also incorporated for its pozzolanic properties. And as Fine aggregates Manufactured Sand (M-Sand), produced by crushing hard granite stones to particles smaller than 4.75 mm, served as a fine aggregate. Crushed angular coarse aggregates of 12.5 mm and 20 mm were used as Coarse Aggregates due to their superior interlocking and mechanical properties. To improve tensile strength and control cracking, alkali-resistant (AR) glass fibers (12 mm length, 14 μm diameter) from Cem-FIL ANTI-CRAK HD were added. A naphthalene-based superplasticizer (Conplast SP-430) was used at 0.4% of total

binder weight to enhance workability without compromising strength.

Sodium hydroxide solution of 10 molarity concentration was prepared by dissolving sodium hydroxide flakes in the water. The alkali solution was prepared by mixing both sodium silicate solution and sodium hydroxide solution together at least one day prior to use, so that effective reaction of alkaline solution to takes place. (10M- 10 Molarity, 10M = 10 moles of NaOH pellets in water and dilute it to 1liter total volume). The alkaline solution used to activate the geopolymer reaction consisted of a 10 molarity sodium hydroxide (NaOH) solution and a commercially available sodium silicate (Na_2SiO_3) gel, mixed together at least 24 hours before use.

III. STEP BY STEP PROCEDURE

- Material Selection
- Mix design and proportioning
- Preparing/ casting specimens
- Flexural test
- Results

MIX DESIGN AND MIX PROPORTIONING

Materials required for one Beam are as follows:

Mix	M1	M2	M3	M4
Cement	25.08	25.08	-	-
Flyash	-	-	12.8	12.8
GGBS	-	-	19.2	19.2
Fine aggregates	47.66	47.66	36.17	36.17
Coarse aggregates	82.28	82.28	87.06	87.06
Glass Fiber	-	0.03	-	0.03
HPC-W/B	0.36	0.36	-	-
GPC-A/B	-	-	0.4	0.4
NaOH Solution	-	-	3.01	3.01
Na_2SiO_3 Solution	-	-	7.53	7.53

To start with, weighed quantity of sodium hydroxide (NaOH) in flakes form to suit 10 Molarity (10M) is dissolved in distilled water and mixed thoroughly with a glass rod, until the solution was cooled. The solution thus prepared was kept for 24 hours. This waiting time allows the polymerization process among the alkaline solution mixed. The mix of sodium hydroxide and sodium silicate was added to the dry mix of Flyash, GGBS, Glass fibres, fine aggregate and coarse aggregate in a metallic tray. The Mix proportion of Binders: Fine aggregate: Coarse aggregate are 1: 1.13: 2.7 was used in the present study. Water was added to the dry mix slowly as per the calculated quantity. The dry mix was thoroughly mixed for 5 minutes. Measured quantity of super plasticizer also added to the mixture for the considerable workability. The Glass fibres were used in the dosage of 0.03% of the mass of Concrete. It is sprinkled uniformly throughout the concrete for uniform mix. The fresh concrete was casted into moulds immediately after mixing. The fresh concrete was casted into 150 x 150 x 150 mm cubes and 500 x 100 x 100 mm prisms, cured and tested to find the Compressive strength and Flexural Strength. After casting, all the specimens were kept at room temperature for ambient curing and after demoulding the specimens on the next day, they were kept at ambient temperature, till the date of testing. The casted prisms and cubes, after ambient curing, were tested at 3 days, 7 days and 28 days in the flexural testing machine for its compressive and flexural strength.

IV. EXPERIMENTAL PROGRAM

The experimental investigation was conducted using a bending testing machine with a known capacity of approximately 30 tons (300 kN). To ensure controlled and accurate loading, a maximum applied load of 25 tons (245 kN) was considered safe and within the system's operational range. The beams were tested on a loading frame with an overall capacity of approximately 500 kN, while the load was applied incrementally using a 200 kN capacity hydraulic jack. Following this, load increments of 2.5 kN were applied gradually using the hydraulic jack.



Fig.1 Test setup

V. TESTS AND RESULTS

We investigated the Compressive Strength, Flexural Strength and Static bending test of concrete mixes. The results involve testing standard cubes and prisms to assess the mechanical properties of the concrete matrices.

RESULTS OF COMPRESSIVE STRENGTH

Compressive strength assessments for each mix were conducted on standard cube specimens (150×150×150 mm) after 3, 7 and 28 days of curing periods.

Table.1: Summary of 3, 7 and 28 days Compressive Strength of Test Specimens

Propertie s	Age (Day s)	M-40 (N/m m ²)	M-40+ GF (N/m m ²)	GPC+1 0M (N/mm ²)	GPC+10+ GF (N/mm ²)
Compress ive strength	3	19.42	20.24	20.04	21.28
	7	31.56	33.15	32.37	34.08
	28	48.56	49.25	49.12	50.79

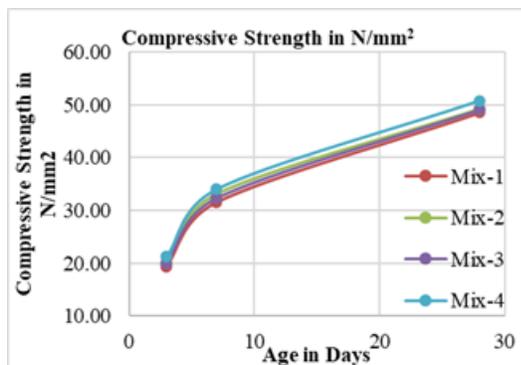


Fig.2 Comparison of Compressive Strength with Age of different concrete matrices

The experimental compressive strength values obtained for different concrete mixes at 3, 7 and 28 days are given in Fig 2. The compressive strength of M-40, M-40+GF, GPC-10M, GPC-10M+GF, is 48.56 N/mm², 49.25 N/mm², 49.12 N/mm², 50.79 N/mm², respectively at 28 days of testing which is more than the prescribed strength as per Indian standards IS456-2000. The test results for Mix 1 to Mix 4 are 0.64%, 2.03%, 1.77%, 5.00%, respectively which are higher than the target strength (48.25 N/mm²) at 28 days.

1. RESULTS OF Flexural STRENGTH

Flexural strength assessments for each mix were conducted on standard prisms specimens (500×100×100 mm) after 3, 7 and 28 days of curing periods.

Table.2: Summary of 3, 7 and 28 days Flexural Strength of Test Specimens

Propertie s	Age (Day s)	M-40 (N/m m ²)	M-40+ GF (N/m m ²)	GPC+1 0M (N/mm ²)	GPC+10M +GF (N/mm ²)
Flexural Strength	3	2.00	2.15	2.11	2.28
	7	3.25	3.39	3.36	3.66
	28	5.01	5.23	5.16	5.45

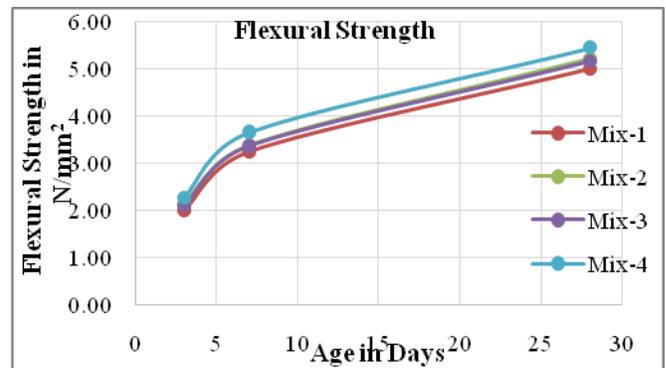


Fig.3 Comparison of Flexural Strength with Age of different concrete matrices

The flexural strength for required characteristic strength at 28 days is 4.86 N/mm². From the Table 2 the flexural strength of M-40, M-40+GF, GPC-10M, GPC-10M+GF, test specimens is 5.01 N/mm², 5.23 N/mm², 5.16 N/mm², 5.45 N/mm² respectively at 28 days of testing. It is observed that from experimental results, flexural strength for Mix 2, Mix 3, Mix 4 has achieved 4.20%, 2.90%, and 8.07% of Mix 1 (control mix) respectively.

RESULTS OF FLEXURAL BEHAVIOUR OF BEAMS

The experimental program consists of testing four beam specimens under flexural loading. The parametric studies are carried out were,

1. Load Deflection Behavior

For the test beam specimens evaluated in this investigation, both the first crack load and the ultimate load were determined, providing insight into the cracking behaviour and load carrying capacity of each mixture. In this

study, all test beam specimens were instrumented to capture their load-deflection response, and the aggregated curves for the various concrete mixtures are presented graphically. These graphs illustrate both individual and comparative performance across different concrete compositions.

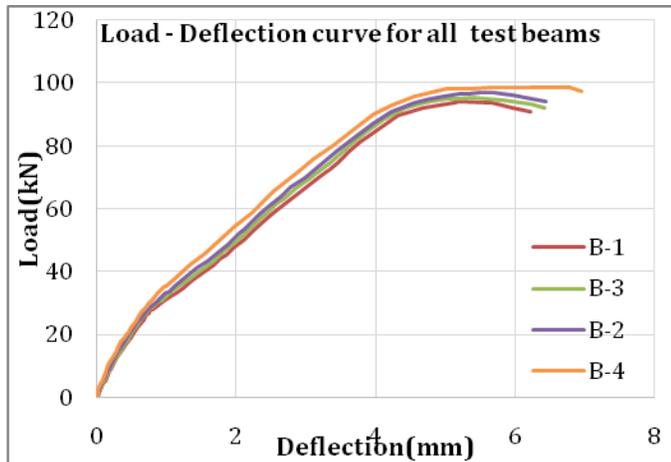


Fig. 4: Load - Deflection Curve upto Ultimate Load

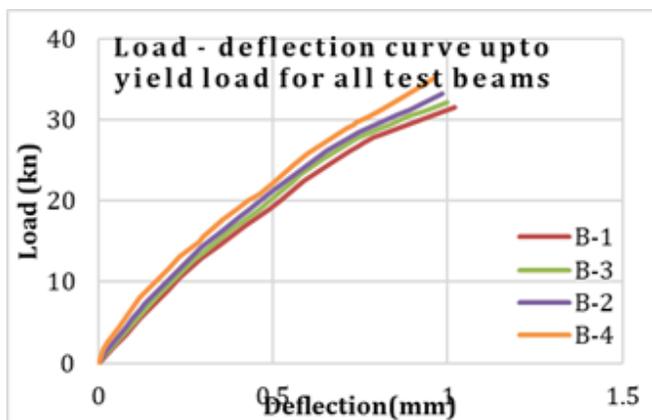


Fig. 5: Load - Deflection Curve upto First crack

2. First Crack load

This is the load at which the first visible crack appears on the surface of beam due to development of tensile stresses. The first crack loads of the mixes in the present analytical study (i) B-1 (ii) B-2 (iii) B-3 (iv) B-4 are 31.6 kN, 33.2 kN, 32.57 kN, 35.23 kN, respectively. It is observed that from analytical results, first crack load for other beams as achieved up to 4.81 %, 2.97%, 10.3%, with respect to control beam B-1.

Table.3: Experimental & Theoretical Values of First Crack loads

Designations	Beam Description	Experimental first crack load in kN (E)	Theoretical first crack load in kN (T)	Ratio (E/T)
B-1	M-40	31.6	29.9	1.06
B-2	M-40+ GF	33.2	31.09	1.07
B-3	GPC+10M	32.2	30.2	1.07
B-4	GPC+10M+ GF	35.02	31.7	1.10

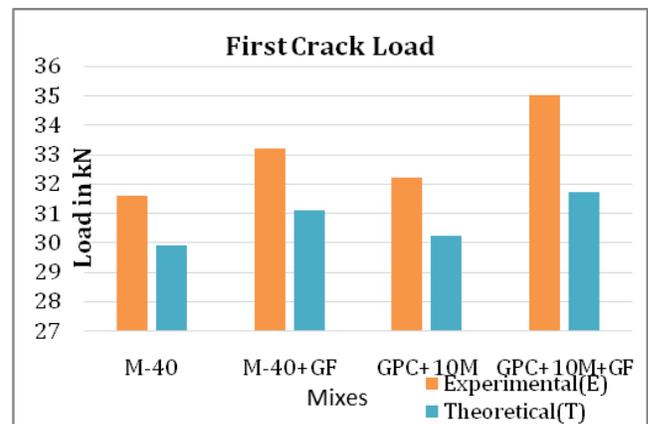


Fig.6: Experimental & Theoretical Values of First Crack loads

3. Ultimate Load

It represents the maximum load a member can sustain before experiencing structural failure. The ultimate loads of the mixes in the present analytical study (i) B-1 (ii) B-2 (iii) B-3 (iv) B-4 are 94.22 kN, 97.23 kN, 95.41 kN, 98.36 kN, respectively. It is observed that from analytical results, ultimate load for other beams are achieved up to 3.09%, 1.24%, 4.2%, with respect to control beam B-1.

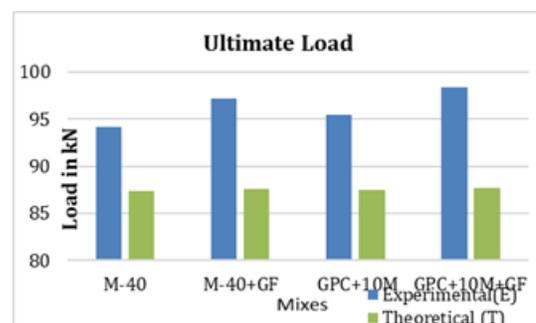


Fig.7: Experimental & Theoretical Values of Ultimate Loads

Table.4: Experimental & Theoretical Values of Ultimate loads

Designations	Beam Description	Experimental Ultimate load in kN (P _e)	Theoretical Ultimate load in kN (T)	Ratio (P _e /T)
B-1	M-40	94.22	87.42	1.08
B-2	M-40+ GF	97.23	87.59	1.11
B-3	GPC+10M	95.41	87.505	1.09
B-4	GPC+10M+ GF	98.36	87.74	1.12

4. Ductility Index

The ductility index of a beam is a measure of its ability to undergo significant plastic deformation before failure. From the experimental results it can be seen that Ductility index is achieved with respect to B-1 by 12.06%, 6.76%, 27.86% for B-2, B-3, B-4, beam specimens respectively.

Table.5: Ductility Value

Designations	Beam Description	Ultimate Deflection (mm)	Yield Deflection (mm)	Ductility Index
B-1	M-40	5.2	1.02	5.10
B-2	M-40+ GF	5.7	0.983	5.80
B-3	GPC+10M	5.4	0.988	5.47
B-4	GPC+10M+ GF	6.8	0.962	7.07

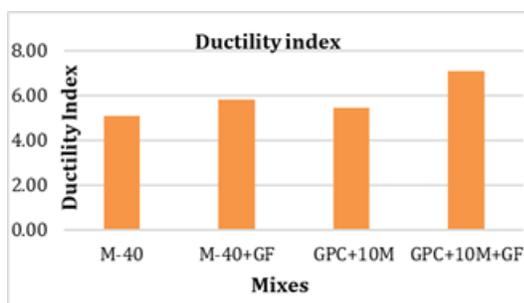


Fig.8: Ductility Index

5. Energy Absorption Capacity

The specimen's load versus deflection curve may be used to determine the material's energy absorption capability. The experimentally obtained values of Energy absorption capacity B-1, B-2, B-3, B-4, concrete test beam specimens are 396.67 kN-mm, 435.18 kN-mm, 424.189 kN-mm, 500.056 kN-mm, respectively. It is observed that from experimental results, energy absorption capacity for B-2, B-3, B-4 has been achieved up to 8.84%, 6.4% , 20.67%, respectively with respect to beam B-1.

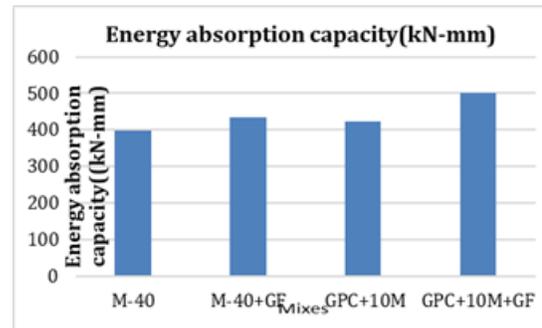


Fig.9: Energy Absorption capacity

Table.6: Energy Absorption capacity

Test Beam Specimen	Designations	Beam Description	Energy Absorption Capacity (kN-mm)
Beam-1	B-1	M-40	396.6733
Beam-2	B-2	M-40+ GF	435.18
Beam-3	B-3	GPC+10M	424.189
Beam-4	B-4	GPC+10M+GF	500.056

6. Toughness Index

The Toughness Index is a quantitative measure of a material's ability to absorb energy during deformation particularly post-cracking behavior in concrete or other brittle materials. It is typically evaluated from the area under the load-deflection curve obtained from a flexural test. From the results it can be seen that toughness is achieved with respect to B-1 by 2.21%, 5.82%, 16.81%, for B-2, B-3, B-4, test beam specimens respectively.

Table 4.5: Toughness Index

Designations	Beam Description	Area under curve upto 0.8 Pu (kN-mm)	Area under curve upto first crack load (kN-mm)	Toughness Index
B-1	M-40	396.6733	19.026	20.849
B-2	M-40+ GF	435.18	19.344	22.497
B-3	GPC+10M	424.189	19.16	22.139
B-4	GPC+10M+GF	500.056	19.95	25.065

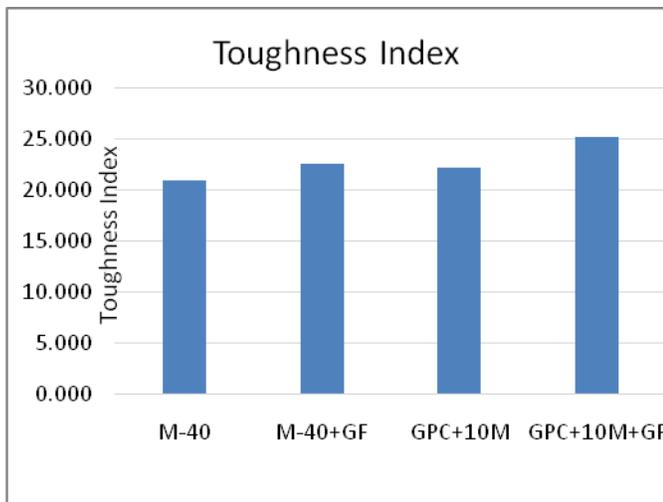


Fig.10: Toughness Index

V. CONCLUSION

The following conclusions may be derived based on this experimental investigation into the flexural strength of fibre reinforced geopolymer concrete beams:

- The basic property of flexural strength of fiber reinforced concrete are studied.
- Addition of Glass fibers in concrete reduce the formation of internal micro cracks.
- The results showed that, as compared to CC beam's, the GPC beam's load bearing capacity has significantly improved.

- Workability of the geopolymer concrete decreases with increases in the fibre content irrespective of fibre utilized.
- From the experimental test results it is observed that the CC and GPC beams, when modified with Glass fiber behaved much better with regards to first crack load and ultimate load which enhanced the flexural behavior characteristics.

REFERENCES

- [1] **Ratna Srinivas, M., Himath Kumar, Y., & Sarath Chandra Kumar, B.** (2019). Studies on Flexural Behavior of Geopolymer Concrete Beams with GGBS. *International Journal of Recent Technology and Engineering (IJRTE)*, 7(6C2).
- [2] **Srinivasan, S., Karthik, A., & Nagan, S.** (2014). An Investigation on Flexural Behaviour of Glass Fibre Reinforced Geopolymer Concrete Beams. *International Journal of Engineering Research Technology*. <https://www.researchgate.net/publication/304656646>
- [3] **S. A. Bhalchandra and A. Y. Bhosle** "Properties of Glass Fibre Reinforced Geopolymer Concrete", *International Journal of Modern Engineering Research (IJMER)* Vol. 3, Issue.4, Jul-Aug.2013, <https://doi=b7df9f3bfee67a4a39931a4b4856c790318e7d00>.
- [4] **Uday Kumar, P., & Sarath Chandra Kumar, B.** (2016). Flexural Behaviour of Reinforced Geopolymer Concrete Beams with GGBS and Metakaoline. *International Journal of Civil Engineering and Technology*, 7(6), 260–277.
- [5] **Srinivas, S. V., Srinidhi, S. V., & Ramana Rao, N. V.** (2020). A Review on Flexural Behavior of RCC Beams Made with Geopolymer Concrete. *E3S Web of Conferences*, 184, 01096. <https://doi.org/10.1051/e3sconf/202018401096>