

Performance of GFRP Bars in Flexural Members: A Comparative Study with Metal Bars Using FEA and Experimental Study

Siddharth Agrawal¹, Rajendra Khapre^{2*}, Chetan Pawar³, Anuj Shendre⁴

Abstract

In recent years, GFRP bars have been introduced as a replacement for metal bars as reinforcement in flexural members. This study evaluates the use of GFRP bars as the main reinforcement in flexural members such as beams through computer simulations and experimental work. A 4-meter beam from a sample structure, analyzed as per IS 875 (1987) Part 2, was considered for the study. This beam was designed considering both metal and GFRP bars to resist the designed bending moments. Finite element models of these beams were developed and analyzed in ANSYS. An experimental setup was prepared for beams with a 500 mm length, reinforced with 6 mm and 20 mm GFRP bars. These beams were tested for flexure as per IS 516 (2021): Part 1. Finite element models of these beams were also developed and analyzed using ANSYS. These models were further analyzed by replacing GFRP bars with their equivalent metal bars for comparison purposes. Simulation results showed that models with metal bars exhibited slightly lower deformation, resulting in higher stresses in the concrete and metal bars compared to those with GFRP bars. The experimental results demonstrated that larger GFRP bars provide greater strength. The findings suggest that GFRP bars are a viable alternative to metal bars for reinforcing beams, particularly for applications requiring high strength and reduced stress.

Keywords: Composite concrete, GFRP rebar, finite element modelling, ANSYS simulation, experimental validation

INTRODUCTION

In Reinforced Cement Concrete (RCC) structures, metal reinforcements in the form of High Yield Strength Deformed (HYSD) steel bars are provided to resist moments and shear forces generated by external loading. The compressive strength of concrete and the tensile strength of metal bars work collectively to strengthen the concrete section, ensuring it lasts for a considerable span over its lifetime. Corrosion of metal bars inside concrete members is a major problem that occurs after a certain period of time. Many factors contribute to this corrosion. Unfortunately, it is an irreversible process that cannot be repaired. As the metal bars corrode, their effective diameter decreases, resulting in a reduced moment resistance capacity of the overall section.

Fiber Reinforced Polymer (GFRP) is defined as a composite cloth which is made from polymer matrix strengthened with glass fibers. Matrix inside this composites offers bonding and protection to the fibers and it facilitates within the transfer of strain.

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GFRP composites are also utilized in various industries which include motors, aerospace and electronics. GFRP rebar have been introduced in recent years as a replacement for metal bars. These bars are almost completely resistant to corrosion, ensuring the full moment resistance capacity of the RCC section throughout its lifespan.

BACKGROUND

A study [1] analyzes glass fiber reinforced polymer composites produced using various glass types and manufacturing technologies, highlighting how increased glass fiber content enhances mechanical and thermal properties. The research underscores the significance of glass fibers in improving the strength, flexibility, and durability of these composites under mechanical loading. Literature [2] presents a comparative study of GFRP rebar and steel rebar. The study shows experimental work on beam sections, indicating a reduction in reinforcement requirements by half with the use of GFRP rebar. Similar type of study is reported [3] that depicts higher flexural strength for concrete reinforced with GFRP bars.

Another study [4] examines the bond between GFRP bars and concrete in a seawater environment, concluding that the seawater environment has an insignificant impact on bond strength. Interesting study [5] reports linear reduction in strength of hollow GFRP bars with increase in the diameter of opening. GFRP bars are also used in prestressed concrete beams [6]. Numerical study shows better crack mode and higher ultimate load for beams with GFRP rebar. Literature [7] reviews recent developments in polymer matrix composites, focusing on their synthesis, microstructure, properties, and expanding applications across various industries, including the use of natural fibers as reinforcements.

Literature [8] investigates the mechanical properties and water resistance of hybrid GFRP composites, identifying specific combinations of reinforcing materials and fillers that enhance water absorption resistance, making them more suitable for structural applications in flood-prone areas. This study concludes that the composites with kenaf fibers and fillers like nano-silica and fly ash, exhibited the best performance in minimizing water absorption. Literature [9] offers a detailed review of composite materials, focusing on their machining processes, including turning, milling, and drilling, and the related challenges such as damage due to their anisotropic structure. The review is structured into seven sections, covering composite materials, reinforcements, manufacturing methods, post-processing, and the machining of various reinforced polymer composites, with an emphasis on factors affecting machinability, including cutting forces, tool wear, delamination, and surface finish. Recent study [10] evaluates the use of GFRP spirals as a cost-effective alternative to more expensive corrosion-resistant materials in prestressed concrete piles for marine environments. Through impact experiments and finite element modeling, the study demonstrates that GFRP spirals effectively confine PC piles without compromising their load-carrying capacity.

Objective

The main objective of this research work is to evaluate performance of the GFRP rebars and compare it with the traditional metal bars used as reinforcement in flexural members. According to the literature [11], GFRP rebar have higher strength and lower density as compared to the metal rebar. Considering various benefits offered by GFRP rebar, detailed finite element study followed by experimental work is presented in this paper.

Methodology

A sample building with dimensions of 4m x 4m is considered. Loading is applied as per IS 875 (1987) Part 2 [12] for this building. The analysis was conducted using STAAD.pro, and shear forces along with bending moments were calculated in the beams. The beams' dimensions were considered to be 230 x 300 mm, and the reinforcement required to resist the design bending moment [13] is equivalent to 3 bars of 20 mm diameter.

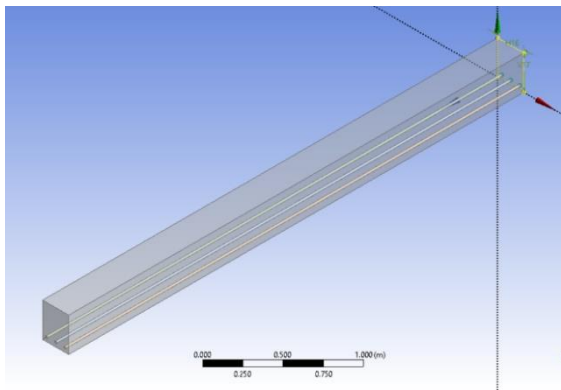


Figure 1. 3D model of beam with reinforcement.

This beam was further modeled in ANSYS [14] for detailed finite element analysis. Figure 1 shows the three-dimensional model of the beam under consideration. According to the specifications [11], a 20 mm diameter metal bar is equivalent to a 16 mm diameter GFRP bar (see Figure 2). Therefore, the model shown in Figure 1 was re-modeled with 16 mm diameter bars.

Both models, as shown in Figure 2, were further analyzed for a uniformly distributed load of 94.5 kPa with boundary conditions as simply supported at both ends. Table 1 shows the comparison of results obtained from the finite element analysis. The study indicates that the model with GFRP bars shows greater deformation compared to the model with metal bars. The study also reveals that the maximum compressive stress in the concrete was slightly greater for the model with GFRP bars compared to the model with metal bars. When comparing the maximum tensile stress in the bars, it was found that metal bars exhibit greater axial stress compared to the GFRP bars.

Experimental Work

An experimental setup was created to test the field performance of GFRP bars. Two types of beams were prepared, using 6 mm and 20 mm GFRP bars as the main reinforcement. The beam size was 100 x 100 x 500 mm with M50 grade concrete. Six samples were prepared for each: two GFRP bars of 6 mm diameter were placed with a 20 mm clear cover, and two GFRP bars of 20 mm diameter were placed with zero cover.

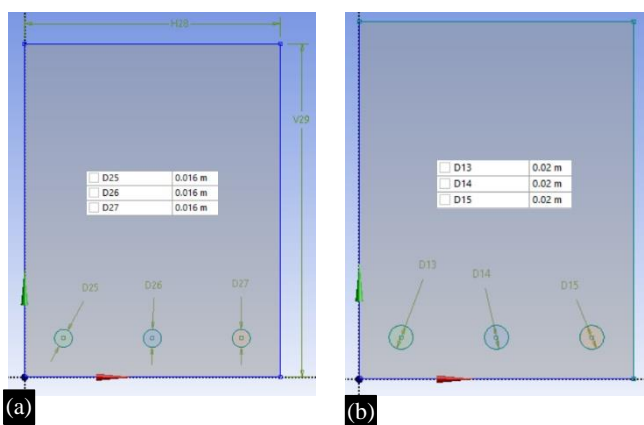


Figure 2. Concrete section with (a) GFRP rebar (b) Metal rebar.

Table 1. Results of finite element analysis of beam with metal bars and GFRP bars.

Parameters	Model with metal bars	Model with GFRP bars
Vertical Deformation (mm)	4.27	4.71
Max. Compressive stress in Concrete (MPa)	11.82	12.56
Max. Tensile stress in bars (MPa)	58.96	18.92



Figure 3. Test setup for flexural testing of beams.



Figure 4. Failure of beam section.

Three samples were tested after 7 days of curing, and the remaining three samples were tested after 28 days for bending. The strength of the beam was measured according to the guidelines of IS 516 (2021): Part 1 [15]. Figure. 3 shows the test setup, and Fig. 4 shows a photo of the beam after testing. It is evident from Table 2 that the average strength of samples with 6 mm diameter GFRP bars (24.91 MPa) is lower than the average strength of samples with 20 mm diameter GFRP bars (35.79 MPa).

Table 2. Average strength of concrete section reinforced with GFRP rebar.

Sample	Load (kN)	Strength (MPa)	Average strength (MPa)
2# 6 mm ϕ @ 20 mm clear cover	61	35.81	24.91
	70.5	28.2	
	32.5	10.725	
2# 20 mm ϕ @ 0 mm clear cover	88.5	34.52	35.79
	95	37.05	
	95.5	35.81	

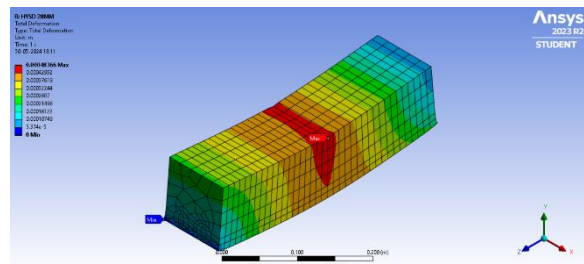
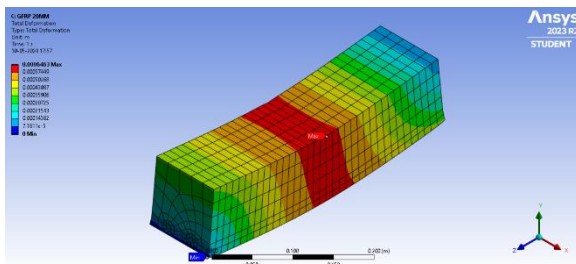


Figure 5. Deformed shapes of concrete section reinforced with (a) 20 mm GFRP rebar (b) 28 mm metal rebar

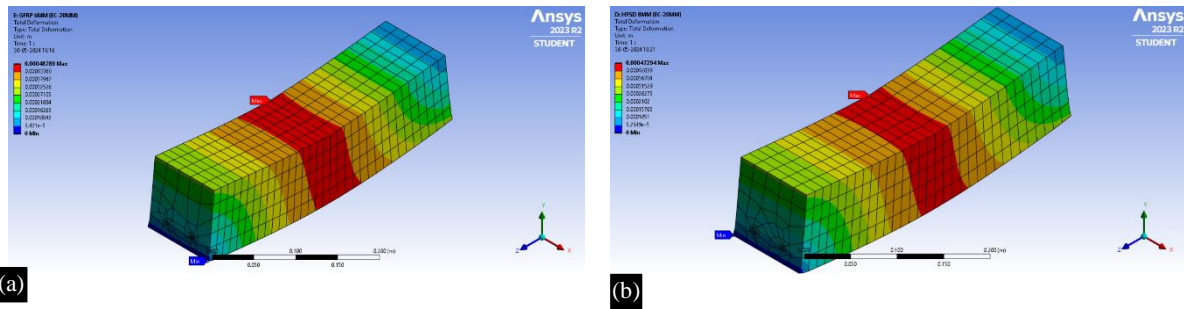


Figure 6. Deformed shapes of concrete section reinforced with (a) 6 mm GFRP rebar (b) 8 mm metal rebar.

Table 3. (a) Comparison of results of 28 mm metal bars with 20 mm GFRP bars.

Parameter	Model with Metal Bars 28 mm	Model with GFRP Bars 20 mm
Vertical Deformation (mm)	0.46	0.61
Max. Compressive stress in Concrete (MPa)	125.94	104.25
Max. Tensile stress in bars (MPa)	204.19	137.44

Table 3. (b) Comparison of results of 28 mm metal bars with 20 mm GFRP bars.

Parameter	Model with metal bars 8 mm	Model with GFRP bars 6 mm
Vertical Deformation (mm)	0.45	0.46
Max. Compressive stress in Concrete (MPa)	75.20	72.27
Max. Tensile stress in bars (MPa)	140.75	40.21

GFRP Vs Metal Rebar

Finite element models of both samples were prepared using the symmetry option and analyzed in ANSYS to understand the flexural behavior of beams with GFRP reinforcement. The dimensions and material properties of the finite element model were kept the same as the actual tested samples. Another analysis was carried out where the GFRP bars were replaced with their equivalent metal bars: 20 mm GFRP bars were replaced with 28 mm metal bars, and 6 mm GFRP bars were replaced with 8 mm metal bars. Figure 5 shows the deformed shape of the beam with 20 mm GFRP bars and 28 mm metal bars. Figure 6 shows the deformed shape of the beam with 6 mm GFRP bars and 8 mm metal bars.

Table 3 shows the comparison of various results obtained from the finite element analysis. It can be observed that the deformation in the model with GFRP bars is higher compared to the model with metal bars. This table also indicates that the difference in deformation values is marginal when smaller diameter bars are used, but the difference is significant when larger diameter bars are used in the beams. When comparing compressive stresses in the concrete, higher values are observed in the model with metal bars compared to GFRP bars. It was also observed that the metal bars are subjected to higher axial stresses compared to GFRP bars which is in agreement with literature [3].

CONCLUSION

After performing computer simulations and experimental work, it can be concluded that GFRP bars can be used as the main reinforcement in flexural members such as beams. Experimental results show that larger GFRP bars used as main reinforcement exhibit greater strength. Simulation results indicate that models with metal bars exhibit slightly lower deformation (4.27 mm) in the beam compared to models with GFRP bars (4.71 mm). This results in higher stresses in metal bars nearly 2-3 times stresses in GFRP. Although the model with GFRP bars shows higher deformation, its high strength reduces nearly 85% stresses in the concrete resulting in smaller sections required to resist compressing stresses.

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