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Comparative Analysis of Glass Fiber Rebar and Steel Rebar

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Abstract: *Reinforced concrete structures commonly use steel rebars due to their high strength and ductility; however, steel is susceptible to corrosion in aggressive environments. Glass Fiber Reinforced Polymer (GFRP) rebars have emerged as a promising alternative because of their high tensile strength, lightweight nature, and excellent corrosion resistance. This study presents a comparative analysis of steel and GFRP reinforced concrete beams under flexural loading. The performance of both reinforcement materials was evaluated based on load-carrying capacity, deflection behavior, crack patterns, failure modes, durability, and cost considerations. Experimental results showed that steel reinforced beams exhibited ductile behavior, better crack control, and lower deflection, whereas GFRP reinforced beams demonstrated higher corrosion resistance and tensile strength but failed in a brittle manner with larger crack widths and higher deflections.*

Keywords: GFRP Rebar, Steel Rebar, Reinforced Concrete Beam, Flexural Behavior, Deflection, Crack Pattern, Failure Mode, Durability, Corrosion Resistance, Structural Performance

I. INTRODUCTION

Reinforced concrete (RC) is one of the most widely used construction materials in modern infrastructure due to its strength, durability, and versatility. Traditionally, steel reinforcement bars (rebars) have been used in concrete structures to resist tensile stresses and improve structural performance [1]. Steel rebars possess high tensile strength, ductility, and good bond characteristics with concrete, making them suitable for a wide range of structural applications [2].

Despite these advantages, steel reinforcement is highly susceptible to corrosion when exposed to moisture, chlorides, and aggressive environmental conditions. Corrosion of steel rebars leads to cracking, spalling of concrete cover, reduction in load-carrying capacity, and increased maintenance costs, thereby reducing the service life of structures [3]. This issue is particularly significant in marine structures, bridges, tunnels, and wastewater treatment plants where corrosion-related deterioration is common [4].

Among various FRP types, Glass Fiber Reinforced Polymer (GFRP) rebars have gained considerable attention because of their high tensile strength, lightweight nature, corrosion resistance, and electromagnetic neutrality [5]. GFRP reinforcement can significantly enhance the durability and longevity of reinforced concrete structures, especially in aggressive environments [6].

As a result, GFRP reinforced concrete members generally experience larger deflections and wider crack widths under service loads due to their lower modulus of elasticity [7]. Furthermore, failure of GFRP reinforced members is often sudden and brittle, requiring special design considerations to ensure adequate safety and serviceability [8].

Recent advancements in material technology and design standards have encouraged the use of GFRP rebars in bridges, marine structures, parking garages, and coastal infrastructure. Several international design guidelines such as ACI 440 and CSA S806 provide recommendations for the design and application of GFRP reinforced concrete structures [9].

The findings of this study will help engineers and researchers evaluate the suitability of GFRP rebars as a sustainable alternative to steel reinforcement in modern construction practices [10].

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II. PROBLEM STATEMENT

Steel reinforcement has been widely used in reinforced concrete structures due to its high strength and ductility; however, its susceptibility to corrosion in aggressive environments such as coastal regions, marine structures, and chemical plants leads to structural deterioration, increased maintenance costs, and reduced service life. Glass Fiber Reinforced Polymer (GFRP) rebars have emerged as a potential alternative because of their excellent corrosion resistance, lightweight nature, and high tensile strength. Nevertheless, GFRP rebars exhibit lower stiffness, larger deflections, wider crack widths, and brittle failure behavior compared to steel reinforcement. Therefore, a comprehensive comparative analysis is required to evaluate the structural performance, durability, serviceability, and economic feasibility of GFRP and steel rebars in reinforced concrete beams, enabling engineers to select the most suitable reinforcement material for sustainable and long-lasting infrastructure.

III. OBJECTIVES

- To compare the mechanical properties and structural behavior of reinforced concrete beams reinforced with Steel Rebars and GFRP Rebars.
- To evaluate and compare the load-carrying capacity, deflection characteristics, and crack patterns of Steel and GFRP reinforced concrete beams under flexural loading.
- To investigate the failure modes, ductility, and serviceability performance of beams reinforced with Steel and GFRP rebars.
- To assess the durability, corrosion resistance, and suitability of GFRP rebars as an alternative to conventional steel reinforcement in different environmental conditions.

IV. LITERATURE SURVEY

Benmokrane et al. (2017) presented a comprehensive study on the behavior of GFRP-reinforced concrete structures. The researchers found that GFRP rebars provide excellent corrosion resistance and high tensile strength compared to conventional steel reinforcement. However, due to their lower modulus of elasticity, GFRP-reinforced members exhibited higher deflections and wider cracks under service loads.

El-Salakawy and Benmokrane (2003) investigated the bond performance of GFRP and steel reinforcement in concrete beams. Their study revealed that GFRP bars possess lower bond strength than steel rebars and require longer development lengths. The results emphasized the importance of proper anchorage design when using GFRP reinforcement in concrete structures.

Grace et al. (2005) evaluated the long-term performance of GFRP-reinforced bridge decks exposed to harsh environmental conditions. The study demonstrated that GFRP reinforcement significantly improved durability and resistance to corrosion, resulting in reduced maintenance requirements and extended service life compared to steel-reinforced structures.

Bank (2006) analyzed the structural and economic feasibility of Fiber Reinforced Polymer reinforcement in civil engineering applications. The study concluded that although GFRP rebars have a higher initial cost than steel, their lower maintenance costs and superior durability make them more economical over the lifespan of structures exposed to aggressive environments.

Ahmed et al. (2019) conducted experimental testing on reinforced concrete beams reinforced with steel and GFRP rebars under flexural loading. The results showed that GFRP-reinforced beams achieved comparable or higher ultimate load capacities but exhibited brittle failure modes and greater deflections than steel-reinforced beams, which displayed ductile behavior.

Nanni and Dolan (1993) examined the serviceability performance of GFRP-reinforced concrete members. Their research highlighted that the lower stiffness of GFRP reinforcement leads to increased deflection and crack widths. The study recommended stricter serviceability criteria and design provisions to ensure the safe application of GFRP reinforcement in structural elements.

Comparison Table

Author & Year	Method Used	Advantages	Limitations
Benmokrane et al. (2017)	Flexural testing of GFRP beams	High strength, corrosion resistant	Higher deflection
El-Salakawy & Benmokrane (2003)	Bond strength analysis	Better understanding of bond behavior	Lower bond strength than steel
Grace et al. (2005)	Bridge deck performance study	Excellent durability	Higher initial cost
Bank (2006)	Lifecycle cost analysis	Lower maintenance cost	Limited ductility
Ahmed et al. (2019)	Comparative beam testing	Higher load capacity of GFRP	Brittle failure
Nanni & Dolan (1993)	Serviceability evaluation	Improved design recommendations	Larger crack widths and deflection

V. WORKING OF SYSTEM

The working of the proposed study involves the preparation, casting, curing, and testing of reinforced concrete beams reinforced with Steel Rebars and GFRP Rebars. The objective is to compare their structural performance under flexural loading.

Step 1: Preparation of Beam Mould and Casting

The beam mould was prepared according to the required dimensions. Concrete was mixed using cement, sand, coarse aggregate, and water in the specified proportions. The concrete was poured into the mould containing the reinforcement cage and compacted properly to remove air voids.

Fig.1: Casting of Reinforced Concrete Beam

Step 2: Curing of Beam

After casting, the beams were allowed to set and were cured for 28 days to achieve the required strength. Proper curing ensured adequate hydration and improved durability of the concrete.

Step 3: Test Setup

The cured beam specimens were placed on a loading frame machine. The beam was simply supported at both ends and positioned accurately under the loading arrangement. Measuring instruments such as load cells and dial gauges were installed to record load and deflection values.

Step 4: Application of Load

Load was applied gradually through the hydraulic loading frame until failure occurred. The load and corresponding deflection values were recorded continuously during the test.

Fig.2: Flexural Testing of Reinforced Concrete Beam

Step 5: Observation of Crack Pattern

During loading, crack initiation and propagation were carefully observed. The crack patterns, spacing, and width were marked on the beam surface for further analysis.

Step 6: Failure Analysis

After reaching the ultimate load, the failure mode of each beam was examined. The behavior of steel-reinforced and GFRP-reinforced beams was compared based on crack formation, deflection, load-carrying capacity, and failure characteristics.

Fig.3: Analysis of Failure Pattern of Beam

Step 7: Comparison of Results

The recorded data were analyzed to compare the structural performance of Steel Rebar and GFRP Rebar reinforced beams. Parameters such as ultimate load, deflection, crack width, ductility, and durability were evaluated to determine the suitability of each reinforcement material.

Fig.4: Comparative Performance of Steel and GFRP Reinforced Beams

VI. SYSTEM DESIGN

1. Beam Design

The reinforced concrete beam was designed with specified dimensions and reinforcement details. Two types of reinforcement, namely Steel Rebar and GFRP Rebar, were used to prepare separate beam specimens for comparison.

2. Material Selection

The materials used for beam casting included cement, sand, coarse aggregate, water, and reinforcement bars. Identical concrete materials were used for both beams to ensure a fair comparison.

3. Reinforcement Arrangement

The reinforcement cage was fabricated according to the design requirements. Steel reinforcement was used in one beam, while GFRP reinforcement was used in the other beam with the same reinforcement layout.

4. Beam Casting

Concrete was mixed and poured into the prepared moulds containing the reinforcement cages. Proper compaction was carried out to eliminate air voids and achieve uniform strength.

5. Curing Process

The cast beams were cured for 28 days to attain the required compressive strength and durability before testing.

6. Experimental Testing

The cured beams were tested under flexural loading using a loading frame machine. Load was applied gradually until failure while load and deflection readings were recorded.

7. Observation and Analysis

Crack formation, deflection behavior, ultimate load capacity, and failure patterns were observed and compared for both Steel and GFRP reinforced beams.

8. Cost Analysis

A cost comparison was carried out to evaluate the economic feasibility of both reinforcement materials.

Sr. No.	Material	GFRP Beam (₹)	Steel Beam (₹)
1	Cement	280	280
2	Sand	90	90
3	Aggregate	65	65
4	Reinforcement	290	425
Total		**725**	**860**

Cost Analysis Description

The cost analysis shows that the total cost of the GFRP reinforced beam was ₹725, whereas the total cost of the steel reinforced beam was ₹860. Although the costs of cement, sand, and aggregate remained the same for both beams, the reinforcement cost differed significantly. The GFRP beam resulted in an overall cost reduction of approximately 15.7% compared to the steel beam. Therefore, GFRP reinforcement proved to be a more economical option in this experimental study while also providing additional benefits such as corrosion resistance and lower maintenance requirements.

VII. RESULTS

The experimental investigation was conducted on reinforced concrete beams reinforced with Steel Rebars and GFRP Rebars. Both beam specimens had identical dimensions of 1000 × 200 × 300 mm and were cast using M25 grade concrete to ensure a fair comparison of their structural performance under flexural loading. The beams were tested under monotonic loading until failure, and parameters such as ultimate load, deflection, strain, crack pattern, and failure mode were recorded.

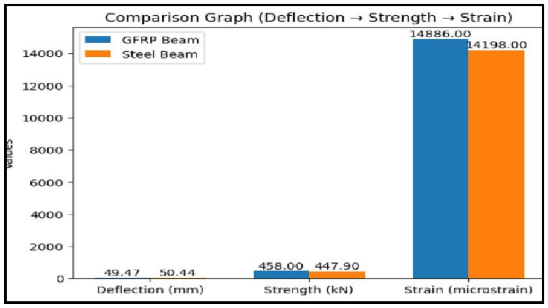

Fig.5: Comparison Graph of Deflection, Strength and Strain of Steel and GFRP Reinforced Beams.

The results showed that the Steel Rebar Beam carried an ultimate load of 447.9 kN and exhibited a maximum deflection of 49.47 mm. The beam displayed ductile behavior, where significant deformation occurred before failure. This ductile nature provides warning signs prior to collapse and contributes to better structural safety and serviceability. The load-deflection graph indicates a gradual increase in deflection with increasing load, confirming the energy absorption capability and toughness of steel reinforcement.

The GFRP Rebar Beam achieved a slightly higher ultimate load of 458 kN, indicating its superior tensile strength and load-carrying capability. However, the beam experienced a maximum deflection of 50.44 mm, which was higher than that of the steel reinforced beam. The GFRP beam failed in a brittle manner without noticeable yielding, resulting in sudden failure. The load-deflection curve shows that the GFRP beam maintained nearly linear behavior up to failure due to the absence of a yielding stage.

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The comparison graph of deflection, strength, and strain further highlights the differences between the two reinforcement materials. The GFRP beam exhibited a higher strain value of approximately 14886 microstrain compared to 14198 microstrain for the steel beam. Although both beams demonstrated similar load-carrying capacities, the higher strain and deflection values observed in the GFRP beam indicate its lower stiffness. The graph also confirms that GFRP reinforcement provides higher tensile performance while steel reinforcement offers better serviceability characteristics.

A comparison of the results indicates that GFRP reinforcement offers higher strength and excellent resistance to corrosion, making it suitable for aggressive environmental conditions such as marine and coastal structures. On the other hand, steel reinforcement provides better ductility, lower deflection, and improved serviceability performance, making it more suitable for structures where safety and deformation control are critical.

Overall, the study concludes that while GFRP reinforced beams demonstrate slightly higher load-carrying capacity and strain resistance, steel reinforced beams exhibit superior ductility and structural behavior. Therefore, the selection of reinforcement material should be based on the specific performance requirements, durability requirements, and environmental conditions of the structure.

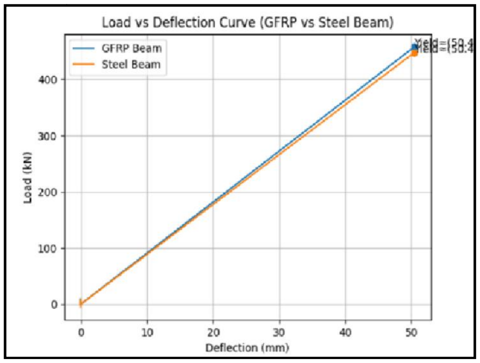

Fig.6: Load vs Deflection Curve for Steel and GFRP Reinforced Beams.

VIII. CONCLUSION

The present study compared the structural performance of reinforced concrete beams reinforced with Steel Rebars and GFRP Rebars under flexural loading. The experimental results revealed that the GFRP reinforced beam achieved a slightly higher ultimate load capacity of 458 kN compared to 447.9 kN for the steel reinforced beam, demonstrating its high tensile strength and corrosion resistance. However, the GFRP beam exhibited greater deflection and failed in a brittle manner, whereas the steel reinforced beam showed ductile behavior with better crack control and serviceability. Although steel reinforcement remains preferable for structures requiring ductility and safety under loading, GFRP reinforcement offers significant advantages in corrosive environments due to its lightweight nature, durability, and resistance to corrosion. Therefore, the selection between steel and GFRP reinforcement should be based on the structural requirements, serviceability criteria, and environmental conditions of the project.

IX. FUTURE SCOPE

The present study can be extended by investigating the long-term performance of GFRP reinforced concrete structures under different environmental conditions such as marine, coastal, and chemical exposure. Future research may focus on the behavior of GFRP reinforced beams under cyclic, seismic, and impact loading conditions to evaluate their suitability for critical infrastructure. Advanced studies can also be carried out on hybrid reinforcement systems combining steel and GFRP bars to achieve both ductility and corrosion resistance. Additionally, the use of different FRP materials such as Carbon Fiber Reinforced Polymer (CFRP) and Basalt Fiber Reinforced Polymer (BFRP) can be explored and compared with GFRP. Further experimental and analytical investigations on large-scale structural elements will help develop more efficient design guidelines and promote the wider adoption of FRP reinforcement in sustainable construction practices.

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