Investigation of HYSD Steel Bars and GFRP Bars

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Abstract

The evolving demands of modern construction, especially in corrosive and high-performance environments, have led to the exploration of alternative reinforcement materials beyond traditional steel. This research investigates the mechanical behavior, bond performance, and environmental durability of **High Yield Strength Deformed (HYSD) steel bars** and **Glass Fiber Reinforced Polymer (GFRP) bars**, with the aim of understanding their comparative strengths and limitations in reinforced concrete applications. A comprehensive experimental program was carried out, including tensile strength tests, flexural performance evaluations, and pullout tests to assess the bond characteristics between the bars and concrete. HYSD steel bars, known for their excellent ductility and well-established structural reliability, were used as the benchmark. GFRP bars demonstrated significantly higher tensile strength but lower modulus of elasticity, resulting in reduced stiffness and ductility, which are critical for energy dissipation and crack control in structural elements. Furthermore, the study investigated the effects of accelerated environmental exposure, simulating aggressive conditions such as moisture, temperature variations, and chemical attacks. Pullout tests post-exposure revealed a notable reduction in bond strength for GFRP-reinforced specimens, underscoring the importance of understanding long-term durability. Despite this, the non-corrosive nature of GFRP bars presents a substantial advantage in structures exposed to marine or chemically aggressive environments. The findings highlight the trade-offs between the two reinforcement materials: HYSD steel remains superior in terms of ductility and bond reliability, whereas GFRP offers enhanced corrosion resistance and tensile strength. The research concludes that while GFRP bars have the potential to replace steel in specific applications, further refinement in bond performance and design approaches is essential for their broader adoption in structural engineering. The study recommends ongoing research and development of design standards to support the safe and efficient integration of GFRP bars in reinforced concrete systems.

Keywords: GFRP, HYSD, structural tests, reinforced specimens

I. Introduction

The evolution of materials used in civil engineering has been marked by a continuous pursuit of strength, durability, and sustainability. In the context of reinforced concrete structures, the choice of reinforcement plays a critical role in determining not only the structural integrity but also the long-term performance and maintenance costs of a building. For decades, High Yield Strength Deformed (HYSD) steel bars have served as the conventional choice for reinforcement due to their excellent mechanical properties, including high tensile strength, ductility, and a well-established record of performance under various loading and environmental conditions. However, the corrosion susceptibility of steel, especially in aggressive environments such as coastal or industrial areas, has prompted the search for alternative materials with superior durability characteristics. Among the promising alternatives, Glass Fiber Reinforced Polymer (GFRP) bars have gained significant attention in both academic and industrial domains. GFRP bars, being composed of high-strength glass fibers embedded within a polymer matrix, offer exceptional resistance to corrosion, chemical attack, and electromagnetic interference. Their lightweight nature also presents logistical advantages, such as ease of handling, reduced transportation costs, and lower dead loads in structural applications. Despite these advantages, GFRP bars are not yet widely adopted as a direct substitute for steel in conventional construction. The primary concerns revolve around their relatively low modulus of elasticity, reduced ductility, and different failure mechanisms compared to steel. This study focuses on an in-depth investigation and comparison of HYSD steel bars and GFRP bars through a comprehensive series of experimental evaluations. The aim is to critically assess the mechanical behavior of both materials under tensile loading and to analyze their bond characteristics with concrete. Tensile strength, strain behavior, failure modes, and bond stress development are among the key parameters examined in this investigation. Furthermore, the project includes pullout tests to understand the bond behavior under various simulated environmental exposures, thereby offering insights into long-term durability. HYSD steel bars are characterized by their deformed surface, which enhances mechanical interlock with concrete and significantly contributes to bond strength. These bars generally exhibit ductile failure, a desirable trait in structural applications, allowing structures to undergo deformation and warning signs before catastrophic collapse. On the other hand, GFRP bars, despite having superior tensile strength on a weight basis, tend to exhibit brittle failure without significant deformation, raising concerns about their performance under seismic or dynamic loading conditions. The bond between reinforcement and concrete is a crucial factor in reinforced concrete design, as it governs load transfer and crack control. Unlike steel, which exhibits strong mechanical and chemical bonding with concrete, GFRP bars often rely predominantly on surface treatments or mechanical interlocks for bonding. This study investigates these characteristics through carefully designed laboratory tests, seeking to quantify the difference in bond behavior and its implications for structural performance. In addition to mechanical properties, environmental durability is a central focus of this research. GFRP bars are inherently non-corrosive, offering an extended service life in chloride-laden or chemically aggressive environments. Accelerated aging tests simulating prolonged exposure to moisture, temperature cycles, and chemical attacks are included in this study to evaluate the long-term integrity of GFRP-concrete bonding. These tests provide critical data for engineers considering the use of GFRP in infrastructure projects like marine structures, sewage systems, and bridges. The cost and sustainability aspects of both reinforcement types are also explored. While the initial cost of GFRP bars is higher compared to HYSD steel bars, the reduced maintenance needs and extended lifespan in corrosive environments may result in lower life-cycle costs. Additionally, the environmental impact of GFRP production, though lower in use-phase emissions due to the absence of corrosion, involves more energy-intensive manufacturing processes. These trade-offs are examined to provide a holistic view of material performance from a sustainability standpoint. This investigation aligns with global trends in civil engineering aimed at developing durable, cost-effective, and environmentally responsible construction practices. With the rising demand for resilient infrastructure capable of withstanding harsh environmental conditions, the exploration of alternative reinforcements like GFRP becomes increasingly relevant. At the same time, a realistic assessment of their limitations is necessary to ensure safe and effective implementation in structural applications. A major contribution of this study lies in its empirical approach. The results presented are grounded in experimental data obtained from tensile testing and bond behavior evaluations using standardized methods and equipment such as the Universal Testing Machine (UTM). The analysis of stress-strain curves, modulus of elasticity, ultimate load capacities, and failure patterns provides quantitative evidence to support conclusions regarding the comparative performance of HYSD steel and GFRP bars. Moreover, this research emphasizes the need for updated design codes and construction practices to accommodate the distinct behavior of GFRP reinforcement. Current standards are predominantly developed for steel reinforcement and may not adequately address the linear-elastic, brittle nature of GFRP. Through this investigation, gaps in existing knowledge and practice are highlighted, laying the groundwork for future studies and code development. The findings of this study are also intended to inform civil engineers, contractors, and policymakers about the practical considerations involved in selecting reinforcement materials. Factors such as availability, ease of fabrication, compatibility with construction techniques, and regional climate influences are discussed to guide informed decision-making. While the current research is limited to 10 mm and 12 mm diameter bars, the implications of the findings extend to a broader range of applications. Future work may involve larger bar diameters, hybrid reinforcement systems combining GFRP and steel, and the integration of smart monitoring systems to assess structural health in real-time. The advancement of material science and structural engineering practices continues to present new opportunities for innovation in this field. This research paper presents a rigorous comparative analysis of HYSD steel bars and GFRP bars, bridging the gap between traditional reinforcement and emerging composite materials. It highlights the distinct mechanical behaviors, bond performances, and environmental responses of both materials while offering critical insights into their application potential in modern civil engineering projects. Through its detailed methodology, empirical results, and contextual discussion, the study contributes to the growing body of knowledge aimed at enhancing structural resilience and sustainability in construction.

II. Literature Review

The quest to find alternatives to conventional steel reinforcement in concrete structures has led researchers to explore materials such as Glass Fiber Reinforced Polymer (GFRP) bars, particularly for environments susceptible to corrosion.

This section reviews significant contributions from past studies that inform the current research on HYSD steel and GFRP bars.

1]. Dr. Sunil Kumar Patil and Ankita Vilas Dhongade (2021) conducted a comprehensive study on the use of GFRP in civil construction, emphasizing its application in bridge elements and structural retrofitting. Their review noted that while GFRP offers advantages such as lightweight nature and corrosion resistance, its cost and sensitivity to fire hinder widespread adoption. The Near Surface Mounted (NSM) method was discussed for improving bond strength and flexural capacity of concrete elements reinforced with GFRP. Prabhakar Sangave and Amit Rao (2015) investigated the use of GFRP in coastal and marine structures, focusing on durability under wet-dry cycling and saltwater exposure. Their findings highlighted the superior corrosion resistance of GFRP bars compared to traditional reinforcement, although they noted concerns related to the bars' brittle behavior and the challenges in achieving sufficient bond strength. Yi Chen et al. (2020) performed accelerated aging tests to examine the durability of GFRP bars under environmental stressors such as high temperature, alkaline, saline, and chloride exposure. Their study concluded that GFRP bars degrade significantly under high temperatures and alkaline conditions, impacting both tensile and bond strength. The authors suggested further improvements in material composition and matrix formulation.

2]. Bogachan Basaran et al. (2020) developed a novel plastic gripping mechanism for GFRP bars during tension testing. Their work demonstrated that properly designed grips (using PA6G plastic) could prevent premature bar failure during testing, providing more accurate tensile strength results. The study reinforced the importance of appropriate anchorage systems for GFRP bars in experimental and real-world scenarios. Toufeeq Anwar et al. (2020) explored the bond strength of Basalt GFRP (BGFRP) bars embedded in concrete with steel slag aggregates. The results indicated improved bond strength with the use of steel slag, suggesting that aggregate composition plays a critical role in optimizing GFRP-concrete interaction. Their findings also showed that GFRP performance was comparable to HYSD bars in certain configurations. S.F. Husain et al. (2018) compared GFRP and steel bars in reinforced concrete members, particularly in terms of flexural strength and ductility. The authors observed that GFRP-reinforced beams exhibited wider cracks and more deflection under load due to their lower stiffness. Despite this, GFRP bars were found to perform well in durability and strength when properly designed and detailed.

3]. Deepti Hazari et al. (2023) used ETABS and STAAD.Pro to compare multistorey buildings reinforced with GFRP and HYSD bars. GFRP-reinforced structures showed less displacement and base shear under seismic and wind loads, along with reduced structural weight. The study highlighted the potential of GFRP in earthquake-resistant design but stressed the need for more research into flexural performance and long-term deflection control Rifat Resatoglu and Muhammad Sagir Muhammad (2019) studied the performance of GFRP and steel bars in RC members exposed to aggressive coastal environments. Their experimental findings revealed that GFRP-reinforced beams resisted corrosion effectively and performed better in terms of bond with concrete, though steel bars showed higher overall load capacity and stiffness**.** Ahmed et al. (2019) presented a comprehensive review of GFRP-reinforced concrete structures, summarizing global design approaches and experimental evidence. The study called for improved standardization of GFRP detailing in concrete design, especially for seismic and high-load-bearing applications.

4]. Amr E. Abdallah & Ehab F. El-Salakawy (2022) explored the seismic behavior of GFRP-reinforced columns. The study confirmed that although GFRP performs well in terms of corrosion resistance and weight reduction, its brittle nature makes it less suitable for energy-dissipating members unless combined with other materials like steel. Mostafa Ibrahim et al. (2023) proposed a hybrid approach using steel-GFRP reinforcement to overcome the brittleness of GFRP and leverage the ductility of steel. Their findings revealed promising improvements in structural resilience, especially under flexural loading.

Summary of Research Gaps

From the reviewed literature, several research gaps emerge:

1. **Bond Strength Degradation**: Multiple studies indicated that GFRP bars suffer significant bond strength loss in high-temperature and alkaline environments. However, consistent long-term comparative data with HYSD steel bars is lacking.

2. **Ductility and Brittle Failure**: The brittle nature of GFRP bars is a known limitation, especially under dynamic or seismic loads. Despite efforts to address this, the literature lacks practical design guidelines to compensate for the absence of plastic deformation.

3. **Design Standardization**: Existing standards are mostly tailored to steel. Limited national and international codes exist for the proper structural detailing of GFRP bars, particularly in load-critical applications.

4. **Composite Use Strategies**: Few studies comprehensively evaluate hybrid use (steel + GFRP) in critical zones of concrete members to balance durability with ductility.

5. **Cost-Benefit Analysis**: While many studies mention cost implications, systematic analyses comparing initial, maintenance, and lifecycle costs of GFRP vs. steel remain sparse.

How This Study Addresses the Gaps

This project fills several of the above gaps through direct experimental investigation:

- **Direct Comparison**: The tensile strength, elongation, and stress-strain behavior of both 10mm and 12mm HYSD and GFRP bars were tested under uniform lab conditions, offering clear performance benchmarks.
- **Bond Durability Assessment**: By performing pullout tests and simulated environmental exposure, the study evaluates how bond characteristics evolve over time, addressing long-term durability concerns.
- **Material Cost and Weight Analysis**: The inclusion of comparative cost and weight data provides a more holistic understanding of the trade-offs between HYSD steel and GFRP bars.
- **Realistic Testing Setup**: Using a Universal Testing Machine and precise measurement tools, the study mimics field conditions to ensure reliable, real-world applicability of the results.
- **Foundation for Standardization**: The study highlights practical insights that can inform future design guidelines, particularly for integrating GFRP in infrastructure exposed to corrosive environments.

III. Current Uses of GFRP and the Need for This Assessment

In recent years, Glass Fiber Reinforced Polymer (GFRP) bars have emerged as a viable alternative to traditional steel reinforcement in various sectors of civil engineering. Their corrosion resistance, lightweight, and high tensile strength-to-weight ratio make them especially suitable for environments where steel suffers from long-term degradation. GFRP is being actively used in marine infrastructure, bridge decks, tunnels, parking garages, chemical plants, and wastewater treatment facilities all of which are prone to corrosion due to moisture, chloride exposure, or chemical aggressiveness. In the transportation sector, several state Departments of Transportation (DOTs) in the United States and Canada have approved GFRP-reinforced bridge elements due to their ability to significantly reduce life-cycle maintenance costs. In bridge decks, for example, GFRP helps mitigate chloride-induced corrosion from deicing salts. Similarly, in coastal regions, structures like piers, jetties, and retaining walls benefit from GFRP's non-corrosive nature, contributing to longer service life and reduced repair frequency. Additionally, GFRP's non-magnetic and non-conductive properties make it suitable for applications near sensitive equipment, such as in MRI rooms, power substations, and railway signaling infrastructure. Despite these successes, GFRP is not without limitations. Its brittle failure mode, lower modulus of elasticity, and reduced ductility compared to steel pose significant design and safety challenges, particularly in applications where energy absorption and plastic deformation are crucial, such as in seismic zones. Furthermore, limited design codes and inconsistent guidelines across countries hinder widespread adoption in general-purpose structural elements. Many current uses of GFRP are therefore confined to non-critical components or hybrid systems where GFRP complements, but does not replace, steel reinforcement. This brings us to the critical need for comprehensive assessments such as the one presented in this study. While previous research has often focused either on the tensile strength of GFRP or its corrosion resistance in isolation, there remains a lack of direct, side-by-side experimental comparisons between GFRP bars and conventional HYSD steel bars under controlled conditions. Such comparative analysis is essential to bridge the knowledge gap in understanding how GFRP truly performs under identical loading, bonding, and environmental exposure scenarios. The present assessment is particularly timely, given the rising global interest in sustainable construction and the push toward low-maintenance, long-lifespan infrastructure. As construction codes gradually evolve to include provisions for composite reinforcements, empirical data from localized experimental studies can play a crucial role in shaping policy, guiding design practices, and educating practitioners about the feasibility and limitations of GFRP usage. Moreover, the Indian construction industry, which is rapidly expanding, especially in coastal and industrial zones, stands to benefit immensely from adopting corrosion-resistant alternatives like GFRP. However, there is a scarcity of region-specific data concerning the behavior of GFRP under Indian environmental conditions and in comparison with commonly used HYSD steel bars. By focusing on tensile strength, elongation, cost, weight, and bond behavior, this project provides valuable insights that can inform both academic research and practical applications in real-world construction.

IV. Methodology

Materials and Devices Used in Testing

a) Universal Testing Machine (UTM):

The Universal Testing Machine (UTM) is a versatile electromechanical testing device used for determining the mechanical properties of materials under tension, compression, bending, and shear forces. In this study, a 400-kilonewton capacity UTM was employed for conducting tensile strength tests on both HYSD steel and GFRP bars. The machine applies a controlled axial load to the specimens until failure, capturing critical data such as elongation, ultimate tensile strength, and fracture behavior. It also supports testing for material hardness and is widely used across various engineering disciplines for evaluating raw materials and finished components.

b) Vernier Caliper:

The Vernier Caliper is a precision instrument used to measure internal and external dimensions with high accuracy, typically up to 0.01 mm. In this experiment, it was utilized to determine the initial diameter and length of both HYSD and GFRP specimens, which are essential for accurate calculation of stress and strain during tensile testing.

c) Weighing Machine:

A laboratory-grade weighing machine was used to measure the mass of each specimen. Accurate weight determination is necessary for evaluating the density and cost-efficiency of the materials. The weighing device used in this study offers readability in grams and milligrams, ensuring precision in measurement for comparative analysis.

Tests Performed on GFRP and HYSD Steel Bars

Sr. No.	Test	Relevant IS Code	Equipment Used
1	Ultimate Tensile Strength	IS 1786:2008	Universal Testing Machine
2	Density Measurement	—	Weighing Machine
3	Cost Comparison	—	Market Data
4	Pull-Out Test (to be performed)	IS 2770	Universal Testing Machine
5	Fire Resistance	IS 15103:2002	Oven

	(to be performed)		
6	Electrical Conductivity (planned)	IS 5082:1998	—

Specimen Setup

The test specimens, consisting of HYSD steel and GFRP bars of varying diameters, were mounted on the Universal Testing Machine between the fixed upper crossbeam and the movable lower crossbeam. The UTM applied tensile force via the lower crosshead, while the specimen's response load, elongation, and fracture point was monitored in real time through a digital control panel. This setup allowed precise evaluation of the stress-strain behavior of the materials. Special care was taken to align the specimens properly and prevent premature failure due to grip slippage or eccentric loading.

Fig i: Testing setup

Testing Procedure

1.Sample Preparation:

Specimens of HYSD steel and GFRP bars were prepared according to standardized dimensions. The diameter and length of each bar were measured using a Vernier Caliper. The surfaces of the samples were inspected to ensure they were free from defects such as notches, rust, or irregularities that could influence test results.

2. Test Setup:

The bars were securely clamped into the grips of the calibrated UTM. The alignment was carefully verified to ensure that the axial load would be applied centrally, preventing bending or eccentric stress during testing. The machine was configured to perform a uniaxial tensile test, applying force until fracture or until the pre-defined strain limit was reached.

3. Tensile Testing:

The UTM gradually applied increasing tensile force to the specimen. During this process, the machine recorded elongation and the corresponding tensile load. Data collected allowed the generation of stress-strain curves, and calculation of key mechanical properties including:

- Yield Strength (for HYSD steel),
- Ultimate Tensile Strength (UTS),
- Modulus of Elasticity,
- Elongation at Break,
- Fracture Mode (ductile or brittle).

4. Data Collection and Analysis:

Real-time load and elongation data were recorded at regular intervals. Using these values, stress and strain were computed, and plotted to obtain stress-strain curves for each bar type and diameter. From these curves, the elastic modulus and ultimate strength were derived.

5.Comparative Assessment:

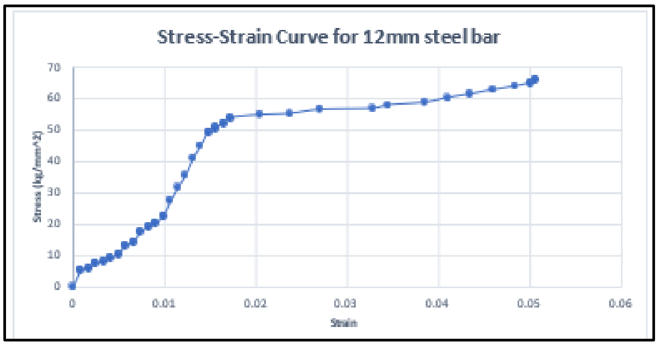
The mechanical behavior of the two materials was evaluated based on:

- **HYSD Steel Bars**: Known for their high tensile strength, ductility, and established bonding performance with concrete. The steel samples typically exhibited plastic deformation prior to fracture, reflecting ductile failure.
- **GFRP Bars**: Characterized by their corrosion resistance and high strength-to-weight ratio, but showed brittle failure under tension with limited elongation. The linear stress-strain response highlighted their elastic but low ductility behavior.

This methodical setup and testing protocol enabled a comprehensive comparison of the performance characteristics of HYSD steel and GFRP reinforcement bars, providing crucial empirical data for evaluating their suitability in various civil engineering applications.

Observations and Results

The tensile strength and elongation characteristics of both HYSD steel bars and GFRP bars were investigated through controlled laboratory testing using a Universal Testing Machine (UTM).



12mm Steel Bars Stress and Strain Curve

Calculation: -

Length of Rods (L) = 610mm,

Diameter of Rods (D) = 12mm

Area = 3.14/4*D2 = 3.14/4*122

Area = 113.09 mm2

Stress = Load/Area =600/113.09

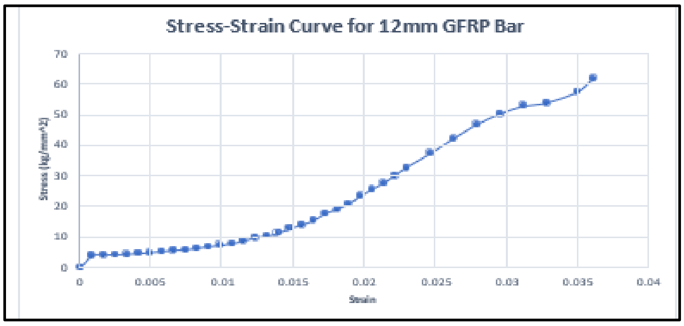
Stress = 5.305 kg/ mm2

Strain = Elongation/length of rod = 0.5/610

Strain = 0.0008197

Modulus of Elasticity = Stress/Strain = 6472.720842 Kg/mm2

The specimens were prepared in 10 mm and 12 mm diameters, and various mechanical properties including stress, strain, modulus of elasticity, and fracture behavior were recorded.



12mm GFRP Stress and Strain Curve

Calculation: -

Length of Rods (L) = **610mm**, Diameter of Rods (D) = **12mm**

Area =3.14/4*D^2 = 3.14/4*12^2 Area =**113.09mm^2**

Stress = Load/Area =450/113.09 Stress = **3.979131 kg/mm^2**

Strain = Elongation/length of rod = 0.5/610 Strain = **0.0008197**

Modulus of Elasticity = Stress/Strain = **4854.540631 Kg/mm^2**

10 mm Steel Bars Stress and Strain Curve

Calculation: -

Length of Rods (L) = **610mm**, Diameter of Rods (D) = **10mm**

Area = 3.14/4*D^2 = 3.14/4*10^2 , Area = **78.50mm^2**

Stress = Load/Area =500/113.09

Stress = **6.366993506 kg/mm^2**

Strain = Elongation/length of rod = 0.5/610 Strain = **0.0008197**

Modulus of Elasticity = Stress/Strain = **4854.540631 Kg/mm^2**

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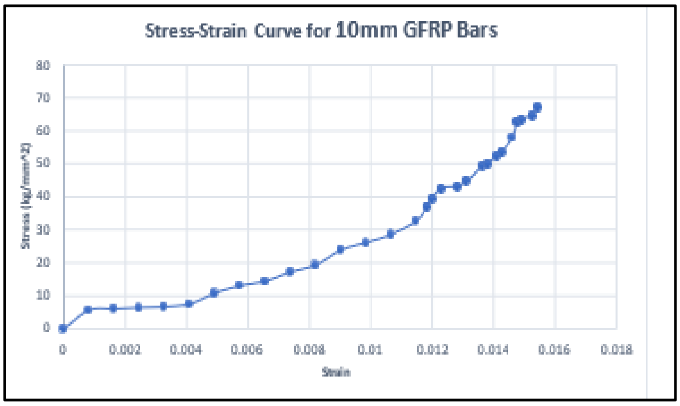

10 mm GFRP Stress and Strain Curve

Calculation: -

Length of Rods (L) = **610mm**, Diameter of Rods (D) = **10mm**

Area = $3.14/4*D^2 = 3.14/4*10^2$ Area = **78.50 mm^2**

Stress = Load/Area =450/113.09 Stress = **5.729637505 kg/mm^2**

Strain = Elongation/length of rod = 0.5/610, Strain = **0.0008197**

Modulus of Elasticity = Stress/Strain = **4854.540631 Kg/mm^2**

Results

Elongation Test Result

Bar Dia.	**10mm Bars**		**12mm Bars**	
Bars type	GFRP Bars	HYSD Bars	GFRP Bars	HYSD Bars
Elongation	9.4mm	8.9mm	22mm	30.8mm

Tensile Test Result

Bar Dia.	**10mm Bars**		**12mm Bars**	
Bars type	GFRP Bars	HYSD Bars	GFRP Bars	HYSD Bars
Ultimate Tensile Strength	5260kg	6100kg	7000kg	7460kg

Weight and Cost Test Result

Bar Diameter	**Test**	**HYSD steel bars**	**GFRP Bars**
10mm	Weight	0.364 kg/m^3	0.085 kg/m^3
12mm	Weight	0.470 kg/m^3	0.123 kg/m^3
10mm	Cost	Rs. 55 per kg	Rs. 140 per kg
12mm	Cost	Rs. 53 per kg	Rs. 160 per kg

GFRP 12mm and 10mm Dia. Breaking

GFRP and HYSD Bars Weight Analysis

The results clearly revealed significant differences in the performance of these two materials, reflective of their distinct structural compositions and mechanical responses. For the 12 mm HYSD steel bars, the stress-strain curve indicated a well-defined yield point, followed by a plastic deformation phase and a gradual fracture, typical of ductile materials. The steel bars achieved an ultimate tensile strength of approximately 7460 kg, with a maximum elongation of 30.8 mm. This behavior illustrates the ability of steel to undergo substantial deformation before failure, an essential quality for structural applications subjected to dynamic and seismic loads. The modulus of elasticity values further supported the superior stiffness of steel, confirming its suitability in critical load-bearing components. In comparison, the 12 mm GFRP bars exhibited a completely different mechanical profile. The stress-strain curve was linear up to failure, indicating brittle behavior with no plastic deformation. The GFRP bars reached an ultimate tensile strength of about 7000 kg, which is slightly lower than the steel bars, but with a much lower elongation of 22 mm. This behavior highlights the limitation of GFRP in ductile performance, though it shows promise in high-strength applications where flexibility is not a primary requirement. The relatively lower modulus of elasticity recorded for GFRP bars further emphasizes their susceptibility to deflection under sustained loads. For 10 mm specimens, the results followed a similar trend. The 10 mm HYSD steel bars demonstrated a higher tensile capacity, reaching a maximum load of 6100 kg with elongation of 8.9 mm. In contrast, the 10 mm GFRP bars sustained a lower ultimate load of 5260 kg and fractured at around 9.4 mm elongation. Though the elongation value for GFRP appeared close to that of steel in the 10 mm category, the material's response was still brittle and sudden, with minimal energy absorption before failure. From the comparison of stress-strain behavior across both diameters, it is evident that HYSD steel consistently outperformed GFRP in terms of ductility, strain capacity, and deformation characteristics. However, GFRP bars, despite their brittleness, showcased relatively high tensile strength-to-weight ratios and lightweight properties, making them suitable for specific applications, especially in corrosive environments where long-term durability is prioritized over ductility. Additionally, weight and cost comparisons indicated that GFRP bars are significantly lighter—approximately four times lighter than HYSD steel bars—but also more expensive. For example, a 12 mm GFRP bar costs approximately Rs. 160 per kg, compared to Rs. 53 per kg for steel. Despite the cost, GFRP bars offer advantages in transportation, handling, and corrosion resistance, potentially offsetting the initial investment over the structure's lifecycle. Overall, the experimental data validate the structural reliability of HYSD steel for conventional applications, while also demonstrating that GFRP bars are a viable alternative in environments where corrosion resistance, lightweight, and longevity are more critical than ductility. The study provides essential insight into the mechanical performance of both materials and supports the rationale for selective or hybrid use in structural engineering applications.

Conclusion

The comparative experimental study of HYSD steel bars and GFRP bars has provided critical insights into their mechanical behavior, highlighting both the advantages and constraints associated with each material. HYSD steel demonstrated superior performance in terms of tensile strength, ductility, and energy absorption, which are essential properties in structural elements subjected to dynamic loads or seismic activity. Its pronounced yield plateau and post-yield deformation before failure affirm its role as a dependable reinforcement material in conventional reinforced concrete structures. In contrast, GFRP bars displayed a linear elastic behavior followed by sudden brittle failure, indicating their limited ductility. However, the material still achieved commendable tensile strength, particularly in the 12 mm diameter specimens, approaching that of steel. GFRP's lightweight nature—approximately four times lighter than steel—along with its excellent resistance to corrosion, positions it as an attractive alternative in specialized applications, particularly in marine, coastal, or chemically aggressive environments. Although GFRP bars were found to be costlier per kilogram, their reduced self-weight can lead to overall savings in transportation, handling, and maintenance, especially over the lifespan of a structure. Ultimately, this study concludes that while HYSD steel remains the preferred choice for general-purpose structural applications requiring ductility and resilience, GFRP bars are promising candidates for projects where weight reduction, corrosion resistance, and long-term durability are prioritized over plastic deformation capacity. The findings support the selective use of GFRP in reinforced concrete design and suggest potential in hybrid reinforcement systems, where both materials can be synergistically employed to optimize performance and sustainability. Further research into long-term durability, fire resistance, and large-scale behavior of GFRP in varied environmental conditions is recommended to enhance its acceptance in mainstream civil engineering applications.

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