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# Experimental Investigation of Flexural Behavior, Crack Propagation, and Structural Performance of Reinforced Concrete Beams Reinforced with GFRP and CFRP Bars

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## *Abstract*
*The requirement for robust and corrosion-resistant reinforcement materials has increased the use of FRP bars in reinforced concrete constructions. The corrosion-prone nature of conventional steel reinforcement reduces structural performance, maintenance costs, and service life. "Glass Fiber-Reinforced Polymer (GFRP) and Carbon Fiber-Reinforced Polymer (CFRP)" bars might serve as substitutes because of their resilience for environmental deterioration, low weight, and great tensile strength. This examination examined the flexural capabilities and failure modes of strengthened concrete beams reinforcing with glass fibre reinforced plastic (GFRP) and carbon fibre reinforcing plastic (CFRP) bars. The research made use of examples of concrete reinforced beams that had GFRP and CFRP bars added to them, cured, and tested for flexural loading. Performance criteria like load-deflection behaviour, first-crack load, ultimate load capacity, crack propagation, stiffness, and failure modes were compared. CFRP-reinforced beams had better flexural strength, stiffness, and crack control, while GFRP beams had better deformation capacity and load-bearing behaviour. The study found that GFRP and CFRP bars can improve reinforced concrete structure durability and sustainability compared to steel reinforcement.*

***Keywords:*** *Fiber-Reinforced Polymer (CFRP), Reinforced Concrete Beams, Flexural Performance, Crack Propagation, Structural Durability.*

## INTRODUCTION
Concrete with reinforcement constructions rely on structural steel, but engineers as well as scientists are looking at solutions that are more environmentally friendly, corrosion-resistant, and long-lasting. "Fiber-Reinforced Polymer (FRP) bars, especially GFRP and CFRP bars, are popular due to their high tensile strength, lightweight, and corrosion and environmental degradation resistance" [1]. The usage of FRP reinforcement in infrastructure exposed to harsh climatic conditions has grown since conventional steel reinforcement corrodes and reduces service life [2]. Flexural stresses are not a problem for beams reinforced with glass fibre reinforced plastic (GFRP) or carbon fibre reinforced plastic (CFRP), according to recent research, improving durability and dependability [3]. CFRP bars have greater stiffness and tensile strength, while GFRP bars are cost-effective and load-carrying [4]. FRP-reinforced concrete beams' flexural behaviour and failure causes have been thoroughly studied under various loads and environmental circumstances, demonstrating their potential as alternative reinforcement systems [5]. Examining the load-carrying capacity, lateral bending behaviour, crack development, and failure reasons of structural concrete beams supplemented with GFRP and CFRP bars, this study empirically explores their flexural performances and failure properties.

### Literature review
The following table elaborates on the past literature related to this study in detail.

*Table 1: Related Works*

| Authors and Year | Methodology | Key Findings |
|---|---|---|
| [6] | Perform experimental testing on geopolymer-based concrete beams subjected to flexural pressure using steel and FRP bars as reinforcements. Observations and comparisons were made regarding the beginning, progression, and bending response of cracks. | Crack patterns and widths varied according to reinforcement type, with FRP bars demonstrating distinct post-cracking behavior compared to steel reinforcement. |
| [7] | Executed RILEM beam tests to assess the behaviour of bonds between self-consolidating and fiber-reinforced concrete, as well as between steel, GFRP, and CFRP reinforcements. We measured the attachment strength and the slip parameters. | Fiber-reinforced concrete improved bond performance and reduced slip, enhancing overall structural interaction between concrete and reinforcement. |

| | | |
|---|---|---|
| [8] | Ultra-High Productivity Concrete (UHPC) beam embedded with a combination of glass fibre reinforced plastic (GFRP) and steel bars were studied chemically and physically. We looked at how it flexed, how it responded to load deflection, and how it failed. | The combination of GFRP and steel bars effectively utilized the advantages of both materials, resulting in enhanced structural performance. |
| [9] | Used reinforced concrete beams that had FRP bars with various fibre kinds and surface properties to carry out experimental experiments. The effect of reinforcing qualities on the behaviour of structures. | Improved surface characteristics enhanced bond strength and flexural performance. |
| [10] | Underwent experimental evaluations of various shear reinforcement methods in reinforced GFRP concrete beams that were loaded. The investigation focused on the structural reaction and the mechanisms of collapse. | The study highlighted the importance of shear reinforcement selection for enhancing structural safety and serviceability. |

## Research Gap

Concrete beams reinforced by reinforcement using GFRP and CFRP bars have been the subject of several flexural behaviour investigations, including crack formation, bond performance, hybrid reinforcing systems, and speciality concrete kinds. Only a few studies have compared GFRP- and CFRP-reinforced concrete beams under identical conditions. Studying individual reinforcing systems rather than their load-carrying capability, load-deflection response, stiffness, fracture propagation, and failure characteristics is common. This work aims to address that knowledge gap by conducting experimental comparisons of the flexural stability and failure behaviour of beams made of reinforced concrete supplemented using GFRP and CFRP bars.

## Methodology

The bending performances and failure features of concrete with reinforcement (RC) beam reinforcement with "glass fibre reinforced plastic (GFRP) and carbon fibre reinforced plastic (CFRP)" bars were investigated in this creative experimental study. Empirical framework assessment of reinforced concrete beams with FRP subjected to stretching load formed the basis of the technique. The same dimensions and concrete qualities were used to make reinforced concrete beam specimens using GFRP and CFRP bars. A loading frame was used to test specimen's flexural strength after curing. First fracture load, load-deflection response, crack propagation, ultimate load-carrying capability, and failure mechanisms were recorded during testing. The experimental data were compared to the two reinforcement systems. To assess if GFRP and CFRP bars are durable alternatives to steel reinforcement, the study examined flexural strength, stiffness, ductility, crack management behaviour, and structural performance.

## Results and Discussion

"Braces made of glass fibre reinforcing plastic (GFRP) and carbon fibre reinforced plastic (CFRP)" were subjected to flexural, fracture transmission, and strength of structure tests. The initial fracture load, final flex load, and loading-deflection reaction of the specimens, and failure characteristics were used to interpret the results. Crack patterns showed that both reinforcing systems survived tensile stresses, although the mode of failure differed by reinforcement arrangement and concrete type. Flexural failures were most common in beams BS150, BS300, BG150, 800HBG150, and 1400HBG150, while inclined diagonal cracks propagated into the compression zone and caused shear-compression failures in CFRP- and GFRP-wrapped hybrid beams.

***Table 2: First Crack and Ultimate Load of Selected Tested Beams***

| Beam ID | "First Crack Load (kN)" | "Ultimate Flexural Load (kN)" | "Failure Mode" |
|---|---|---|---|
| BG150 | 19.7 | 74.6 | Flexure |
| BG300 | 11.2 | 56.8 | Shear Compression |
| 1400HBG150 | 13.3 | 70.6 | Flexure |
| 1400HBG300 | 9.6 | 60.3 | Shear Compression |
| 1400HBC150 | 18.3 | 100.1 | Shear Compression |
| 1400HBC300 | 15.4 | 63.5 | Shear Compression |

Table 2 shows that CFRP-wrapped beams have greater ultimate flexural capabilities than GFRP beams. Beam 1400HBC150 reached 100.1 kN, but beam 1400HBG150 failed at 70.6 kN. Increased shear stirrup spacing reduced ultimate load capacity and caused shear failures. The load-deflection behaviour in Figure 1 showed that stiffness decreased with shear stirrup spacing. Due to their higher modulus of elasticity and reinforcement ratio, steel rebar beams were stiffer than GFRP beams. However, hybrid beams reinforced with GFRP and CFRP had steady load-deflection responses and good deformation capacity.

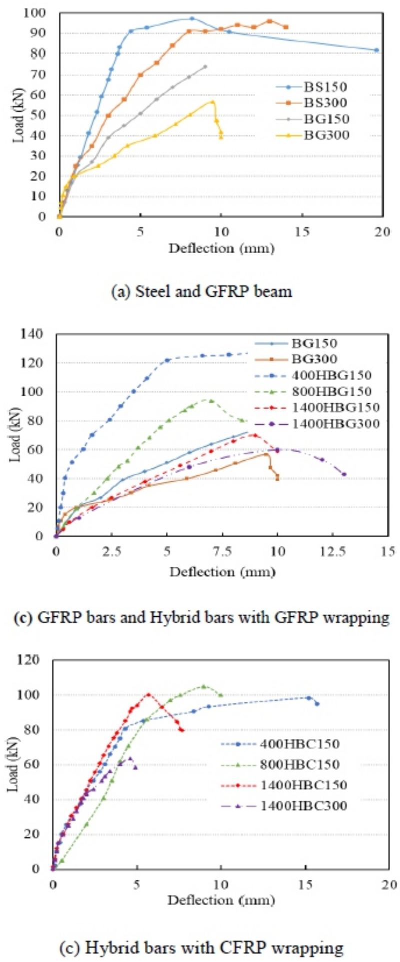
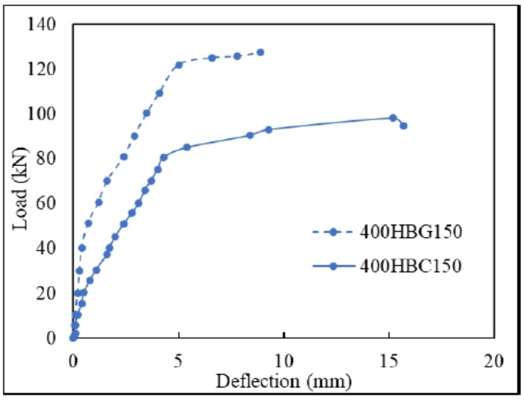
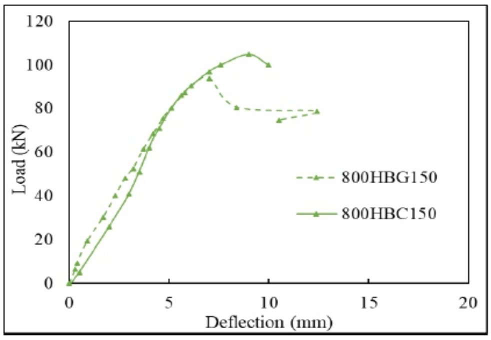



***Figure 1: Load deflection graphs of beams without fibres***

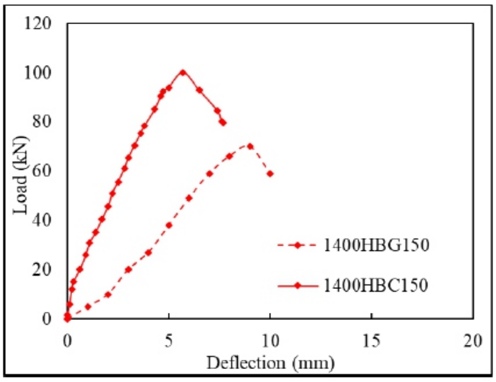
Figure 2 shows how FRP type affects structural performance. CFRP-wrapped beams were stiffer than GFRP-wrapped beams when wrapped to the maximum beam length (1400 mm). Stiffness increased fracture management and minimised loading deflection.



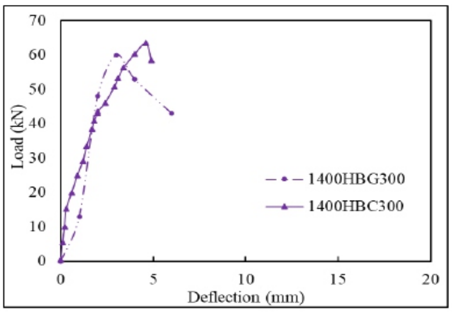

**(a) 400 mm wrapping length**




(b) 800 mm wrapping length




(c) Full wrapping and 150 mm stirrups spacing




(d) Full wrapping and 300 mm stirrups spacing

*Figure 2: Load deflection graphs of beams in normal concrete*

Figure 3 showed that steel fibres stiffened beams and delayed crack propagation. Fibres increased shear resistance and changed crack growth patterns, improving structural performance. Experimental results show that CFRP reinforcement has greater load-carrying capacity and stiffness, whereas GFRP reinforcement has adequate flexural performance, corrosion resistance, and lightweight construction. These findings show that reinforcing techniques can build lasting concrete structures.

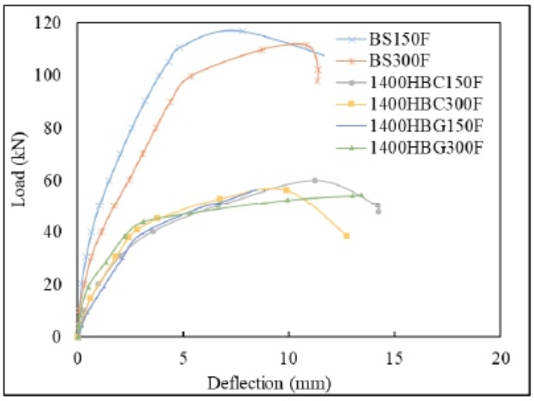



*Figure 3: Load vs deflection curves of beams with steel fibres*

## CONCLUSION

This study tested reinforced concrete beams with "GFRP and CFRP" bars for flexural behaviour, fracture propagation, and structural performance. Both reinforcing techniques are effective alternatives to steel reinforcement, especially in corrosion-prone settings. Due to improved tensile strength and elastic modulus, CFRP-reinforced beams have better flexural strength, stiffness, fracture management, and load-carrying capability. In contrast, GFRP-reinforced beams performed well with increased deformation capacity and flexibility. Buildings made of FRP-reinforced masonry have been shown in experiments that are reliable, durable, and sustainable, making them suitable for long-term infrastructure applications that demand increased structural performance and decreased maintenance.

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