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Comparative Study of GFRP & Conventional Steel in Road Drainage Design

Sanket Karande[1], Amruta Bhosale[2], Pranav Patil[3], Aryan Patil[4], Ashitosh Bodake[5], Dharmraj Kakade[6]
D.Y. Patil College of Engineering and Technology, Kasaba Bawada, Kolhapur – 416 006, Maharashtra, India

Abstract: ***The Glass Fibre Reinforced Polymer (GFRP) is becoming a good alternative to regular steel reinforcement in concrete structures. It is mainly used because it does not rust easily, is lightweight, and has high strength. This study explains the use of GFRP bars in reinforced concrete and examines their performance in construction. It also discusses the benefits, disadvantages, and future scope of GFRP in the construction industry.***

The study highlights that GFRP reinforcement significantly enhances the durability of concrete structures, especially in those aggressive environmental conditions such as marine, coastal, and chemical exposure areas, where steel reinforcement is prone to the corrosion. Additionally, GFRP bars are lightweight and non-magnetic too, which improves handling, reduces dead load, and makes them suitable for specialized structures.

Keywords: GFRP, Strength, RC structure, Drainage structure, durability, sustainability,

I. INTRODUCTION

Glass Fibre-Reinforced Polymer (GFRP) bars are non-corrosive, lightweight, high-strength reinforcement increasingly used as an alternative to steel in reinforced concrete, especially where corrosion is a major concern. Glass Fibre reinforced polymer (GFRP) is a lightweight composite made from glass Fibres embedded in a polymer matrix. It was first used for electrical and marine components in the 1930s and is now common in automotive, aerospace, construction, and power systems due to its strength, durability, and corrosion resistance. In beams and slabs, GFRP reinforcement can give similar or higher ultimate load capacity than steel but with larger deflections and wider cracks due to low modulus and brittle bar behaviour Glass Fiber-Reinforced Polymer (GFRP) bars are increasingly popular in structural engineering because they are completely rust-proof and highly durable in the harsh alkaline environment of concrete. While other advanced materials like carbon fiber or basalt fiber have been tested, GFRP provides better long-term reliability against chemical breakdown. As a result, using these non-metallic bars drastically reduces the need for costly structural repairs, making them an excellent choice for infrastructure exposed to moisture or road salt. This review explains the use of Glass Fiber Reinforced Polymer (GFRP) bars as an alternative reinforcement material in flexural members. With the growing availability on sustainable construction, GFRP bars have gained attention as a viable substitute for conventional steel reinforcement. Their high strength to weight ratio, excellent corrosion resistance, and also nonmagnetic nature make them particularly suitable for modern infrastructure applications.

The paper presents a detailed evaluation of the mechanical properties, durability, and bond behavior of GFRP bars when used in flexural members, based on an extensive review of existing research studies. It highlights how these properties influence the structural performance and long-term reliability of reinforced concrete elements.

For the review discusses the key challenges and limitations associated with the use of GFRP bars, such as the issues related to design standards, cost considerations, and material behavior under such different loading conditions. Finally, recommendations are provided to guide future research and to support the effective implementation of GFRP reinforcement in practical engineering applications.

A. Introduction of FRP

In the construction, the reinforcement materials are used to increase the strength and durability of structures like beams, slabs, and columns. Mostly, steel has been the most commonly used reinforcement material is because of its high strength and ductility. However, steel has some disadvantages such as corrosion, heavy weight, and maintenance issues.

Fibre Reinforced Polymer (FRP) is a modern alternative to steel reinforcement. It is made by combining fibres (like glass, carbon, or aramid) with a polymer resin. FRP bars are lightweight, corrosion-resistant, and have high tensile strength, making them suitable for harsh environments such as coastal areas and drainage systems.

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B. History

Feasibility studies of GFRP reinforcing bars began in the 1980s, and their applications gained much attention to prevent corrosion of steel reinforcing bars in the late 1990s.The applications are for both new constructions, where the steel bars are either partially or fully replaced by GFRP bars, or for rehabilitation of deteriorated structures or construction of new structures. In 1986, the world's first highway bridge deck with GFRP rebars was built in Germany. In the beginning of 21stCentury extensive studies and trials conducted with GFRP rebars in countries like America, Russia and Europe. ACI & ASTM has prepared their first edition of standards of GFRP rebars in 2001.In the coastal area and chloride rich environmental conditions GFRP rebars gained more popularity because of its non-corrosive nature. Since then, through the different research programs and developments, constructions using GFRP-reinforced concrete have been carried out throughout Europe, America, and Japan. One of the earliest documented industrial motivations was corrosion of rebars in highway bridges in the 1960s, where de-icing salts caused severe steel deterioration and prompted exploration of GFRP rebars as an alternative. The early exploration of GFRP in structural applications became more visible around the 1980s, particularly in the United States, with research and applications focusing on composite bridge decks and GFRP-reinforced highway structures.

C. Properties of FRP

The Fibre Reinforced Polymer (FRP) and steel are two important materials used in construction and engineering, both with distinct characteristics and applications. FRP is a composite material made by combining strong fibres such as glass, carbon, or aramid with a polymer resin that binds them together, resulting in a lightweight yet high-strength material with excellent resistance to corrosion and environmental effects. Different types of FRP include glass fibre reinforced polymer (GFRP), which is economical and widely used, carbon fibre reinforced polymer (CFRP), known for its very high strength and stiffness, and aramid fibre reinforced polymer (AFRP), which offers good impact resistance and durability. In contrast, steel is an alloy primarily composed of iron and carbon, and it is one of the most commonly used construction materials due to its high tensile strength, ductility, and versatility.

Depending on the carbon content and alloying elements, steel can be classified into mild steel, medium carbon steel, high carbon steel, stainless steel, and alloy steel, each having specific properties suited to different applications. While steel is strong and cost-effective, it is susceptible to corrosion unless properly protected, whereas FRP provides a corrosion-resistant and lightweight alternative, making both materials essential in modern construction depending on the structural requirements.

D. Benefit

GFRP is much lighter than steel (about 20–25% of steel's density) yet can offer similar or higher tensile strength, giving excellent strength-to-weight performance [1] Corrosion and chemical resistance GFRP bars and profiles are non-corrosive and resist chemical and microbiological attack, making them attractive in marine, waterside, and aggressive environments and extending service life with low maintenance [2] Energy absorption and ductility with proper systems: GFRP-bar slabs in glass-fibre-reinforced concrete reached high ultimate load with 17% higher energy absorption and acceptable ductility when the system was optimized [3]

E. Comparison

Parameter	GFRP Bars (12mm & 10mm)	Steel Bars (12mm & 10mm)	Remarks
Total Length of Bars	100.00 m	100.00 m	Same BBS layout
Total Weight	1707.6 kg	6761.2 kg	Steel weight ~4 times higher
Rate per Kg	₹160 / kg	₹55 / kg	GFRP has higher unit cost
			Steel cost is higher

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Total Cost	₹3,12,576	₹4,25,259	overall
Density	Low	High	Affects dead load
Corrosion Resistance	Excellent (non-corrosive)	Poor (Corrosion prone)	Major advantage of GFRP
Maintenance Cost	Very Low	High	Steel needs protection
Service Life	Long (50+ years)	Moderate	GFRP durable
Suitability for Drainage	Highly Suitable	Conventional	GFRP preferred in wet zones

Table: Parameters of GFRP & Steel bars

F. Drawback

Low modulus, stiffness, and ductility: GFRP bars have a low elastic modulus, low stiffness, and low ductility compared with steel, leading to linear-elastic behaviour up to sudden brittle failure without a yield plateau [4]

Lower compressive strength: Compressive strength is only about 50–77% of tensile strength, raising concern for compression-dominated members like columns 1[5]

Low ductility in nature of GFRP rebars has created some limitations of use in RCC structures. So, at present it is not a 100% replacement for steel. Fire resistance properties are little less than steel rebars. Due to its brittle nature, it cannot be bend or weld like steel on site while using in RCC structures. GFRP Rebars are not recyclable like steel Rebars. Not Efficient in Earthquake prone zone

G. Influence factor

Temperature and time: Degradation rises sharply above about 60 °C, with higher temperatures and longer exposure accelerating strength loss in water, alkali, seawater and concrete pore solutions [6]

Moisture diffusion & interface damage: Long-term degradation is mainly driven by moisture ingress through the resin-rich layer and fibre–matrix interface debonding [7]

Low modulus and stiffness: Their lower elastic modulus leads to larger deflections and wider, deeper cracks, which often control design and reduce shear contribution of concrete

II. POTENTIAL PROBLEMS IN EXISTING STRUCTURES

A. Strength

Poor initial design, construction and maintenance can all lead to damage and loss of strength in the structure. Moreover, in severe situations such as earthquakes and hurricanes, the strength of the structure may not be enough to carry these sudden loads.

B. Durability

In civil engineering and infrastructure construction, structural degradation can also be caused by low durability, especially in areas with high levels of chloride in the air, such as coastal areas. After the original structure has eroded, the additional expense of repairing the degraded structure and replacement

C. Sustainability

Sustainable development has become a widely concerned issue, and according to the current trend of environmental protection, this will become more important in the future and extend to other fields. So, how to improve the sustainability of buildings should not only be 3.

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III. METHODOLOGY

The methodology adopted with understanding the fundamental concepts and properties of GFRP materials, followed by the preparation of road drainage and highway design layouts incorporating GFRP reinforcement. GFRP bars are then procured and test specimens are prepared for experimental evaluation. Tensile and compressive strength tests are conducted on both GFRP and conventional steel bars to assess their mechanical behaviour. The experimental results are compared with theoretical predictions to analyse performance differences. Finally, a cost–benefit and environmental analysis is carried out to determine the economic viability and sustainability of using GFRP in road drainage design compared to conventional steel reinforcement. considered from aspects of design, such as green roofs and improving the utilization rate of natural light and ventilation, but also innovative materials to reduce pollution from the source.



Figure: Collection of material

IV. SOLUTIONS WITH GFRP

A. Strength

Alkaline concrete pore solution and seawater degrade tensile strength; strength loss increases with temperature, smaller diameter, bent bars, and flexural stress. Up to ~40% tensile strength loss after a few months in hot alkaline/seawater conditions has been reported.[8] FRP winding / confinement: Winding extra GFRP layers (±83.3°) around the bar substantially boosts compressive strength and ductility. Three winding layers increased compressive strength by 63–74%; two layers gave near-optimal strength and ductility. For short and slender FRP-confined bars, at least two winding layers changed behaviour to more ductile, bi-linear stress–strain and clearly higher compressive capacity; higher slenderness still reduces strength

[9] Flexural members: Using GFRP bars in UHPC or glass-fibre-reinforced concrete slabs increased flexural strength by about 55% and improved ultimate displacement and energy dissipation compared with steel in some UHPC beams 9, and produced slab ultimate capacities close to steel-reinforced slabs with higher energy absorption

B. Durability

Lower-pH binders / low-alkalinity concrete (LAC): Reducing pore solution pH from 13 to ~11 nearly doubles tensile strength retention after 12 months at 60 °C (27.6% → 45.9%) and lowers diffusion rates' bars in low-alkalinity concrete exposed to seawater show shear strength retention almost equal to bare bars, while ordinary concrete causes much greater degradation 11.[10]

Thermoplastic GFRP bars show high durability in alkaline conditions with ~87% tensile strength and 100% modulus retention and acceptable creep under sustained load.

C. Sustainability

Sustainable development has become a widely concerned issue, and according to the current trend of environmental protection, this will become more important in the future and extend to other fields. So, how to improve the sustainability of buildings should not only be considered from aspects of design, such as green roofs and improving the utilization rate of natural light and ventilation, but also innovative materials to reduce pollution from the source.

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. No	Diameter (Bar) (mm)	Cross-Sectional Area (mm^2)	Ult. Tensile Force (kN)	Strain (%)	Min. Required Guaranteed Ult. Tensile Force (KN)	Min. Required Ult. Tensile Strain (M6 grade as per ASTM D7957 / G8 grade – IS 18256
1	8.09	51.40	51.96	1.53	≥ 27 (M6 grade as per ASTM D7957) ≥ 40 (G8 grade as per IS 18256)	≥ 1.1 %
2	8.10	51.53	48.76	1.67		
3	8.09	51.40	50.52	1.68		
4	8.10	51.53	49.20	1.55		
5	8.11	51.66	54.56	1.50		
Avg.	8.10	51.50	51.00	1.58		

Table: Tensile Strength Test: Test Method: ASTM D7205-2021 & ASTM D7957M17

V. PROSPECT OF FRP

A. Existing structures

In construction, reinforcement materials are used to increase the strength and durability of structures like beams, slabs, and columns. Traditionally, steel has been the most commonly used reinforcement material because of its high strength and ductility. However, steel has some disadvantages such as corrosion, heavy weight, and maintenance issues.[11]

B. Future Design

Sustainable drainage systems (SuDS) manage stormwater by mimicking natural water cycles through a connected treatment train that emphasizes source control, natural conveyance, and infiltration. Some important devices such as bio-retention rain gardens, permeable pavements, and green roofs are used to filter pollutants and reduce peak runoff volumes near the source. To safely implement these elements, engineers conduct hydrological modelling and assess structural load capacities to ensure the infrastructure can handle extreme precipitation events. Ultimately, transitioning from conventional concrete networks to these multi-functional green solutions requires an integrated approach that balances hydraulic efficiency, material costs, and community amenity value.[12]

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VI. TESTS REPORTS OF STEEL BARS

Test Certificate

Name of Company : DR D. Y. PATIL ENGG. COLLEGE
Address : DYPCET CIVIL

To : CIVIL ENGG DEPT
Address : B TECH CIVIL- A Project (AAB)

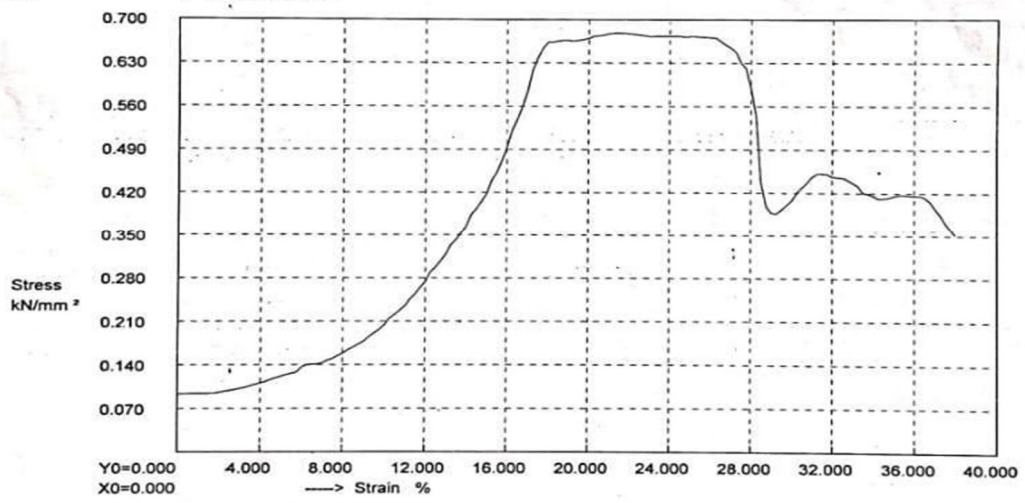
Sample Identification : 08mm TOR STEEL-1

Machine : AUTOMake Univers

Input Data : File Name : DYPCET CIVIL PROJECT-4 , Record No. : 1 , Date : 12/08/2025
: Sample Type – Round Solid Bar Area : 50.286 mm ²
: Diameter = 8 mm
: Gauge Length : 40 mm

Results of : Tension Test
Ult./Break Load : 34.100 kN YS/UTS Ratio : 0.281
Disp. at FMAX : 8.500 mm
Max. Disp. : 15.200 mm
Ult. Stress : 0.678 kN/mm ²
Elongation : 38.000 %
Yield Stress : 0.191 kN/mm ²
* Note : Yield Calculated By Offset method as per ASTM E8 at .2 % Strain offset

Graph : Stress Vs Strain



For DR D. Y. PATIL ENGG. COLLEGE

VII. CONCLUSION

The study of the research paper highlights that Glass Fibre Reinforced Polymer (GFRP) bars are a highly effective alternative to conventional steel reinforcement in drainage system, especially in structures exposed to moisture, chemicals, and aggressive environmental conditions. Through analysis and application in drainage system design, it is observed that GFRP provides excellent corrosion resistance, high tensile strength, and significantly lower weight compared to steel. These properties help in reducing the dead load of the structure and increasing its service life.

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In the design of drainage systems, where continuous exposure to water leads to rapid corrosion of steel, GFRP reinforcement proves to be a more durable and maintenance-free solution. Although the initial material cost of GFRP may be higher, the overall lifecycle cost becomes economical due to reduced maintenance, longer durability, and ease of handling.

However, GFRP also having a certain limitation such as lower modulus of elasticity, brittle failure behaviour, and less ductile in the construction industry. Proper design considerations, codes, and guidelines must be followed while replacing steel with GFRP in structural elements

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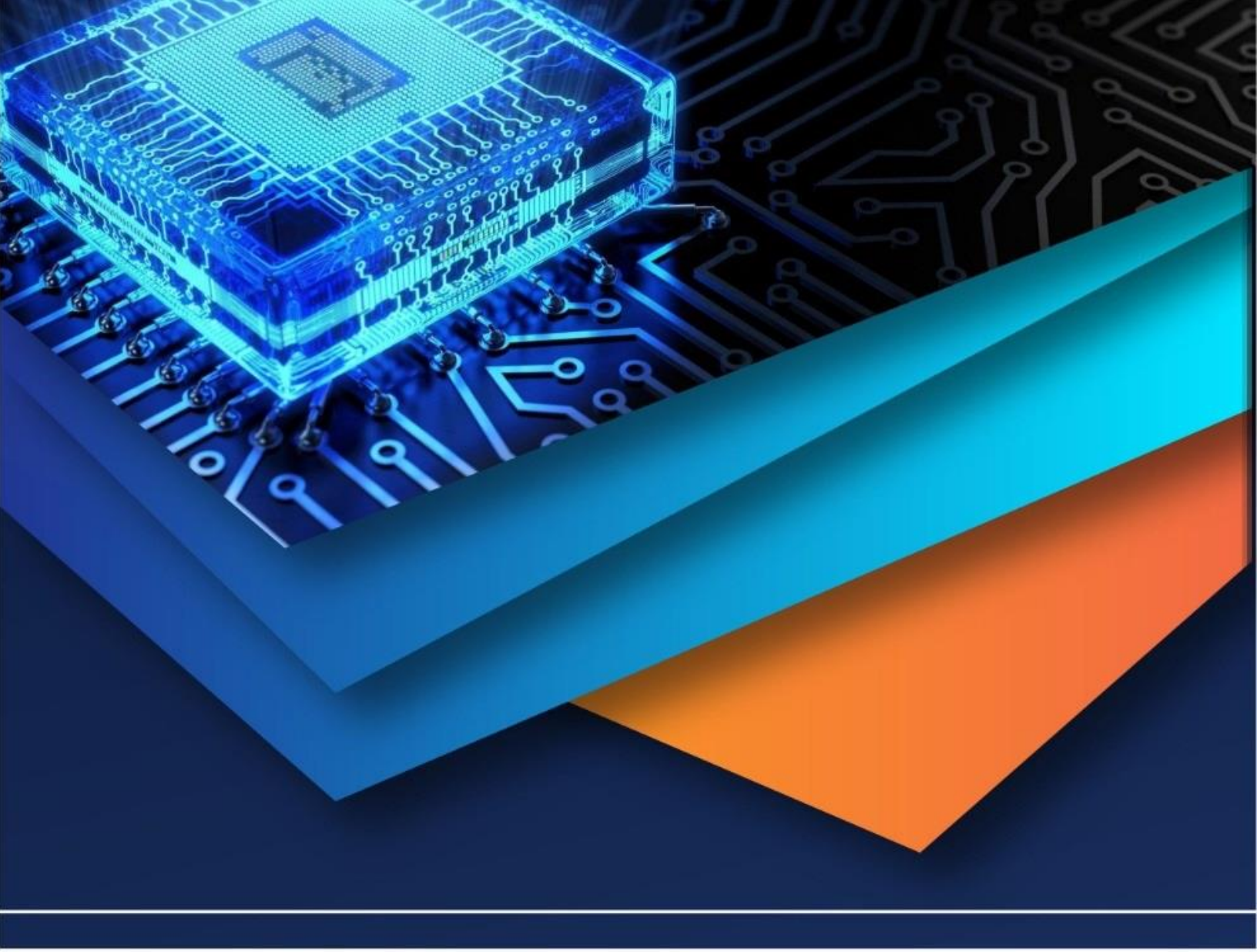
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