Flexural Behaviour of Geopolymer Concrete Slabs

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Abstract- *This study investigates the flexural performance of M40 grade geopolymer concrete (GPC) slabs reinforced with glass fibres (GF). Four slab specimens of size 600 mm × 600 mm × 50 mm were cast and tested under static loading. The mix variations included: (S1) conventional M40 concrete, (S2) M40 + GF, (S3) GPC M40 with 10 Molarity (10M) and (S4) GPC + GF - 10M,.Mechanical properties such as compressive strength, flexural strength, and flexural behaviour were evaluated. Among all specimens, the hybrid fibre-reinforced GPC slab (S4) demonstrated the best performance. It showed the highest first crack load, ultimate deflection, and enhanced post-peak behaviour under flexural loading. The static test results for specimen S4 revealed an ultimate load-carrying capacity of 36.27 kN, a ductility index of 10.29, and a toughness index of 29.26. These results indicate that the integration of glass fibres significantly improves the load-bearing capacity and ductility of GPC slabs, making them a viable alternative to conventional concrete in structural applications*

Keywords- Fibers, Ductility Index , Compressive strength, Flexural strength.

I. INTRODUCTION

Concrete remains the most extensively used material in the construction industry. Conventionally, Ordinary Portland Cement (OPC) acts as the binding agent in concrete. However, producing OPC involves a highly energy-demanding process and is a major contributor to carbon dioxide emissions. For every ton of cement produced, nearly 2.8 tons of raw materials—including fuel—are consumed, leading to significant depletion of natural resources. Furthermore, the chemical breakdown of limestone (calcination) during production emits roughly one ton of CO_2 per ton of cement. These environmental challenges have prompted researchers and engineers to seek more eco-friendly alternatives. As a result, considerable attention is now being directed toward the development of sustainable cementitious materials to replace or reduce the use of traditional OPC in concrete.{1}This study examines the influence of mineral admixtures in ternary cement concrete using water-to-binder ratios of 0.30, 0.40, and 0.45. OPC was replaced with fly ash (20–50%) and silica fume (7% or 10%) in both binary and ternary blends. Comparable 28-day strength can be achieved with lower w/b ratios and higher replacement levels when early strength is not essential.{2}The study explored the strength performance of geopolymer concrete (GPC) using various proportions of fly ash (FA) and ground granulated blast furnace slag (GGBS): 100% FA, 75% FA–25% GGBS, and 50% FA–50% GGBS. Results showed that GGBS significantly improved mechanical properties, allowing GPC to gain strength under ambient curing—unlike FA-only mixes that typically need heat curing. Strength tests included compressive, split tensile, and flexural strength. The mix used 10M sodium hydroxide with a Na_2SiO_3:NaOH ratio of 2.5. Aggregates (20 mm max size) made up 77% of the total mix. The 100% FA mix remained cost-effective while providing acceptable strength.{3} A study on the flexural behavior of geopolymer concrete beams incorporating Ground Granulated Blast Furnace Slag (GGBS) reviewed existing research on bending performance and cracking characteristics. The focus was on how GGBS, used as a partial substitute for cement, influences flexural strength, crack development, and deflection at failure. Key parameters such as the type and concentration of alkaline activators, curing methods, and reinforcement ratios were also examined for their role in flexural response. Based on insights from previous studies, Srinivas et al. tailored their experimental work to assess the specific impact of varying GGBS content on slab performance. {4} The study focused on the punching shear behavior of two-way reinforced concrete (RC) slabs containing multiple openings. Using experimental tests, analytical modeling, and numerical simulations, the researchers examined how openings influence the load-bearing capacity and failure mechanisms of RC slabs. Physical testing provided real-world insights, while analytical and simulation tools helped predict and validate performance trends. The objective was to assess structural integrity and identify critical parameters affecting punching failure. Findings from this study are valuable for improving the design and safety of RC slabs in practical applications where openings are required for utilities or architectural purposes.

III.EXPERIMENTAL INVESTIGATION

The bending test is primarily conducted to evaluate a material's ductility, bending strength, fracture resistance, and overall behavior under flexural loading. It helps determine whether a material can withstand bending forces without failing, which is crucial in structures using ductile materials. In concrete, strength after hardening is a key factor influencing structural behavior and design. Among all properties, strength is often regarded as the most critical, as it provides a reliable indication of concrete quality. This strength is closely linked to the internal structure of the hardened cement paste within the concrete.

IV. MATERIALS AND MIXES

Geopolymer concrete (GPC) is produced by activating aluminosilicate-rich industrial by-products using alkaline solutions. The primary binders used are Fly ash (FA), especially Class F, and Ground Granulated Blast Furnace Slag (GGBS), both known for their high silica (SiO_2) and alumina (Al_2O_3) content. The alkaline activator typically consists of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) with fluid binder ratio is taken as 0.4. Aggregates (fine and coarse) are used similarly to conventional concrete, often constituting about 75–80% of the total mix, while 10M molarity of NaOH solution is used while mixing, it helps to significantly influences strength.

Table -1 : Mix Designation

Mixes	Designation
MIX 1	M-40
MIX 2	M-40+GF
MIX 5	GPC-10M
MIX 6	GPC-10M+GF

V. TESTING PROCEDURE

5.1 Experimental Set up - Static Testing Machine

Static load tests were conducted on slab specimens. The testing setup was designed and installed at the Department of Civil Engineering, Bangalore University, Bengaluru. A manually operated hydraulic jack system, securely anchored to a reinforced concrete (RCC) pedestal foundation, was used for load application. The pedestal extended 1 metre above ground level, including a 0.3-metre-high base. A loading frame, fabricated using an ISMB 250 section, was mounted vertically to a height of 2.5 metres. Another ISMB 250 section was placed horizontally to support the loading mechanism. The test slabs were positioned on a 600 × 600 mm square support frame made of ISHB 160 sections, fixed to the pedestal. During testing, fixed edge boundary conditions were maintained. To measure the deflections LVDT was placed at the center of the specimen, The data acquisition system is used to acquire the specimen's response.

VI. RESULTS AND DISCUSSIONS

6.1 Compressive strength

Compressive strength tests were performed on standard cube specimens of size 150 × 150 × 150 mm for all mix variations. The specimens were tested after curing periods of 3, 7, and 28 days to evaluate the strength development over time. The compressive strength values obtained for each mix at these intervals are summarized in the table below.

Table -2 : Summary of 3, 7 and 28 days Compressive Strength of Test Specimens

Mixes	Compressive Strength in N/mm^2		
	3 days	7 days	28 days
MIX 1	19.42	31.56	48.56
MIX 2	20.24	33.15	49.25
MIX 3	20.04	32.37	49.12
MIX 4	21.28	34.08	50.79

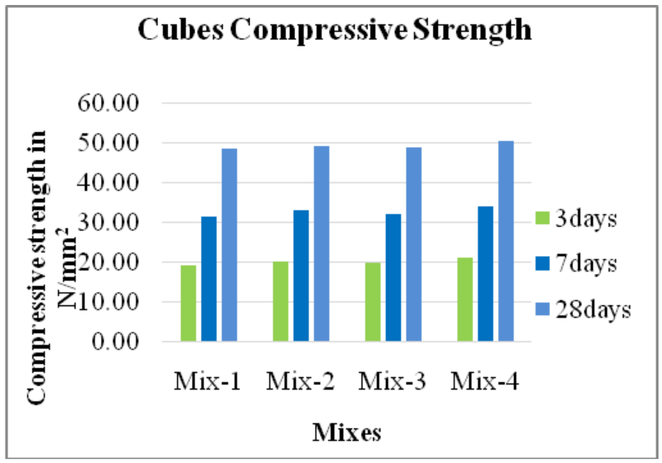

Chart -1: Comparison of Compressive Strength with Age of different concrete matrice

The test results for Mix 1 to Mix 4 are 0.64%, 2.07%, , 3.64% & 5.26% respectively which are higher than the target strength at 28 days.

6.2 FLEXURAL STRENGTH

Flexural strength tests were conducted on beam specimens with dimensions of 100 × 100 × 500 mm. During testing, the maximum load at failure was recorded for each specimen. Using this data, the flexural strength was calculated in accordance with standard procedures. The flexural strength values obtained for all concrete mixes are summarized in the table below.

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

Mixes	Flexural Strength in N/mm^2		
	3 days	7 days	28 days
MIX 1	2.0	3.25	5.01
MIX 2	2.15	3.39	5.23
MIX 3	2.11	3.36	5.16
MIX 4	2.28	3.66	5.45

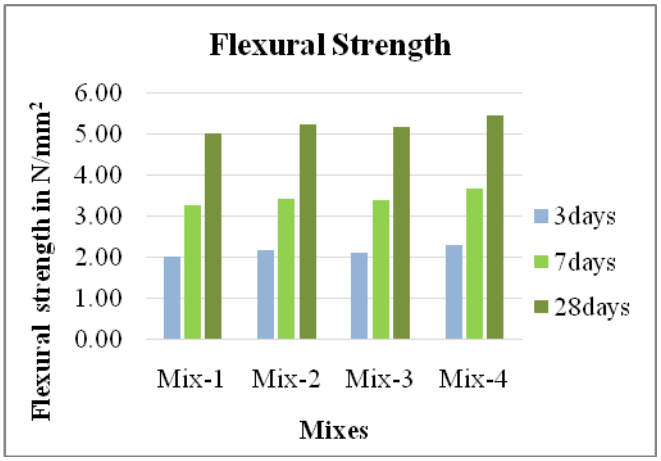

Chart -2: Comparison of Flexural Strength with Age of different concrete matrices

6.3.Results of load deflection curve (P-δ curve)

Load–deflection curves provide critical insight into the structural response of slab specimens under applied loads. They are particularly useful for evaluating behavior within the service load range and identifying the working load limit. For all slab specimens tested in this study, the corresponding load–deflection curves have been plotted and presented in the form of graphs.

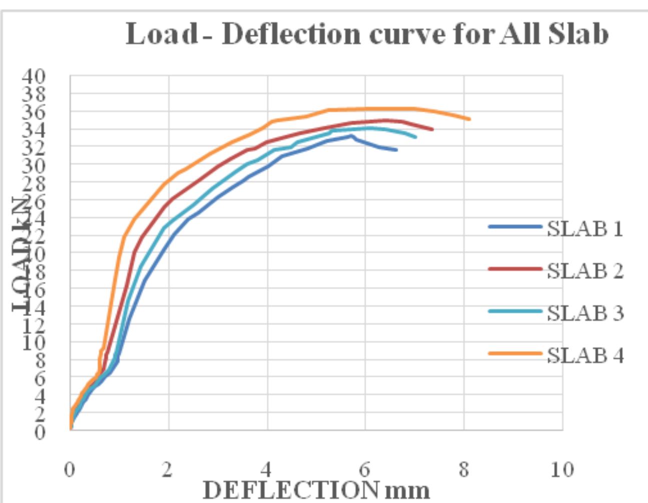

Chart-3: Load - Deflection curve upto Ultimate Load

6.4.First crack load

This is the load at which the first visible crack appears on the surface of the slab dus to the development of tensile stresses.

Table -4: Experimental and Theoretical values of First Crack Loads

Designations	**Theoretical first crack load (kN) - T**	**Experimental first crack load (kN) - E**
MIX 1	8.220	8.62
MIX 2	8.279	8.83
MIX 3	8.268	8.79
MIX 4	8.410	9.26

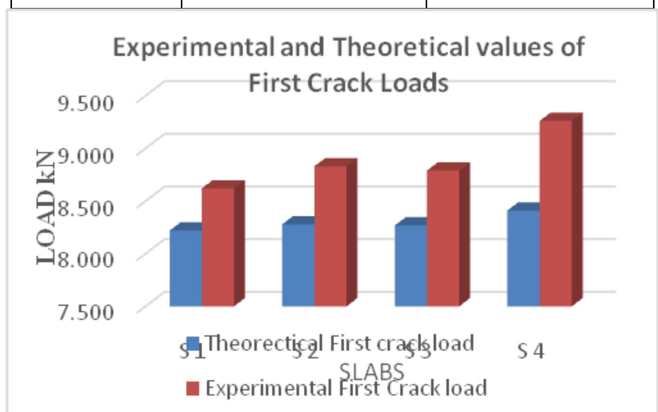

Chart-4: Comparison of Experimental and Theoretical values of First Crack Loads

6.5.Punching Shear

The phrase "ultimate strength" refers, when applied a structural member, to both the resistance that corresponds to the stage at which actual material rupture begins to occur and the maximum resistance that the member can develop due to internal stresses against external forces.

Table -5: Experimental and Theoretical values of Ultimate Load.

Designations	**Theoretical first crack load (kN) - T**	**Experimental first crack load (kN) - E**
MIX 1	24.843	33.25
MIX 2	25.019	35.02
MIX 3	24.986	34.15
MIX 4	25.407	36.27

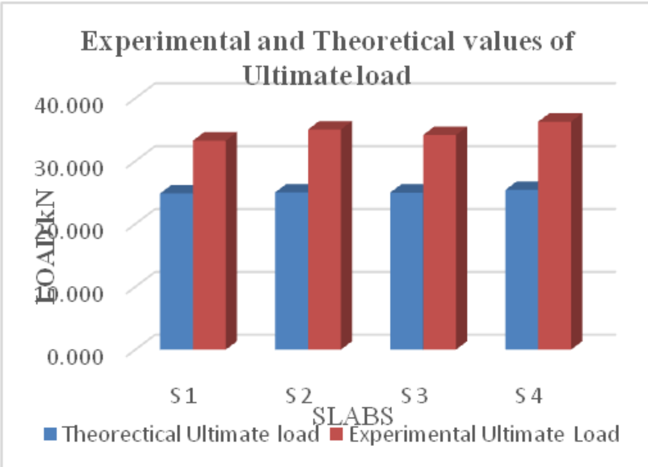

Chart-5: Experimental and Theoretical values of Ultimate load

6.6.Ductility Index

Deflection at yield and ultimate loads are noted down through LVDTs and the same are tabulated below

Table -6: Ductility Index

Designations	Ultimate Deflection (mm)	Yield Deflection (mm)	Ductility Index
MIX 1	5.7	0.980	5.82
MIX 2	6.4	0.750	8.53
MIX 3	6.1	0.926	6.59
MIX 4	7	0.680	10.29

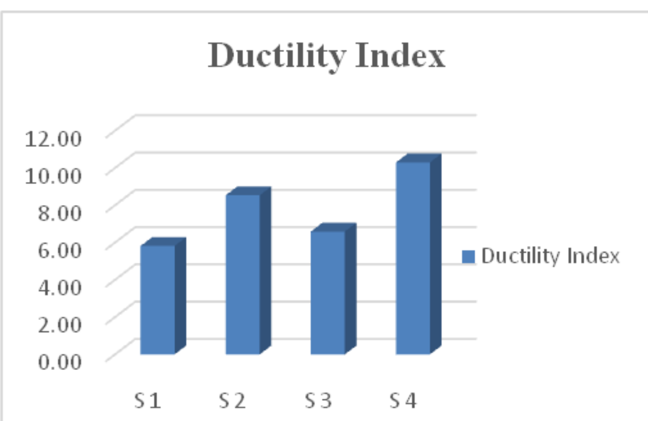

Chart -6. Ductility Index

6.7.Energy Absorption Capacity

The specimen's load versus deflection curve may be used to determine the material's energy absorption capability. The energy absorption capacity of various concrete mix slabs under examination was calculated by calculating the area under the load deflection curve.

Table -7 : Energy Absorption Capacity

Designations	Energy Absorption Capacity (kN-mm)
MIX 1	156.33
MIX 2	201.56
MIX 3	178.73
MIX 4	242.88

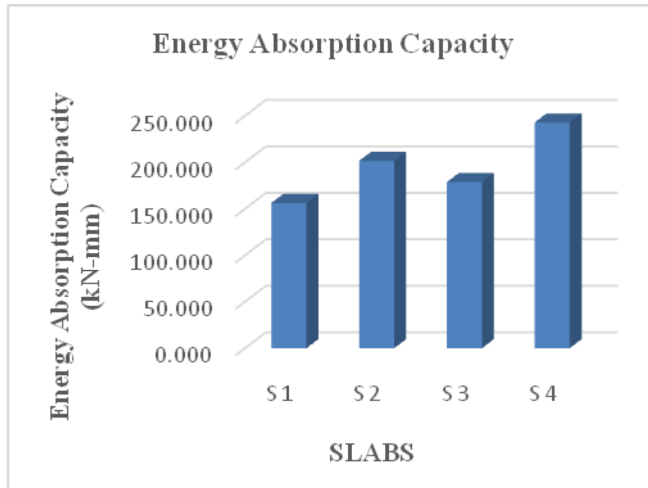

Chart -7. Energy Absorption Capacity

6.8.Toughness Index

Table -8: Toughness Index

Designations	Area under curve upto 0.8 Pu (kN-mm)	Area under curve upto first crackload (kN-mm)	Toughness Index
MIX 1	156.33	5.80	26.95
MIX 2	201.56	7.12	28.31
MIX 3	178.73	6.40	27.93
MIX 4	242.88	8.30	29.26

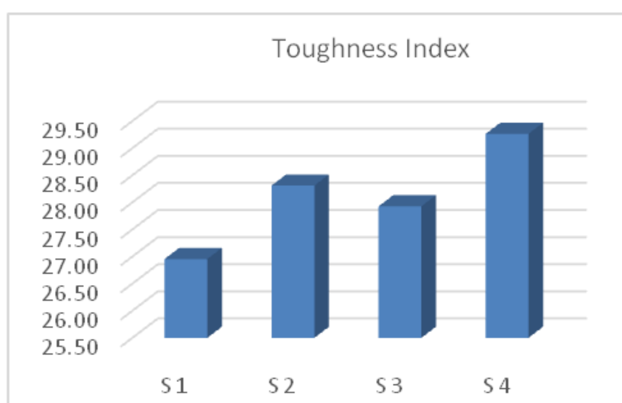

Chart -8. Toughness Index

VII. CONCLUSION

- The compressive strength of 28 days is highest for GPC-10M+GF (Mix 4) in comparison with other concrete matrices used in this investigation i.e. 5.26% than that of 28 days strength,
- The flexural strength of 28 days is highest for GPC-10M+GF test specimen in comparison with M40 used in this investigation i.e. 8.07%.
- It is observed that from experimental results, first crack load for other slabs as achieved up 4.64%, 6.24%, 5.94% & 9.18%, with respect to theoretical values of First Crack Loads..
- It is observed that from experimental results, ultimate load for other slabs are achieved up to 25.29%, 28.56%, 26.84% & 29.95% with respect to theoretical values of Ultimate Loads..
- Ductility is achieved with respect to S-1 by 31.7%, 11.68% & 43.44% for S-2, S-3, & S-4 test slab specimens respectively
- It is observed from that from Experimental results, energy absorption capacity for S-2, S-3 & S-4 has been achieved up to 22.43%, 12.53% & 35.63% respectively with respect to S-1.
- Toughness is achieved with respect to S-1 by 4.80%, 3.5%, 7.8%, for S-2, S-3 & S-4 test slab specimens respectively.
- The percentage change of analytical to experimental ultimate punching shear for S-1, S-2, S- 3 & S-4 is to 25.29%, 28.56%, 26.84%, 29.95% respectively.

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