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Effect of Glass Fiber Reinforced Polymer (GFRP) Rebar on the Flexural Strength of High-Performance Concrete Beams.

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Abstract: *Reinforced Steel bars used in concrete construction are particularly susceptible to corrosion because they don't have enough corrosion resistance, which reduces durability and long-term performance. Glass-fiber reinforced polymer (GFRP) rebar emerged as a promising alternative to traditional steel reinforcement, with excellent results in terms of corrosion resistance. The unique advantages of GFRP over steel bars, such as strong resistance to corrosion, higher tensile strength than steel bars, and a 1/4th of the weight of steel bars, which decreases shipping and labor costs, are now entering the market as a solution to the aforementioned issues. This study compiles the most significant research findings on the flexural behavior of reinforced concrete (RC) beams. A comprehensive review of the literature on the flexural behaviour of RC beams reinforced with steel and GFRP bars is also outlined in this paper.*

Index Terms – GFRP rebars, flexural strength, concrete beam, flexural behavior

1. Introduction

1.1 General:

Fiber-reinforced polymer (FRP) composites have become a more dependable material in the last twenty years for civil engineering applications such as building new structures and renovating aging infrastructure. In addition to offering significant resistance against fatigue loading, shock, and corrosion, GFRP composites also enhance a structure’s ability to absorb energy over the long term. In India, construction is the second-largest economic activity after agriculture. The construction industry, which accounts for nearly 65 percent of total infrastructure investment, is expected to be the biggest beneficiary of the surge in infrastructure investment over the next five years. Concrete structures are increasingly using fiber-reinforced polymer (FRP) bars due to their light weight (1/4th weight of steel rebar), high stiffness to weight ratio, ease of handling, lower maintenance cost, lower transportation fee, easy cutting, and proper bonding to concrete. FRP rebar's tensile strength is typically 1.5 to 2 times greater than steel. Continuous fiber filaments embedded in a resin matrix form the FRP, creating various shapes such as bars, structural sections, plates, and fabric. Nowadays, FRP bars are available in glass, carbon, and aramid fibers, as well as hybrid rods with a combination of fibers. One of the most commonly used composite rebars is glass fiber reinforced polymer (GFRP) bars, mainly due to their relatively low cost combined with good performance. In several ways, the mechanical properties of GFRP bars are superior to those of steel bars. The benefits of GFRP rebar are high corrosion resistance, superior tensile strength, and electric and magnetic neutrality.

1.2 Glass Fiber Reinforced Polymer:

Old infrastructure, such as bridges and residences, have undergone restoration and modification using Glass Fiber Reinforced Polymer (GFRP) materials to enhance their durability and rigidity. The connection between the GFRP plate and the beam floor greatly influences the strength of externally reinforced RC beams reinforced with GFRP plates and textiles. When these beams encounter severe environmental conditions, their performance becomes even more crucial. Assessing the overall performance of RC beams exposed to various environmental factors and externally reinforced with GFRP plates and textiles is crucial. The text

The technological sectors have experienced substantial growth in recent decades, mostly due to their exceptional rigidity and durability. GFRP buildings in aerospace and other structural applications often undergo cycle stress, commonly known as fatigue. In the laboratory, fatigue is defined as a load or stress that varies in a non-sinusoidal manner, with the weight ratio, frequency, and maximum pressure being the defining characteristics. Impact fatigue, also known as IF, refers to the duration of this phenomenon. It is crucial for maintaining the structural integrity of additives and structures, as it has a detrimental impact on overall performance. It can happen after a short range of cycles with low amplitude, which is critical for maintaining the structural integrity of additives and structures.

Researchers have studied a variety of techniques to prevent steel corrosion, one of which involves replacing steel with fiberglass-reinforced polymer bars (Umair-Saleem, Khurram, Nasir-Amin, & Khan, 2018). Glass fiber-reinforced polymer (GFRP) composites offer numerous benefits, leading to their increasing use in various global structures such as bridges, viaducts, tunnels, deck slabs, and reservoirs. Additionally, researchers have extensively studied their properties (ACI, 2015).

ACI 440.1R (2015) defines GFRP bars as a composite material with a high radius-to-length ratio, which makes them suitable for reinforcing concrete internally. A GFRP bar has two parts: a polymeric matrix that protects the fibers and transfers tension between them and the structure around them; and longitudinally organized unidirectional glass fibers that absorb tensile pressures. Implementing helical ribs can enhance the adhesion between concrete and steel. GFRP bars can also employ similar mechanisms (Fava, Carvelli, & Pisani, 2016). The research by Jabbar and Farid (2018) and Fava et al. (2016) suggests that the adhesive force between concrete and GFRP bars is comparable to that of ribbed steel bars.

Reinforced with glass fibers Polymer bars exhibit distinct mechanical characteristics compared to steel bars, such as a high tensile strength coupled with a low elastic modulus and a brittle stress-strain relationship. Because GFRP bars have a linear elastic-brittle behavior, the flexural behavior of GFRP-reinforced concrete beams does not show any ductility. GFRP-reinforced concrete beams should be designed with an excess amount of reinforcement to ensure that failure occurs due to concrete crushing rather than rebar rupture. Sectional analysis determined the beam's flexural capacity, assuming that the rebar maintains a flawless bond with the surrounding concrete. For all of these tasks, it is assumed that the longitudinal reinforcement is completely connected to the surrounding concrete when it fails. The GFRP rebars low modulus of elasticity causes significant deformations and smooth surface features, which in turn contribute to debonding failures. These factors play a crucial role in determining the serviceability and performance of GFRP-reinforced beam sections. Therefore, the limitations of serviceability often dictate the design of GFRP-reinforced beam sections. GFRP materials have distinct advantages, including exceptional resistance to corrosion, a high strength-to-weight ratio, electromagnetic neutrality, and simplicity of handling. These qualities make GFRP materials potentially appropriate for use in reinforced concrete, particularly in situations where conventional steel reinforcement is not ideal.

2. LITERATURE REVIEW

This section specifically examines previous studies conducted on the flexural characteristics of concrete beams reinforced with Glass Fiber Reinforced Polymer (GFRP). The analysis covers the flexural characteristics, such as the load-deflection correlation, flexural strength, stiffness, and failure mode. The beams dimensions, as well as its overall weight, are significant considerations in withstanding dynamic forces.

Nemr et.al (2018) assessed the flexural strength and serviceability of concrete beams that were reinforced with several types of GFRP bars. The beams exhibited characteristic bilinear response in terms of strain and deflection till reaching the point of failure. Reducing the diameter of GFRP while preserving its mechanical qualities and surface profile improves its strain and cracking behavior. Smaller Glass Fiber Reinforced Polymer (GFRP) bars demonstrate reduced stresses and narrower crack widths compared to bigger bars. This is attributed to the restriction of bar spacing, which effectively regulates the propagation of cracks. The observed cracking behavior of the tested beams supports the notion that sand coated GFRP bars exhibit superior bond performance compared to helically grooved bars. GFRP bars are used due to their smooth and uninterrupted surface. Dybel et.al (2020) conducted an examination on the flexural strength of beam elements that were strengthened with GFRP bars. The reinforcement ratio exerted a substantial influence on both the failure mechanism and the flexural strength of bent concrete elements that were reinforced with GFRP bars. Augmenting the reinforcement ratio within the examined range led to a noticeable enhancement in the flexural strength of the section. This increase exhibited a linear relationship. The flexural strength values estimated according to ACI recommendations were, on average, 7% lower than the experimental values. The ACI standard offers cautious estimates of flexural strength, which are further reduced by safety considerations.

In their 2021 study, Sirimontree et.al conducted an experimental investigation on the flexural characteristics of concrete beams reinforced with GFRP bars, in comparison to concrete beams reinforced with traditional steel reinforcements. The maximum load capacity of concrete reinforced with steel bars exhibited a positive correlation with the strength of the steel. The beams maximum load experienced a 69% increase. The concrete beams reinforced with GFRP bars exhibited a maximum load that surpassed the beams reinforced with steel bars of Grade SD30 and Grade SD40 by about 98% and 17% respectively.The findings indicate that the flexural strength of the beams reinforced with GFRP is enhanced, and this improvement is further enhanced when GFRP is utilized as hybrid reinforcement. An augmentation in the strength of concrete leads to corresponding enhancements in both its flexure and shear capacities. Sankalamaddi Rakesh Reddy and CH Lakshmi Nagabala (2022) suggested the incorporation of reinforced polypropylene as an addition to enhance the structural integrity of concrete. The researchers determined that the highest compressive strength of Steel Fiber Reinforced Concrete (SFRC) is 38.61 MPa, achieved when 2% of concrete is mixed with steel fibers (class M30). The highest achievable Compressive Strength (CS) of PPRC is 36.12 MPa, which is attained when 0.30% PPF concrete (grade M30) is added. The compressive strength of High Fiber Reinforced Concrete (HFRC) is 40.19 (MPa), achieved with a concrete mixture containing 2% steel fibers (S) and 0.30% polypropylene fibers (PP), conforming to the M30 grade. The SFRC has a maximum tensile strength of 3.23 MPa, which is 42.2% higher compared to normal concrete. The addition of 0.30% PPRC to conventional concrete increases its tensile strength to 3.14 MPa, which is 51.1% more than the tensile strength of ordinary concrete. Unlike SFRC, it experienced a 6.1% growth.

The effects of changing the quantity and configuration of steel and GFRP reinforcement on the deflection of reinforced concrete beams were investigated by Husain Abbas et al. in 2022. Testing was conducted on a total of sixteen standard concrete beams and beams strengthened with steel fiber reinforced concrete (SFRC). A comprehensive analysis was carried out to investigate the initial stiffness, first fracture and ultimate load, ductility, and flexural strain. The increased surface area of the reinforcement has resulted in improved maintainability and ductility. Determine the beam's bending resistance by incorporating the influence of strain hardening and utilizing the outcomes of the experiments. The studied features encompassed the load at the point where cracking begins, the stiffness during the initial stage, the load at a crucial point, the ability to deform without breaking, the load that the material can sustain during normal operation, and the amount of bending at 50% and 100% of the load that causes failure. Increasing the surface area of the reinforcement has resulted in improved performance and a greater ability to deform without breaking. By incorporating steel fibers (SF) into the concrete, they observed an improvement in the load capacity at the beginning of cracking and the stiffness during the early phase. In the load-bearing portion of the beams, Zhou et al. (2021) created a hybrid integration of FRP and steel rebars. Using FRP and steel materials can improve the flexural strength and ductility of reinforced concrete (RC) beams by optimizing material utilization. The research enhances the design methodology for assessing the flexural strength of FRP hybrid steel. Using reinforced concrete beams is recommended. The design tolerance ensures adaptability in line with the designated level of reinforcement. The ensuing computational technique has identified three predominant bending failure types.

Mahdi Nematzadeh and Saber Fallah-Valukolaee (2021) emphasized that the inclusion of a blend of traditional concrete and fiber-reinforced concrete (FRC) in the shape of two-layer composite elements can improve the flexural strength of beams. This approach also guarantees an appropriate allocation of stress pressures and provides a cost-efficient alternative for decreasing the costs of structural components. The studys goal was to find out how well two-layer fiber-reinforced concrete (FRC) beams supported by glass fiber-reinforced polymer (GFRP) and steel bars could hold weight when loaded in a way that was similar to static weight. The experimentation was carried out with a 3-point loading arrangement. The research showed that adding fibers to the compression zone made beams made of glass fiber reinforced polymer (GFRP) and steel bars in reinforced concrete (RC) structures more flexible. In contrast, the inclusion of fibers in the area of the material subject to tension enhanced the overall resistance to bending forces. Making the layered beams stronger by using concrete with a higher compressive strength and adding more Glass Fiber Reinforced Polymer (GFRP) to the steel reinforcement made the steel rebars better at bending. Nevertheless, replacing steel rebars with GFRP resulted in a decrease in load-bearing capacity, bending resistance, and malleability. In their study, Filipe R.G. de Sa et al. (2020) conducted an experimental program in which they added 10 kg/m3 of PPF to evaluate its effects on the flexural and tensile characteristics of concrete. The researchers conducted pull-out tests and mechanical properties to precisely determine the element's characteristics. The addition of PP macrofiber had negligible effects on the adhesive characteristics between GFRP and concrete. During the cracking stage, the addition of fibers increased the stiffness of the structural parts.

3.EXPERIMENTAL PROGRAM:

The present work implemented the program to learn more about flexural behavior and fracture patterns. This study aims to analyze the flexural behavior of rectangular concrete beams reinforced with glass fiber-reinforced polymer (GFRP) by producing four specimens. Both the tension and compression zones employ bars of uniform length and diameter.

3.1 Test Program

In this study, we use a control specimen that includes: 1. A 12 mm-diameter Fe415 bar in the tension zone, and a 10 mm-diameter bar in the compression zone. 2. A 12 mm-diameter GFRP bar in the tension zone and a 10 mm-diameter Fe415 bar in the compression zone. 3. A 12-mm-diameter Fe415 bar in the tension zone and a 10-mm-diameter GFRP bar in the compression zone. 4. A 12-mm-diameter GFRP bar in the tension zone and a 10-mm-diameter GFRP bar in the compression zone. Table 3. 1.1 displays the experimental program for the various beam specimens.

Table 1: Experimental Program for the tested beams:

Description	Type of rod	Diameter	Position
C2	Fe 415	12 mm	Bottom
	Fe 415	10 mm	Top
GT2	GFRP	12 mm	Bottom
	Fe 415	10 mm	Top
GC2	Fe 415	12 mm	Bottom
	GFRP	10 mm	Top
GF2	GFRP	12 mm	Bottom
	GFRP	10 mm	Top

3.2 Properties of material:

3.2.1 Concrete

The study created the concrete mix for the standard strength grade using conventional Portland cement, natural sand, and 20-mm-sized aggregate.

3.2.2 GFRP Bars

The stirrups are constructed using 8 mm diameter steel bars. The primary longitudinal GFRP bars had a diameter of 10 mm for the top reinforcement and 12 mm for the bottom reinforcement. Table 3.1 presents the mechanical parameters of the locally produced GFRP bars. In this study, we coat the bars with sand to enhance their adhesion to concrete. Figure 1 illustrates the tension behavior of steel and GFRP.

Table 2: Mechanical Properties of GFRP bars:

Description	Units	Values	Diameter
Ultimate tensile strength fu	Mpa	407.4	10 mm
	Mpa	347.5	12 mm
Modulus of Elasticity E	Gpa	33.81	10 mm
	Gpa	32.67	12 mm
Rupture Strain ε		0.029	10 mm
		0.05	12 mm

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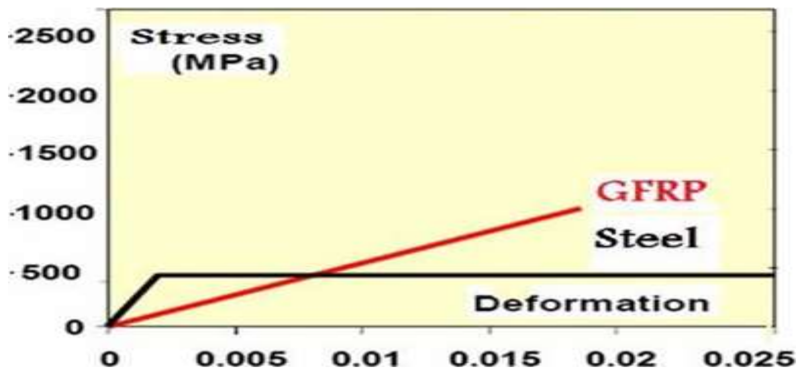

Fig 1: Steel and GFRP tension behavior

3.3 Test setup

Testing took place with the beams simply supported between two stiff supports. Point loads were uniformly distributed over all the beams. The loads were vertically delivered at the center of the beam, evenly distributing the load on two bearings positioned on the top of the beam. The bearings are spaced 450 mm apart and are symmetrically oriented around the centerline of the beam. The deflection was measured at the midpoint using a ±200 mm linearly variable differential transducer.

Table 3: The experimental program of the tested beam

Beam 1	Size	150 x 250 mm
	Length	3 m
Beam 2	Size	200 x 300 mm
	Length	1.2 m

4. CONCLUSION

The main aim of this study was to use eco-friendly materials. It is observed that, the waste glass powder from glass containers and clear glass panels commonly found in doors and windows. Using these materials, the extraction of glass from the environment and its incorporation into concrete is possible. However, the use of glass powder reduces the amount of natural aggregates, thereby aiding in the conservation of natural resources. Prior studies have demonstrated that the utilization of GFRP rebars, in conjunction with their economic advantage over steel constructions, results in a 43% reduction in CO_2 emissions. The attempt was also made to examine the flexural characteristics and crack patterns. It is also observed that, the flexural behavior of rectangular concrete beams reinforced with glass fiber-reinforced polymer (GFRP) good as compared to the natural aggregates.

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