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Use of Glass Fiber Reinforced Polymer (GFRP) bars along with traditional steel making hybrid reinforced concrete Structures.

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Abstract - *This study investigates the structural performance of hybrid beam consisting of traditional steel and Glass fibre reinforced polymer (GFRP) bars as tensile reinforcement in a beam . Four groups of concrete specimens were tested under flexural loading to investigate the influence of hybrid reinforcement (GFRP bars along with traditional steel) with different percentages of steel reinforcements on the structural behavoir of the beam. The structural behavoir in terms of Ultimate bending moment and deflection was investigated by drawing graphs comparing traditional RCC beam with Hybrid beam. Specimens with hybrid reinforcements exhibited an increased load carrying capacity and better ductility as compared to the traditional RCC members. The load carrying capacity showed an increase in 4% to 7.2%. The deformation capacity showed a subsequent increase ranging from 7% to 28%. In conclusion, the results highlight the potential of GFRP bars in increasing the overall strength of concrete structures. Thus, this research aims to set a platform for designing steel–GFRP hybrid RCC sections.*

Keywords: *hybrid beam, flexural loading, GFRP reinforcement, ductility, deformation capacity.*

1.INTRODUCTION

Glass Fiber Reinforced Polymer (GFRP) bars have become very popular as an alternative to steel reinforcement making hybrid reinforced concrete structures. Steel is used in traditional concrete to resist tensile stresses, but it is very prone to corrosion in harsh environments like marine conditions and exposure to chemicals. This damage shortens the life of the structure and raises the cost of upkeep. To deal with these problems, researchers have looked into non-corrosive reinforcement materials, and GFRP bars have stood out as a good option. Glass fibers embedded in a polymer matrix like epoxy or polyester resin make up GFRP bars. This mix gives them special physical and mechanical properties. They are strong, light, and resistant to chemicals, moisture, and corrosion. GFRP bars are also not magnetic and do not conduct electricity, which makes them good for certain uses. GFRP bars, on the other hand, act linearly until they break, which makes them brittle. Steel, on the other hand, does not yield. Their modulus of elasticity is lower than that of steel, which changes how stiff and how much they can bend. These differences in materials have a big effect on how well GFRP-reinforced concrete works as a structure.

GFRP bars have a number of drawbacks that prevent them from being widely used as a replacement to traditional steel, despite their benefits. Their brittle failure behavior is the most important problem because, unlike steel, they don't give a warning before failing. Serviceability is impacted by their lower modulus of elasticity, which causes greater deflection and crack widths. Additionally, GFRP bars have a low compressive strength and perform poorly at high temperatures. They are also more expensive initially than steel reinforcement, which may be a problem for certain projects. To ensure safe and effective use in structural applications, these limitations require careful design considerations and appropriate analysis. Hybrid beams consisting of traditional and GFRP bars can be a promising alternative to traditional RCC structures. However, careful design and engineering judgment are needed due to their brittle nature, lower stiffness, and higher cost.

Since, GFRP-reinforced concrete is less stiff than conventional steel-reinforced concrete, its structural behavior can be different. Design codes are required so that GFRP bars can be used along with steel reinforcement in traditional reinforced structures which need to last a long time and require less maintenance.

2. COMPARISONS BETWEEN GFRP AND STEEL REINFORCEMENTS AS IN PAST PAPERS:

1.Tensile strength: GFRP bars has a high tensile strength (500-1200 MPa) compared to steel rods (250-550 MPa). A shear log bar (or shear-pressure diagram) maps the relationship between shear stress and normal pressure within a material, often showing that shear stress increases with pressure due to higher material density and reduced velocity at boundary layers.

2.Temperature: GFRP bars are also sensitive to normal temperature fluctuations. These bars are highly sensitive to elevated temperatures, as the thermosetting polymer matrix softens near the glass transition temperature ie between 65°C and 120°C leading to a progressive loss of mechanical properties. However, at temperatures above 200°C the strength drops by 40%.

3.Compressive strength: Compressive strength of GFRP bars is generally lower than the tensile strength, usually measuring 50–80% of the tensile capacity. It was found that the compressive modulus of elasticity is less than the tensile modulus of elasticity. Compressive strength is highly dependent on the unbraced length ie shorter bars fail by crushing, while longer bars fail via buckling. A length-to-diameter ratio of 8 is considered standard for representing compressive strength.

4. Creep : GFRP bars are susceptible to creep and creep-rupture under sustained tensile loads, where the polymer matrix deforms over time, leading to potential failure below short-term tensile strength. ACI 440.1R-15 recommends a 0.20 safety factor on the design tensile strength.

5. Fatigue : GFRP bars exhibit excellent fatigue resistance, generally superior to steel in corrosive environments, but lack a distinct endurance limit, making fatigue resistance stress-controlled. Fatigue failure in GFRP is progressive, involving matrix cracking and fiber-matrix debonding, usually limited to 25% of ultimate tensile strength by design codes to prevent failure.

6. Weight : Due to the fibrous origin, GFRP bars are approximately 75% lighter than steel, typically weighing between 0.05 kg/m and 2.5 kg/m depending on the diameter. They generally have a density of 1.8 to 2.1 gm/cm^3 offering a high strength to weight ratio.

3 . METHODS

3.1 Method Adopted

For the experiment, a total of 20 beams in 4 categories were prepared with average of 5 beams in each category, each with a length of 100 cm and an effective length of 90 cm. The cross-sectional dimensions were taken as 15cm × 20 cm. The applied load was placed at the centre of the beam. The distance from the edge of the beam to the support was set at 5 cm. Considering that the beams were to be tested under normal section conditions, no transverse reinforcement was provided in the midspan region. At the regions near the supports, the spacing of transverse bars was set to 5 cm. The reinforcement cage had a length of 90 cm and a height of 18 cm. All beams were reinforced with Fe 415 grade reinforcement and casted in M25 grade concrete. 2 bars of 8mm diameter were placed in the compression zone of the beams. Stirrups were made of mild steel , 6 mm in diameter placed at 150 mm c/c. The cross-sectional dimensions of the beams, the positioning of the reinforcement cage within the beam, and the placement of tension reinforcement including steel and GFRP bars in the tensile zone are illustrated in Fig. 1.

3.2. Behaviour of hybrid steel-GFRP beams at ultimate limit states

In hybrid steel-GFRP reinforced concrete beams, the use of three different materials leads to failure occurring in various combinations. In these cases, failure occurs similarly to the previously described beams, including crushing of concrete in the compression zone, yielding of steel reinforcement, and rupture of GFRP bars as per . R. Mavlonov and S. Razzakov(24) .As noted above, the theoretical study and development of calculation methods for failure of reinforced concrete beams with hybrid steel-GFRP reinforcement differ from those for beams reinforced solely with steel or FRP reinforcement. The beams in category 1 and 3 were designed as underreinforced sections with neutral axis being less than limiting neutral axis as per IS 456 -2000.

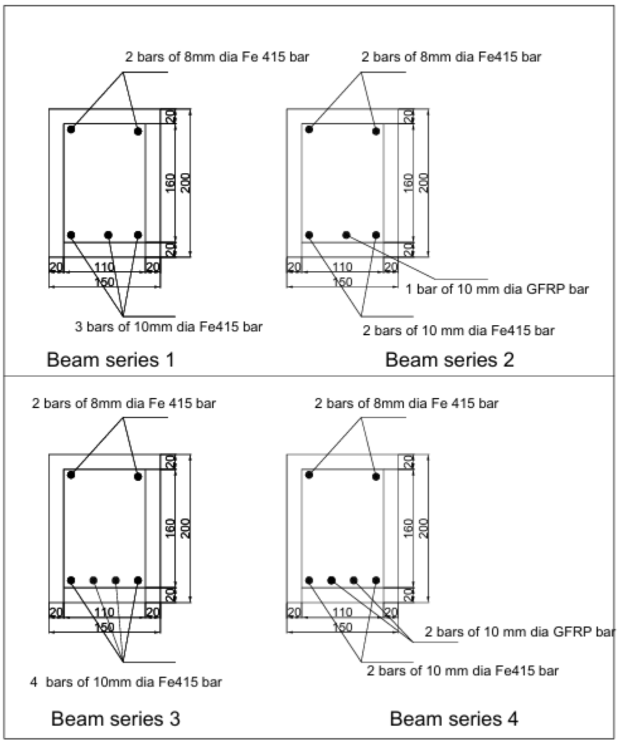
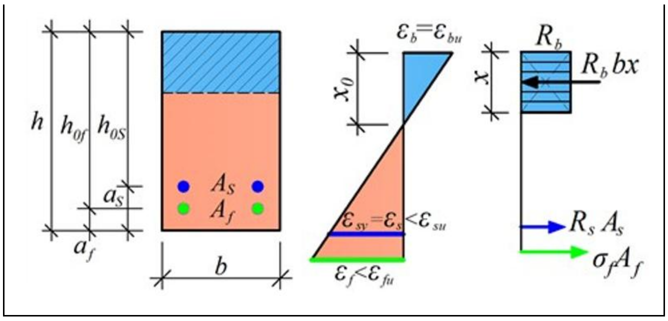


Fig. 1: Cross-sections of the test beams and arrangement of the reinforcement cages

When calculating hybrid steel-GFRP reinforced beams according to ultimate limit states, It is based on the assumption that failure takes place by yielding of steel which is a gradual type of failure and is preceeded by widening of cracks and significant increase in deflection. In this stage, after cracks have formed in the tensile zone, it is assumed that tensile stresses are carried only by the longitudinal reinforcement in the tensile zone, while the contribution of the tensile concrete is neglected [H. Y. Leung and R. V. Balendran]. Initially, the stress in the steel reinforcement reaches its yield strength, after which the stresses are transferred to the GFRP bars, leading to an increase in their deformations; however, rupture does not occur. At the same time, concrete in compression zone crushes. As a result, the strength capacity of the GFRP reinforcement is not fully utilized, leaving an unused reserve (Fig. 2). Ultimate moment of the beam can be determined by calculating the moment relative to the axis passing through the centroid of the GFRP reinforcement in the tensile zone.



Cross section of the beam   strain distribution stress distribution

Fig 2

Where :
b is the width of the beam
h is the depth of the beam
x_o is the depth of neutral axis
h_{of} is the effective depth of GFRP reinforcement
h_{os} is the effective depth of steel reinforcement
A_s is the area of steel reinforcement
A_f is the area of GFRP reinforcement
ε_b is the compressive strain in concrete
ε_{sy} and ε_f are compressive strains in steel and GFRP
R_b is the compressive stress in concrete
R_s is the tensile stress in steel
σ_f is the stress in GFRP reinforcement

From Fig. 2, ultimate moment of the beam can be determined by calculating the moment relative to the axis passing through the centroid of the GFRP reinforcement in the tensile zone:

$$M_u = R_b B_x (h_{of} - \frac{x}{2}) - \sigma_{sy} A_s (h_{of} - h_{os}) \quad \text{----------}(1)$$

By projecting all the forces acting in the cross-section onto the -axis

$$R_b B_x = \sigma_{sy} A_s + \sigma_f A_f \text{--------------} (2)$$

$$\sigma_f = \varepsilon_f E_f \text{ -------------} (3)$$

$$\varepsilon_f = \varepsilon_{bu} \frac{(hof - x0)}{xo} \text{ -------------} (4)$$

Subst eqn (3) and (4) in (2)

$$R_b B_x = \sigma_{sy} A_s + \varepsilon_{bu} \frac{(hof - x0)}{xo} E_f A_f$$

$$R_b B_x = \sigma_{sy} A_s + \varepsilon_{bu} \frac{(hof - \frac{x}{w})}{\frac{x}{w}} E_f A_f$$

Where w = 0.85 is the coefficient used to convert the parabolic stress distribution in the concrete compression zone into an equivalent rectangular stress block.

The height of the compression zone can be determined as follows:

$$X = \frac{\sqrt{(\sigma_{sy}A_s - A_f E_f \varepsilon_{bu})^2 + 4R_b w b h_{of} A_f E_f \varepsilon_{bu} + \sigma_{sy}A_s - A_f E_f \varepsilon_{bu}}}{2R_b b}$$

4. RESULTS AND DISCUSSION

The moment-deflection diagram drawn for the Series 1 beams and series 2 beams under loading is shown in the Fig 3. The vertical axis of the diagram represents the ultimate moment (kN·m), while the horizontal axis indicates the maximum deflection f (mm) at the middle of the beam. This diagram can also be referred to as the stiffness and flexibility of the beam.

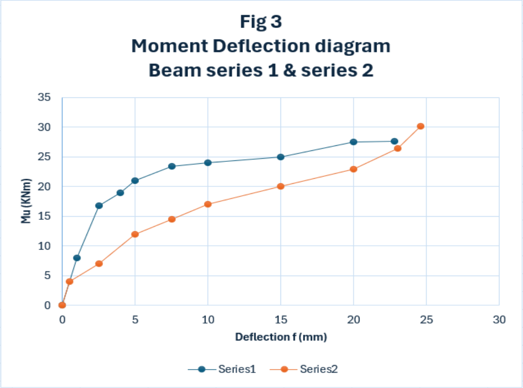


Fig 3
Moment Deflection diagram
Beam series 1 & series 2

The series 1 beam was a normally reinforced concrete beam with steel reinforcement had a linear behavior until reaching the ultimate moment 27.6 kN·m and reached the maximum stiffness. This situation is explained by the theory that normal stress in the steel reinforcement reached its yield limit. The maximum stiffness shown by this beam was 22.8 mm . The series 2 beam had a combined reinforcement of steel and GFRP bars. The ultimate moment reached on loading was 30.14 KNm. It also showed a deflection of 24.60 mm. It was observed that with the same reinforcement ratio, the ultimate moment in series 2 beam was 9.2% higher then series 1 beam . The deflection shown by series 2 was also 7.9 % higher then series 1 beam . Since reinforcements were applied in a combined manner, the ductility of the reinforcements were clearly seen.

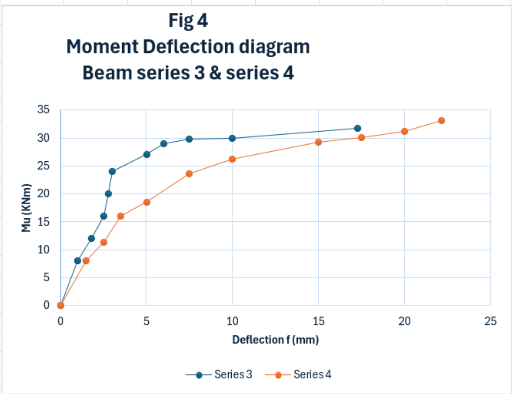


Fig 4
Moment Deflection diagram
Beam series 3 & series 4

Fig 4 shows the graph of Ultimate moment vs Deflection for the beams in series 3 and series 4 beams. The reinforcements in these beams is as shown in fig 1. The series 3 beams had steel reinforcements only and the ultimate moment ranged from 30.56 KNm and went up to 31.68 KNm.

The deflection was a little less as compared to the previous beams and reached 17.30 mm . The series 4 beams had a combination of steel reinforcement and GFRP reinforcement on the tensile side. When loaded at the centre, these beams displayed an ultimate bending moment of 33.11 KNm. This bending moment was 4.5 % higher than the series 3 beams . The deflections in this case ranged from 21.86 mm to 22.14 mm , which was 28 % higher than series 3 beams. In hybrid steel-GFRP reinforced beams, increasing the amount of GFRP reinforcement led to higher deflections while simultaneously achieving ultimate moment. In the initial phase of the loading, the steel reinforcement in hybrid beams reached their yield point, then the GFRP bars continued to carry tensile forces. Thus, failure was delayed, and the moment capacity of the beams increased slightly.

The replacement of GFRP bars prevented the sudden stiffness reduction of the beams and caused redistribution of tensile stresses between the steel and GRRP bars, thus improving their residual strength and deformative properties. The greater deflection is due to the resultant ductility which is an important feature for structural elements subjected to seismic loads.

5. CONCLUSIONS

In this study, load carrying capacity and deflection of hybrid steel-GFRP reinforced concrete beams were investigated as compared to reinforced beams. As a result of the practical analysis, several important results were obtained:

1) Effective utilisation of both the materials can be achieved using steel and GFRP reinforcements in a hybrid way. Steel provides ductility to the structure and prevents brittle failure, while GFRP increases corrosion resistance and increases the overall strength of the beams.

2) In hybrid beams(steel and GFRP), the ultimate load was higher than in conventional steel-reinforced beams and increased by 4 % to 9.2 % depending on the reinforcement method and the percentage of steel reinforcement. The hybrid beams also showed a significant increase in deflection , which improved the ductility characteristics.

3) Hybrid beams thus increase the flexural capacity and ductility of beams , thus making it a good option in concrete structures.

4) The deformability index of hybrid beams is greater than traditional steel reinforced beams by about 7% to 28% , hence making it a better option.

5) Thus hybrid steel-GFRP provides a promising alternative solution for modern structures even in harsh environments. The integration of GFRP into hybrid systems can lead to improved energy absorption and serviceability making it a valuable addition to modern construction practices.

6) Hybrid beams increase the durability of RCC structures and contribute to sustainability by reducing environmental impact.

6 RESEARCH SIGNIFICANCE

There is a growing need in the use of GFRP rebars for reinforcement along with traditional steel in concrete structures. A hybrid combination of GFRP reinforcement and traditional steel reinforcement has the potential to become a commonly used solution in the construction industry, contributing to more resilient and sustainable infrastructure. However, further research and development and the creation of standardized design codes are necessary.

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