International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 01 | Jan 2026 www.irjet.net p-ISSN: 2395-0072

Experimental Study on flexural behavior of HYSD and GFRP Reinforced Concrete Beams

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Abstract - *This study presents an experimental investigation on the flexural behaviour of M30 grade reinforced concrete beams reinforced with HYSD steel, GFRP, and hybrid reinforcement configurations. Four beams with identical geometry were tested under two-point loading to examine load–deflection response, cracking behaviour, stiffness characteristics, and failure mechanisms. The results showed that HYSD-reinforced beams exhibited higher stiffness, lower deflections, and improved crack control, indicating superior serviceability performance. GFRP-reinforced beams demonstrated higher deformability with wider crack openings due to the lower modulus of elasticity of GFRP bars. Hybrid beams exhibited intermediate behaviour, where beams with HYSD as main reinforcement behaved closer to steel-reinforced beams, while beams with GFRP as main reinforcement showed enhanced deformation capacity. The study highlights the significant influence of reinforcement type and configuration on the flexural performance of reinforced concrete beams.*

Key Words: **Glass Fiber Reinforced Polymer (GFRP), High Yield Strength Deformed (HYSD), Cracking Behaviour, Monotonic Loading, Stiffness Degradation**

1. INTRODUCTION

Concrete beams are typically concrete beams reinforced with HYSD steel to help bear tensile forces. Recently, there seems to be a trend toward using Fiber Reinforced Polymer (FRP) and specifically Glass Fiber Reinforced Polymer (GFRP) as an alternative to steel for providing tensile strength in beams because of its very high strength-to-weight ratio and possible corrosion resistance. Most of the research carried out on concrete beams reinforced with GFRP was based on flexural performance compared to structural performance characteristics with reference to cracking patterns, stiffness, load-deflection response, and failure mode, focusing mainly on the characteristics of the converted effects of conventional beams with those cast using steel reinforcements [7, 6]. Experimental assessments always claimed that beams in GFRP compared to beams in steel deflect more with width cracks due to less modulus of elasticity in GFRP bars [7]. It has also been established that the steel-reinforced beams yield before failure and are ductile in nature under consideration, but the GFRP-reinforced concrete beams typically fail in a brittle manner without committing considerable amounts of plastic deformation [6].

Studies on continuous FRP-reinforced concrete beams revealed that moment redistribution occurs owing to stiffness degradation and nonlinearity of concrete instead of yielding of reinforcement [2]. From the experimental investigation concerning over reinforced GFRP concrete beams, concrete crushing governed the failure, which is known to be a more stable and desirable failure compared to that of sudden bar rupture [5]. On account of investigations into crack characteristics, it was confirmed that crack spacing in GFRP-reinforced beams is generally larger in comparison with that of steel-reinforced ones; such a factor would seriously affect serviceability performance [4]. Experimental investigations posit that increasing the axial stiffness of GFRP reinforcement would definitely improve the flexural strength but at a considerably reduced deflection and crack widths [2]. A comparison of different design codes indicated that while ACI 440.1R and the other available codes underestimate deflections of GFRP-reinforced beams, it is necessary to develop a more appropriate serviceability model [1].

However, it is a fact that huge numbers of research studies identify either steel concrete or GFRP concrete beam behavior. A very small number of studies have been done comparatively under almost similar material particulars while keeping the same geometry and loading conditions for both HYSD steel and GFRP reinforced concrete systems. The gap of direct comparisons does not allow a clear understanding of relative structural performance between these two reinforcement systems. Hence this intended study would fill such a gap by conducting experimental analyses of the flexural behavior of grade M30 reinforced concrete beams. The scope of the study includes such important performance parameters such as load-deflection response, cracking behavior, stiffness characteristics, and failure modes for the comparative assessment of structural performance differences between concrete beams reinforced with steel and GFRP.

2. EXPERIMENTAL PROGRAM

2.1 Test Specimens

Four simply supported concrete beams have been fabricated, and were tested under flexural loading. All beam specimens were made with the same geometric dimensions having a width of 150 mm, an overall depth of 200 mm, and a clear span of 1200 mm. Average clear covering of 25 mm were provided for all reinforcements. The longitudinal reinforcement consisted of 12 mm diameter bars, while transverse reinforcement comprised of 8 mm diameter stirrups placed at a constant spacing of 100 mm center to center full span. 135° inclined stirrups to ensure effective anchoring and total concrete confinement. The beam specimens were classified based on types of reinforcement. Beam Type I was fully reinforced with HYSD bars under both longitudinal and transverse loadings. Beam Type II was also completely reinforced with GFRP bars under both longitudinal and transverse reinforcements. Beam Type III received its main longitudinal reinforcement with HYSD steel bars and its transverse reinforcement with GFRP bars used as stirrups while Beam Type IV was longitudinally reinforced with GFRP bars and used HYSD steel bars as stirrups.

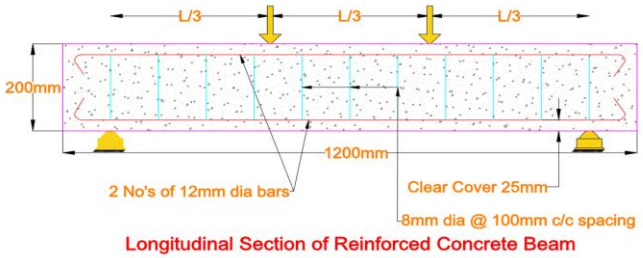

Fig -1: Longitudinal Section of RC Beam

Fig -2: Cross Section of RC Beam

Table -1: Specimen identification and details.

Specimen details and identifications				
Specimen ID	Reinforcement type	Top Reinforcement Bar	Bottom Reinforcement Bar	Stirrups
MH-SH-B1	HYSD	HYSD	HYSD	HYSD
MG-SG-B2	GFRP	GFRP	GFRP	GFRP
MH-SG-B3	Hybrid	HYSD	HYSD	GFRP
MG-SH-B4	Hybrid	GFRP	GFRP	HYSD

2.2 Material Properties and Mix Proportion

The mix-design of experimental concrete was done using Ordinary Portland Cement of 43-grade quality as per IS 12269:2013 [8]. Manufactured Sand (M-sand) was used as fine aggregate and crushed angular coarse aggregate of nominal maximum size of 20 mm was taken. Clean drinking water free of any impurities, salts, and oils, and organic matter was used for mixing and curing. Following the guidelines IS 10262:2019, the concrete was mixed with the intent of achieving M30 design strength. The modulus of elasticity of HYSD steel reinforcement has been taken as 200 GPa according to IS 456:2000. The Fe 500 grade possesses a characteristic tensile strength of 500 MPa. The modulus of elasticity of GFRP reinforcement has been adopted from data based on the provisions with the typical range of 40-60 GPa while the tensile strength values are between 800-1200 MPa as defined in IS 18255:2023. According to IS 10262:2019, the concrete mix for this study is established for M30 grade. The water–cement ratio is 0.43. However, a suitable quantity of super plasticizer was added to improve the workability without causing much variation in strength characteristics

Table -2: Mix proportion details.

Quantities of Material per cubic meter of concrete				
OPC 53 Grade Cement Kg/m³	Water in Liters	Fine Aggregate Kg/m³	Coarse Aggregate Kg/m³	Dosage of Admixture Liters
345	148	832	1114	13.80
1.00	0.43	2.411	3.22	0.04

2.3 Flexure Test Setup and instrumentation

Two simple supports were erected under the test specimens and subjected to an upper loading frame by the flexural load. A 30 T capacity hydraulic actuator bolted to the load got transmitted through the loading setup to the beam, dividing in two equal twin-point loads working symmetrically on the test setup. With this configuration of loading, a constant moment region exists between each loading application.

Mid-span of the specimen was attached to a High precision LVDT to record vertical displacement during loading for deflection measurement. Monitoring the load and deflection is put in place to make sure that the data is continuously registered throughout the testing process. The scheming of flexural test setup can be seen from the figure. An arrangement developed for the instrumentation system can provide reasonable accuracy in measurements of structure responses during tests of flexural loading.

The vertical displacements at mid-span of the beam were recorded with a highly precise LVDT with both of its ends firmly attached to a free reference frame to avoid any ground

effect from support movements. Load was recorded through a load cell. All the measured quantities were logged automatically after certain intervals through a computerized data acquisition system for further analysis.

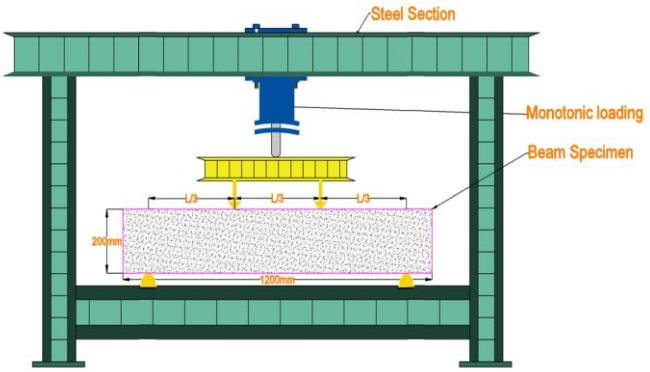

Fig -2: Schematic representation of Flexural test setup for RC Beam

3. RESULTS AND DISCUSSION

3.1 Mechanical properties

The characteristics of the concrete were tested at 28 days where M30 concrete exhibits systematic strength development with curing age in the order of compressive strength, flexural strength, and split tensile strength. Compressive strength shows the highest rate of increase, with gains of 36.14% between 7 and 14 days and a further 40.36% between 14 and 28 days, indicating rapid hydration and effective load-carrying capacity development. Flexural strength follows a similar but relatively moderate trend, increasing by 4.34% from 7 to 14 days and by 29.70% from 14 to 28 days, reflecting gradual improvement in tensile resistance of the concrete matrix. Split tensile strength at room temperature shows comparatively lower but steady enhancement with age, governed mainly by bond development and microstructural refinement. Overall, the room temperature performance establishes a clear hierarchy of strength development, with compressive strength being the most dominant, followed by flexural strength and then split tensile strength, serving as a reliable reference for evaluating thermal exposure effects.

Fig -2: Crack pattern observed in beams

3.2 General Flexural Behaviour of HYSD and GFRP Beams

With regard to the flexural response observed during the experimentation, HYSD beams proved to be better in terms of utmost willingness and serviceability than GFRP-reinforced beams. After first cracking, the deflections at the mid-span of the HYSD beams were significantly lower than those of the GFRP ones, with reductions in the range of around 60-65% when compared to GFRP beams for peak load. It can be understood that such a higher stiffness is actually due to a highly elastic modulus of the reinforcing steel. The different propagation of cracks in the HYSD beams was under control and the widths of cracks were about 50% smaller than those found in GFRP beams, pointing to much better crack distribution and stiffening under tension. On the contrary, GFRP-reinforced beams were more deformable as well as had wider crack openings which showed that they could have kept safe, but their serviceability performance while subjected to flexural loads failed to match that of the HYSD-reinforced beams.

3.3 Flexural Behaviour of Beams with Hybrid reinforcement

Consequently, the flexural behavior of beams with hybrid reinforcement displayed a striking dependence on the arrangement of reinforcement. An observation was made that the beam having HYSD bars as main longitudinal reinforcement and GFRP bars as stirrups underwent delayed first cracking and a relatively stiff post-cracking response, thereby indicating an efficient contribution to flexural resistance by steel in tension. In comparison, the beam with GFRP bars acting as main longitudinal reinforcement and HYSD bars as stirrups had earlier cracking with a post-cracking response that could be classified as more flexible, which was a reflection of the lower modulus of elasticity of GFRP bars .In a comparison, the hybrid beam with HYSD mains showed lesser midspan deflection and stiffness, while the hybrid beam with GFRP mains carried a higher load but exhibited a greater degree of deflection, demonstrating greater deformability. Thus, it could be said that the use of HYSD bars as main reinforcement improves its stiffness properties and crack control, and the use of GFRP bars as main reinforcement increases ductility and deformation capacity; this underlines the importance of the configuration of the reinforcement system for hybrid beam performance.

3.4 Load vs Deflection response

MH:SH-B1 exhibits the highest slope values, indicating maximum initial stiffness and excellent crack control, along with relatively low ultimate deflection that reflects stable and ductile behavior governed by yielding of HYSD reinforcement.MG:SG-B2 shows the minimum slope values, representing lower initial stiffness and earlier crack initiation, while exhibiting very high deflection at failure,

indicating large deformation capacity and pseudo-ductile behavior due to GFRP main reinforcement. MH:SG-B3 demonstrates lower slope values than MH:SH-B1 but still maintains considerable stiffness, confirming effective crack control through the combination of HYSD main bars and GFRP stirrups, with moderate ultimate deflection. MG:SH-B4 represents a hybrid configuration showing moderate slope and ultimate deflection values, achieving a balanced response with reasonable stiffness, controlled cracking, and sufficient deformation capacity, thereby offering an optimal compromise between strength, stiffness, and ductility.

Table -3: Flexural test results of Beams

Specimen ID	Flexure test Results			
	First Crack Load		Ultimate load	
	Load in kN	Deflection in mm	Load in kN	Deflection in mm
MH-SH-B1	38.560	0.444	116.20	2.457
MG-SG-B2	26.22	0.499	106.50	7.80
MH-SG-B3	32.01	0.475	114.50	2.87
MG-SH-B4	30.064	0.480	113.51	7.56

3.5 Failure mechanism and crack pattern

B1 shows the best crack control among all specimens, characterized by closely spaced and fine flexural cracks that develop gradually with load. The presence of HYSD reinforcement ensures high initial stiffness, delayed crack initiation, and a stable ductile failure governed by yielding of steel followed by concrete crushing in the compression zone.

B2 (MG:SG-B2) performs inferior to B1 in terms of crack control. Cracks initiate at lower load levels and are fewer but significantly wider, indicating lower stiffness and reduced tensile restraint. Failure occurs through extensive flexural cracking accompanied by large deflections, demonstrating pseudo-ductile behavior due to the absence of yielding in GFRP main reinforcement.

B3 (MH:SG-B3) performs better than B2 but remains slightly inferior to B1. Cracks are moderately spaced with controlled widths, reflecting improved stiffness due to HYSD main bars. Failure is flexure-dominated with gradual crack propagation, showing a stable response and better crack distribution compared to GFRP-only reinforcement.

B4 (MG:SH-B4) exhibits a balanced crack pattern between B1 and B2. Crack widths and spacing are moderate, indicating reasonable stiffness and effective stress redistribution. Failure occurs in a controlled flexural manner with significant deformation capacity, making B4 structurally more efficient than B2 while still not matching the crack control achieved by B1.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

B1 considered as a reference ultimate deflection, showing the most controlled and ductile structural response. B3 (MH:SG-B3) develops 84.75% load capacity and 85.20% stiffness relative to B1, while its ultimate deflection reaches 121.40% of B1, indicating slightly reduced stiffness but stable post-cracking behavior with good deformation capacity.

B4 (MG:SH-B4) achieves 74.60% load capacity and 75.10% stiffness compared to B1, with an ultimate deflection of 139.85% of B1, reflecting a balanced compromise between strength reduction and enhanced deformability.

B2 (MG:SG-B2) shows the lowest structural resistance with 59.30% load capacity and 54.80% stiffness of B1, but exhibits the highest ultimate deflection at 171.60% of B1, confirming reduced stiffness and pronounced pseudo-ductile behavior.

4.2 Recommendations

Considering the overall structural performance of all four beam specimens (B1–B4), the following comparative recommendations are drawn. B1 (MH:SH-B1) demonstrates the highest load capacity, maximum stiffness, and superior crack control, making it the most suitable option for primary load-bearing members where serviceability and strength govern design. B3 (MH:SG-B3) performs closest to B1, with only a moderate reduction in stiffness and load capacity while offering improved deformation capacity, and is therefore recommended where durability enhancement is required without significantly compromising structural performance. B4 (MG:SH-B4) provides a balanced response with moderate strength, stiffness, and higher deflection capacity, making it appropriate for applications demanding an optimal compromise between rigidity and ductility. B2 (MG:SG-B2), although exhibiting the lowest stiffness and load resistance, shows the highest deformation capacity and pseudo-ductile behavior, and is recommended only for conditions where large deformation tolerance and corrosion resistance are prioritized over strength and serviceability.

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