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EXPERIMENTAL ASSESSMENT OF GLASS FIBER REINFORCED POLYMER (GFRP) BEAMS UNDER FLEXURE LOADING CONDITIONS

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Abstract

Concrete beams having externally bonded glass fiber-reinforced polymer (GFRP) sheets were tested under a symmetrical, static load applied until failure due to bending. For this study, two sets of beam specimens were prepared for flexural testing. In the first set, all three beams exhibited flexural weakness. Among these, one served as a control beam without any GFRP reinforcement, while the remaining two were enhanced using continuous GFRP sheets to improve flexural strength. The second set focused on shear-deficient beams. Here, one beam acted as a plain control without reinforcement, and the other two were reinforced with continuous GFRP sheets to address shear capacity. Each beam was subjected to vertical loading at three evenly spaced points along its length. Deflection measurements were recorded independently for each loading condition during the experiment.

Keywords: GFRP, deflection, OOP, Concentrate load, shear, flexure

Introduction

Reinforcement is often essential across various structural applications, particularly when there is a need to enhance a structure’s load-bearing capacity. This is commonly required when the intended function of a structure changes, necessitating it to support heavier loads than originally designed for. Strengthening may also be undertaken to improve the structure's resilience against unforeseen stresses, such as those caused by seismic activity, high winds, or potential impacts. Enhancing a structure's strength allows it to safely accommodate additional loads not anticipated during the initial design phase. This study focuses on evaluating the flexural and shear performance of solid beams reinforced with Glass Fiber Reinforced Polymer (GFRP) sheets arranged in different configurations and in multiple layers. Specifically, it examines how varying the number of GFRP layers influences both the strength and ductility of the beams. In our investigation, we developed and tested two different bar reinforcement configurations, though these initial attempts did not yield successful outcomes.

In a related experimental investigation, Ceroni (2010) subjected reinforced concrete (RC) beams to cyclic loading, utilizing external reinforcement methods such as Carbon Fiber Reinforced Polymer (CFRP) laminates and Near Surface Mounted (NSM) bars. The study revealed that the NSM bars exhibited a limited number of load cycles within both the elastic and post-elastic ranges. The discrepancies between theoretical and actual failure loads were explored in detail [1]. Similarly, Ghazi et al. (1994) explored the use of fiberglass plate bonding (FGPB) for reinforcing RC beams suffering from shear failure. Their research involved RC beams with extensive diagonal cracking and inadequate shear strength, which were intentionally damaged to simulate deterioration before being retrofitted using FGPB techniques [2]. Further, Hadi [3] evaluated the load-bearing capacity of reinforced concrete (RC) beams and found them inadequate under certain conditions. To address this, various beams were retrofitted with different types and amounts of fiber-reinforced polymer (FRP) and subjected to four-point static loading. These specimens were tested to failure, during which data on loads, deflections, and stress responses were recorded. The findings from this investigation highlighted multiple factors that influence the overall strength of RC beams.

In a 2005 study, Islam et al. [4] explored shear strengthening in deep RC shafts using FRP reinforcement. Six beams of identical dimensions were fabricated and tested until failure. Among these, five were retrofitted using carbon fiber in forms such as wraps, strips, or grids, while one beam was kept unreinforced as a control. Results showed that FRP systems effectively limited diagonal cracking and significantly improved the beams' load-carrying capacity, often meeting required structural performance standards.

Khalifa et al. [5] carried out a comprehensive experimental program focused on shear behavior and failure modes in RC beams enhanced with externally bonded carbon fiber reinforced polymer (CFRP). Twenty-seven beams were tested, considering parameters such as presence or absence of steel stirrups, shear span-to-depth ratios, CFRP quantity and layout, bonding surface, and fiber orientation. The study emphasized the role of interfacial shear bond stress between CFRP and concrete, concluding that premature debonding of the fibers from the concrete substrate was a key factor behind sudden loss of load-bearing capacity in shear-critical beams. Further, Mosallam and Banerjee [6] investigated shear enhancement in RC beams using FRP composites through full-scale experimental testing. A total of nine beams, categorized into three groups, were evaluated in their original (weakened) states and after being repaired. The retrofitting techniques employed included carbon/epoxy precured strips, e-glass/epoxy wet layup, and carbon/epoxy wet layup systems. The study demonstrated substantial improvements in shear strength following the application of these FRP systems. In 2011, Obaidat et al. [7] examined the performance of large-scale RC beams with pre-existing structural deficiencies, which were retrofitted using CFRP laminates. The investigation considered key variables such as internal steel reinforcement ratios, retrofitting location, and CFRP application length. Experimental results confirmed that CFRP retrofitting enhanced both shear and flexural performance, achieving strength and stiffness values comparable to or exceeding those of non-defective control beams.

Experimental Procedure

Experiments utilizing locally available materials have been conducted to examine the flexural and shear performance of reinforced concrete (RC) rectangular beams, both with and without the inclusion of GFRP.

Geometry of Beams

Each beam used in the study has fixed dimensions: a total length of 1300 mm, an effective width of 1000 mm (with 150 mm bearing on either side), a cross-sectional width of 110 mm, and a depth of 200 mm. Although various reinforcement strategies—such as FRP bars, prestressing strands in girders, and conventional steel bars—are employed depending on the design, the beam dimensions remain unchanged throughout the experimental process. A 30 mm diameter service hole is incorporated along the longitudinal axis beneath the neutral axis to facilitate these strengthening methods. All beams are initially designed using the limit state method and are simply supported at both ends. They are subjected to progressively increasing stresses until an ultimate uniformly distributed load (UDL) is applied. Beams from each of control beam (CB), reinforced beam (RB), Beam weak in flexure (RF), and beam weak in shear (RS) series are individually tested until structural failure or collapse occurs (Figs. 1-3).

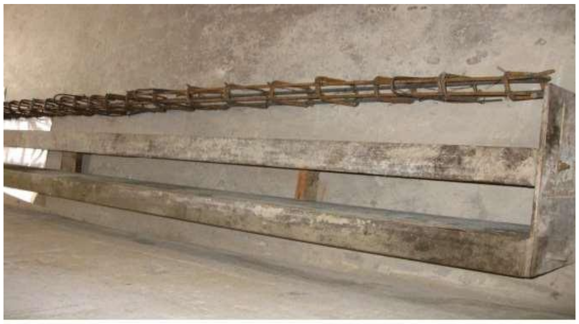

Figure 1. Mould for beam

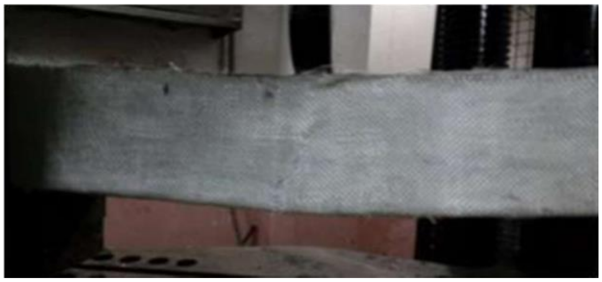

Figure 2. Sample of Glass Fabric Reinforced Concrete Beam

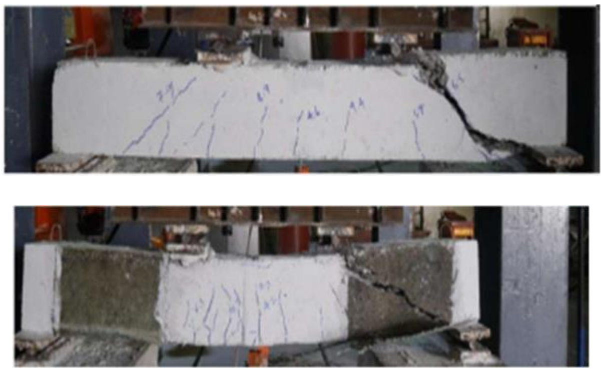

Figure 3. Failure modes of beams

Concrete mix proportioning

To prepare M25 grade concrete in accordance with IS 10262:2009 guidelines, the mix was proportioned by weight in the ratio of 1:1.85:3.70. The mix utilized a maximum coarse aggregate size of 20 mm, maintained a constant water-cement ratio of 0.50, and achieved a slump in the range of 50 to 55 mm.

Results and Discussion

This section presents the experimental findings for three categories of beams: control beams (CB), beams with flexural deficiencies (RF), and beams with shear deficiencies (RS). Among the fifteen beams tested, four served as control specimens without any FRP reinforcement, while five were flexurally weak and were strengthened using FRP to enhance their flexural capacity.

Table 1. Load, deflection and failure for Beam 1

Failure Mode	Deflection (mm)	Load (KN)	Type of beam
-	0.76	5	Control beam
Initial crack	2.14	15	
-	3.94	25	
-	6.25	30	
-	7.64	40	
-	8.34	45	
-	8.91	50	
Shear	10.86	65	
Shear	13.30	45	

Table 2. Load, deflection and failure for Beam 2

Failure Mode	Deflection (mm)	Load (KN)	Type of beam
-	0.9	5	GFRP reinforced beam
-	2.54	15	
Initial crack	4.62	25	
-	7.08	42	
-	9.16	52	
-	11.12	60	
-	12.54	65	
-	13.78	70	
-	15.52	75	
-	17.22	80	
-	19.14	85	
-	23.94	105	
-	25.51	100	
-	26.51	96	
-	27.51	92	
Flexural	29.51	89	

Fifteen beams reinforced with FRP were tested, all of which ultimately failed due to flexure. Among them, one beam was uniquely reinforced solely with FRP, without any steel reinforcement. Prior to testing, tensile properties of the steel reinforcement were evaluated following IS 1786-1985 standards, while the FRP laminates were tested as per ASTM D3039M-08. The experimental program focused on analyzing various performance characteristics such as stiffness, ductility, fracture behavior, and both initial and ultimate load-bearing capacities until failure. Beam 1 functioned as the control specimen. For each beam tested, a two-point loading configuration was applied, and deflection readings were recorded using a dial gauge. The resulting data were used to generate load-deflection curves (see Figs. 4 and 5).

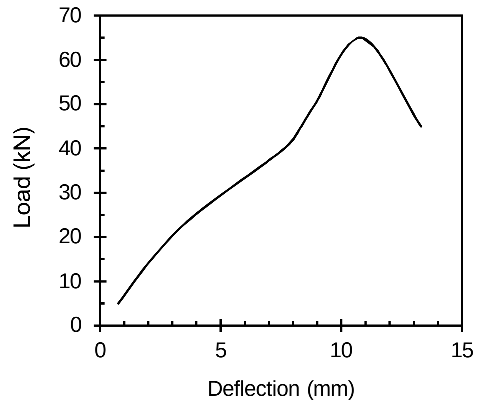

Figure 4. Load ~ deflection curve for CB

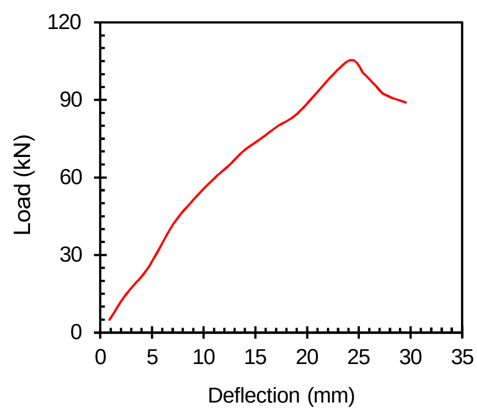

Figure 5. Load ~ deflection curve for beam with GFRP (Beam-2)

Reinforced GFRP Beam 2 was utilized, having been fully strengthened using GFRP sheet U-wrapping. The beam was subjected to loading at two specific points, and dial gauges were used to measure deflection at the points of load application. The collected data was then used to analyze the relationship between load and deflection.

Load at initial crack

Both Beam 1 and Beam 2 were subjected to two-point static loading, during which crack initiation and propagation were closely monitored at each stage of load increment. The load corresponding to the initial crack was observed, documented, and is presented in Fig. 6.

Ultimate load carrying capacity

During the final load application, Fig. 7 illustrates the peak load-bearing capacities of both the GFRP-strengthened beam and the unreinforced control beam. Among all the specimens tested, it was observed that the control beam exhibited a lower load capacity compared to the GFRP-reinforced beam. The enhanced flexibility and conductivity of the GFRP sheets play a significant role in beam performance. The incorporation of GFRP helps delay the onset of initial cracks and subsequent fractures within the beam structure.

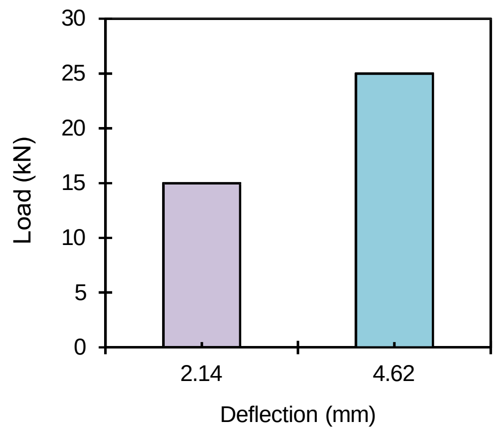

Figure 6. Load at initial crack of CB and RB

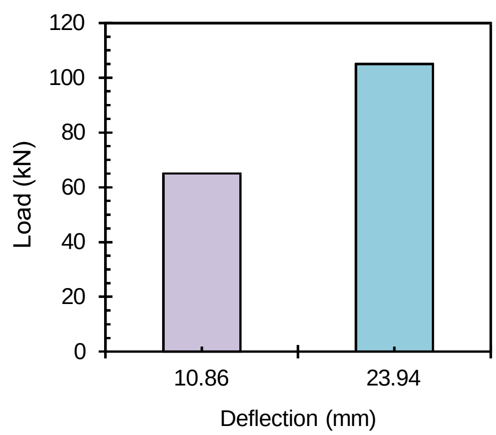

Figure 7. Ultimate load carrying capacity of CB and RB

Conclusion

The experimental study demonstrates that externally bonded Glass Fiber Reinforced Polymer (GFRP) sheets significantly enhance the flexural and shear performance of reinforced concrete (RC) beams. Beams strengthened with GFRP exhibited higher initial cracking loads and ultimate load-carrying capacities compared to unreinforced control beams. The GFRP reinforcement not only delayed the onset of cracking but also improved the beams' ductility and overall structural integrity under flexural loading conditions. The load-deflection behavior confirmed that GFRP wrapping increases both stiffness and energy absorption capacity, resulting in a more robust and resilient structural response. These findings validate the effectiveness of GFRP as a practical retrofitting solution for upgrading existing RC beams, particularly in scenarios where increased load-bearing capacity and durability are required.

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