Experimental Investigation on Flexural Behaviour of Concrete Beams Reinforced with GFRP Bars

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Abstract

Glass fibre-reinforced polymer (GFRP) bars are increasingly considered as an alternative to conventional steel reinforcement in concrete structures where corrosion resistance and reduced reinforcement weight are important. This study experimentally compares the flexural response of M25-grade concrete beams reinforced with conventional steel bars and GFRP bars. Beam specimens of 150 mm × 150 mm × 1000 mm were cast and cured for 28 days. The fresh concrete was evaluated through slump, compaction factor, flow table and Vee-Bee tests. The beams were subjected to incremental flexural loading, and load-deflection response and calculated flexural stress were recorded up to a maximum recorded load of 40 kN. At 40 kN, the steel-reinforced beam showed a mid-span deflection of 2.495 mm, while the GFRP-reinforced beam showed 2.415 mm, corresponding to approximately 3.21% lower deflection for the tested GFRP specimen. The corresponding calculated flexural stresses were 11.600 N/mm² and 11.585 N/mm², respectively. The results indicate broadly comparable flexural response within the investigated loading range. The findings support the potential use of GFRP reinforcement in corrosion-prone concrete structures, while emphasizing that its lower elastic modulus, non-yielding response, bond behaviour and serviceability requirements must be addressed in design.

Keywords: *GFRP Bars, Reinforced Concrete Beam, Flexural Behaviour, Load-Deflection, Flexural Stress, Corrosion-Resistant Reinforcement.*

I. INTRODUCTION

Reinforced concrete is one of the most widely used construction materials because concrete provides high compressive strength while reinforcement resists tensile stresses. Conventional carbon-steel reinforcement, however, can corrode in chloride-rich, marine and chemically aggressive environments. Corrosion causes expansion of the reinforcement, cracking and spalling of the cover concrete, deterioration of bond and reduction in structural service life. These durability concerns have encouraged the use of non-metallic fibre-reinforced polymer (FRP) reinforcement.

GFRP bars consist of continuous glass fibres embedded in a polymeric matrix. They offer high longitudinal tensile strength, low density, electrical non-conductivity and strong resistance to electrochemical corrosion. Their mechanical response differs substantially from steel: GFRP bars generally have a lower modulus of elasticity and remain approximately linear elastic until rupture without a distinct yield plateau. As a result, deflection, crack width, bond and failure mode often become critical design considerations [1]-[4].

The objective of the present work is to compare the flexural response of a conventional steel-reinforced concrete beam and a GFRP-reinforced concrete beam produced using the same concrete grade, beam dimensions and comparable longitudinal reinforcement arrangement. The comparison focuses on applied load, mid-span deflection and calculated flexural stress.

2. RESEARCH BACKGROUND

Previous studies have established that GFRP reinforcement can provide adequate flexural strength but may exhibit larger service-load deformations than steel reinforcement because of its lower elastic modulus. Benmokrane et al. [5] documented the distinctive flexural response of FRP-reinforced concrete beams, while Toutanji and Deng [6] highlighted the need for modified crack-width and deflection prediction procedures. Ashour [7] showed that the failure mode of GFRP-reinforced beams depends on reinforcement ratio and may shift from FRP rupture to concrete crushing or shear-related failure.

Saikia et al. [8] evaluated strength and serviceability performance and emphasized the importance of cracking, deflection and post-cracking stiffness. Ascione et al. [9] further examined the flexural behaviour of concrete beams reinforced with GFRP bars. Studies on bond have also shown that surface treatment, casting position and concrete properties strongly affect anchorage and stress transfer [10]. Maranan et al. [11] demonstrated satisfactory performance of GFRP-reinforced geopolymer concrete beams and reported that reinforcement ratio and anchorage configuration significantly influence serviceability and capacity.
Collectively, the literature indicates that GFRP can be a viable alternative in corrosion-sensitive applications; however, direct comparison with conventional steel reinforcement remains useful because the two materials differ in stiffness, yielding characteristics and bond response. The present study therefore evaluates the load-deflection and flexural-stress responses of steel- and GFRP-reinforced beams tested under identical laboratory conditions.

3. MATERIALS AND METHODS

3.1 Constituent Materials

M25-grade concrete was prepared using hydraulic cement, manufactured sand (M-sand), 20 mm nominal maximum-size coarse aggregate and potable water. The fine aggregate was classified approximately as Zone II. The adopted water-cement ratio was 0.45. Conventional deformed steel bars and GFRP bars were used as longitudinal reinforcement in the control and GFRP specimens, respectively.

Table 1. Selected Material/Test Properties Used in The Experimental Programme

Property/Test	Result	Remark
Concrete grade	M25	Designed concrete grade
Water-cement ratio	0.45	Adopted value
Slump	21 mm	Low workability
Compaction factor	0.89	Measured
Flow value	56%	Measured
Vee-Bee time	17 s	Low workability
Fine aggregate specific gravity	2.741	M-sand
Coarse aggregate specific gravity	2.92	Measured; relatively high value
Coarse aggregate water absorption	0.638%	Measured

3.2 Beam Specimens and Reinforcement

The comparative beam specimens had nominal dimensions of 150 mm × 150 mm × 1000 mm. The conventional specimen was reinforced with steel bars, while the alternative specimen used GFRP longitudinal reinforcement. The reinforcement arrangement adopted approximately 10 mm top bars and 12 mm bottom bars with 8 mm transverse reinforcement and 15 mm concrete cover. All specimens were cured for 28 days before testing.

3.3 Experimental Procedure

Fresh concrete workability was assessed using slump, compaction factor, flow table and Vee-Bee tests. After curing, the beams were placed in the flexural testing setup and loaded incrementally. At each load stage, mid-span deflection was recorded. Flexural stress values corresponding to the applied loads were calculated for comparison. Because the available dataset extends to 40 kN and does not document a verified complete failure load beyond this value, 40 kN is reported as the maximum recorded load rather than the ultimate capacity.

4. RESULTS AND DISCUSSION

4.1 Load-Deflection Response

The deflection of both beams increased progressively with applied load. At 40 kN, the steel-reinforced beam recorded 2.495 mm deflection, whereas the GFRP-reinforced beam recorded 2.415 mm. For the tested specimens, the GFRP beam therefore showed approximately 3.21% lower deflection at this load. This result should not be generalized to all GFRP-reinforced beams, because GFRP normally has a lower elastic modulus than steel and may exhibit greater service-load deformation depending on reinforcement ratio, bond, geometry and material properties.

Table 2. Load-Deflection Results for Steel- And GFRP-Reinforced Beams

Load (kN)	Steel Beam Deflection (mm)	GFRP Beam Deflection (mm)
5	0.130	0.125
10	0.445	0.385
15	0.622	0.425
20	0.870	0.825
25	1.160	1.135
30	1.515	1.295
35	2.005	1.930
40	2.495	2.415

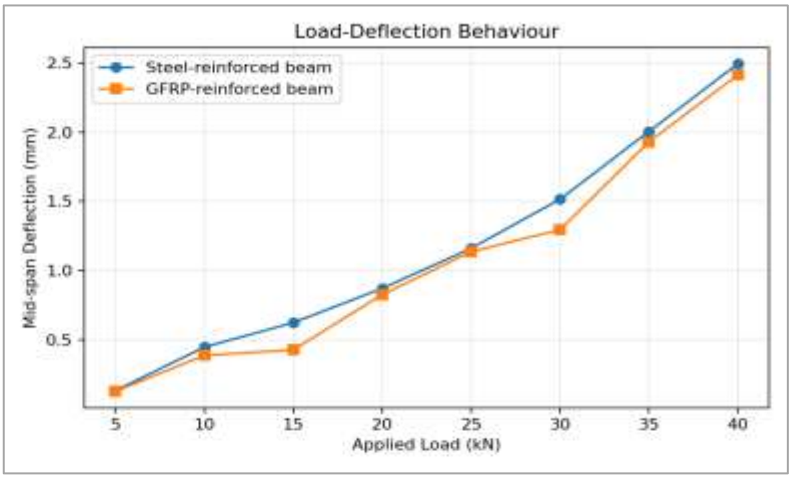

Figure 1. Comparison of Load-Deflection Behaviour of Steel- and GFRP-Reinforced Beams

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4.2 Load-Flexural Stress Response

The calculated flexural stress increased nearly proportionally with the applied load for both specimens. At 40 kN, the calculated stresses were 11.600 N/mm² for the steel-reinforced beam and 11.585 N/mm² for the GFRP-reinforced beam. The difference is negligible. Since flexural stress at intermediate load stages is not equivalent to failure strength, these values are reported as calculated flexural stresses rather than flexural strengths

Table 3. Applied Load and Calculated Flexural Stress

Load (kN)	Steel Beam Stress (N/mm²)	GFRP Beam Stress (N/mm²)
5	1.450	1.450
10	2.900	2.910
15	4.350	4.360
20	5.800	5.789
25	7.250	7.270
30	8.700	8.690
35	10.150	10.025
40	11.600	11.585

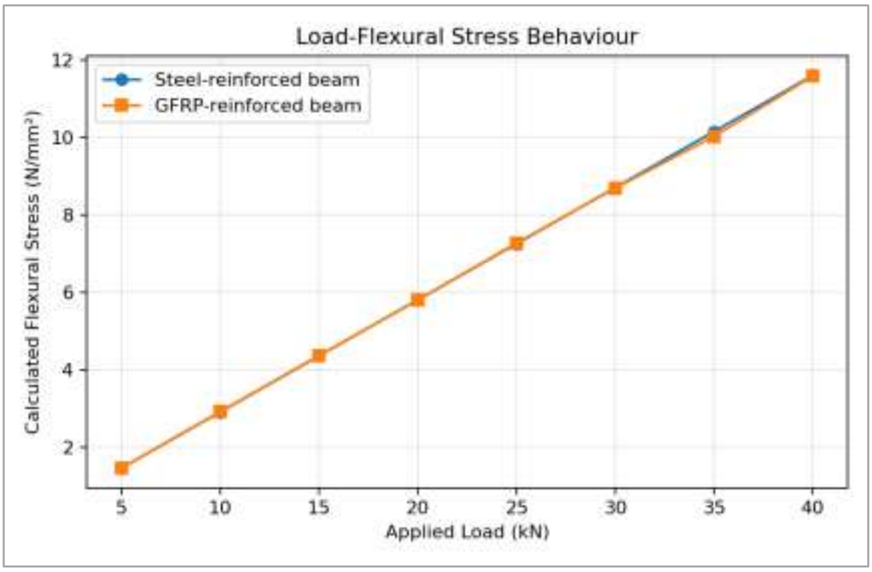

Figure 2. Applied Load Versus Calculated Flexural Stress

4.3 Comparative Assessment

Within the investigated load range, the two beams showed broadly similar load-deflection and calculated flexural-stress responses. The GFRP specimen demonstrated satisfactory behaviour and no experimental basis was found in the available dataset for claiming an 18.78% increase in ultimate load-carrying capacity. A claim of increased ultimate capacity would require verified failure-load data from specimens tested to complete failure. The current results instead support the more conservative conclusion that the tested GFRP-reinforced beam achieved flexural performance comparable to the steel-reinforced control beam up to the maximum recorded load of 40 kN.

5. CONCLUSION

- Both the steel-reinforced and GFRP-reinforced beams were tested up to a maximum recorded load of 40 kN under the adopted experimental conditions.
- At 40 kN, the calculated flexural stresses were 11.600 N/mm² for the steel beam and 11.585 N/mm² for the GFRP beam, indicating nearly identical flexural-stress response.
- The measured mid-span deflections at 40 kN were 2.495 mm for the steel beam and 2.415 mm for the GFRP beam; the tested GFRP specimen therefore showed approximately 3.21% lower deflection at that load.
- The load-deflection responses of both specimens increased progressively with load and remained relatively close throughout the investigated loading range.
- GFRP reinforcement provided satisfactory flexural performance under the specific material, geometric and loading conditions of the present investigation.
- GFRP offers additional advantages including low self-weight, corrosion resistance and electrical non-conductivity, but its lower elastic modulus and non-yielding response must be considered in structural design.
- The present dataset does not justify a claim that GFRP increased the ultimate load capacity by 18.78%; additional specimens tested to complete failure would be required for such a conclusion.

6. FUTURE SCOPE

Future investigations should include a larger number of replicate specimens, different GFRP reinforcement ratios and bar diameters, several concrete grades, detailed crack-width and strain measurements, bond-slip evaluation, full load-to-failure testing, fatigue and sustained-loading studies, durability under chloride/alkaline exposure, fire performance, hybrid steel-GFRP reinforcement and finite-element modelling. Full-scale structural members should also be evaluated to establish the reliability of design procedures for practical applications.

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