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# A study on Steel Rebars Replacement with GFRP Rebars in Coastal Concrete Structure

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**Abstract-** Reinforced concrete structures are widely used in modern infrastructure due to their strength and durability. However, in coastal and aggressive environments, conventional steel reinforcement suffers from corrosion due to chloride attack, leading to deterioration, reduced service life, and increased maintenance cost. This study investigates the feasibility of replacing conventional steel rebars with Glass Fiber Reinforced Polymer (GFRP) rebars in coastal concrete structures. The research focuses on comparing the mechanical behavior, durability, and structural performance of steel and GFRP reinforced concrete specimens under simulated marine conditions. Experimental investigations were carried out on concrete cubes and beams to evaluate compressive strength, flexural strength, and durability characteristics. The results indicate that compressive strength is not significantly affected by the type of reinforcement, while GFRP rebars exhibit comparable flexural strength but higher deflection due to lower modulus of elasticity. However, GFRP demonstrates superior corrosion resistance and long-term durability compared to steel.

**Keywords-** GFRP Rebars, Steel Reinforcement, Coastal Structures, Corrosion Resistance, Durability, Flexural Strength, Sustainable Construction.

## I. INTRODUCTION

Reinforced concrete (RC) structures form the backbone of modern infrastructure, including bridges, buildings, marine structures, and pavements. Traditionally, steel has been used as reinforcement due to its high tensile strength, ductility, and excellent bond with concrete. However, one of the major drawbacks of steel reinforcement is its susceptibility to corrosion, particularly in coastal regions where chloride ions penetrate the concrete and initiate corrosion processes. Corrosion of steel reinforcement leads to cracking, spalling, and eventual structural failure. This significantly reduces the lifespan of structures and increases maintenance and repair costs. With the growing demand for sustainable and durable construction materials, there is a need to explore alternative reinforcement materials. Glass Fiber Reinforced Polymer (GFRP) rebars have emerged as a promising alternative due to their high tensile strength, lightweight nature, and complete resistance to corrosion. GFRP is composed of glass fibers embedded in a polymer matrix, making it non-metallic and immune to electrochemical corrosion. Despite its advantages, GFRP has certain limitations such as lower modulus of elasticity, brittle failure behavior, and different bonding characteristics with concrete. Therefore, a detailed investigation is necessary to evaluate its performance compared to conventional steel reinforcement. This research aims to analyze the behavior of GFRP reinforced concrete and assess its suitability as a replacement for steel in coastal environments.

## II. LITERATURE REVIEW

The study on flexural behavior of GFRP and steel rebars (2025) showed that steel beams have higher load capacity while GFRP beams exhibit higher deflection but better corrosion resistance and durability, making them suitable for aggressive environments; research on jointed reinforced concrete pavement using GFRP (2025) confirmed its excellent performance in marine conditions with reduced corrosion and satisfactory structural behavior; a comparative study (2025) highlighted that GFRP offers superior corrosion resistance and durability while steel provides higher ductility, recommending hybrid systems; experimental comparison (2025) revealed GFRP has comparable strength and better durability with satisfactory bond strength; studies on smart technologies (2025) emphasized challenges like low ductility and bond strength in GFRP requiring further optimization; sustainability assessment (2025) showed GFRP reduces maintenance and lifecycle cost despite higher initial cost; bond behavior research (2024) indicated weaker bonding and wider cracks in GFRP but good durability, suggesting surface treatment improvements; lifecycle assessment (2024) confirmed GFRP reduces CO<sub>2</sub> emissions and maintenance making it more sustainable; studies on replacement of steel (2024) showed improved durability but increased deflection and brittle failure recommending hybrid systems; further analysis (2024) confirmed high strength and corrosion resistance of GFRP with lower stiffness; hybrid reinforcement studies (2023) proved improved ductility and durability; marine slab study (2022) demonstrated enhanced durability and construction efficiency using GFRP; experimental research (2020) showed high tensile strength and improved bonding with surface treatment; column performance study (2020) indicated improved load capacity and crack control; feasibility studies (2020) confirmed environmental benefits with concern of brittle failure; comparative study (2019) highlighted higher strength in steel and better durability in GFRP with more cracks and deflection; flexural studies (2018) confirmed adequate strength and corrosion resistance of GFRP; slab design study (2017) indicated need for improved design guidelines; seismic study (2004) showed good strength but low ductility in GFRP frames; and early research (2002) concluded that FRP improves durability and has strong future potential in civil engineering applications .

## III. PROPOSED METHODOLOGY

### 3.1 Materials Used

In this study, different materials were used to prepare reinforced concrete specimens and to compare the performance of steel and GFRP rebars under coastal conditions. The quality and properties of materials play a very important role in the strength, durability, and overall performance of concrete structures.

*The materials used in this study are explained below in detail:*

#### 3.1.1 Cement (OPC 53 Grade)

Ordinary Portland Cement (OPC) of 53 grade was used in this study. This cement is commonly used in structural works because it provides high early strength and good durability. The cement used was fresh, free from lumps, and stored properly to avoid moisture exposure. It plays an important role in binding the aggregates together and providing strength to the concrete.

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Figure 3.1: Cement (OPC 53 Grade)

### 3.1.2 Fine Aggregate

Fine aggregate used was natural river sand or manufactured sand (M-sand), which was clean and free from impurities like clay, silt, and organic matter. The sand was well graded and passed through 4.75 mm sieve. Fine aggregate helps in filling the voids between coarse aggregates and improves the workability of concrete.



**Figure 3.2: River Sand**

### 3.1.3 Coarse Aggregate

Coarse aggregates of size 20 mm were used in this study. These aggregates were hard, durable, and free from dust and impurities. Coarse aggregate provides strength and stability to concrete and forms the main skeleton of the concrete structure.



**Figure 3.3: Coarse Aggregate**

### 3.1.4 Steel Rebars (Fe500)

Fe500 grade steel reinforcement bars were used as conventional reinforcement. Steel rebars have high strength and good bonding with concrete. However, they are prone to corrosion in coastal environments, which reduces their effectiveness over time.

### 3.1.5 GFRP Rebars

Glass Fiber Reinforced Polymer (GFRP) rebars were used as an alternative to steel reinforcement. These rebars are made of glass fibers and polymer resin. They are lightweight, corrosion-resistant, and have high tensile strength. GFRP rebars were selected to study their performance in aggressive coastal conditions.

### 3.1.6 Water

Clean and potable water was used for mixing and curing of concrete. Water should be free from harmful substances like salts, oils, and acids, as they can affect the strength and durability of concrete.

## 3.2 Properties of Materials

The important properties of steel and GFRP rebars used in this study are compared in Table 3.1.

**Table 3.1: Comparison of Steel and GFRP Rebars**

Property	Steel Rebar	GFRP Rebar
Tensile Strength	415–500 MPa	800–1500 MPa
Modulus of Elasticity	200 GPa	40–60 GPa
Corrosion Resistance	Low	Excellent
Weight	Heavy	Lightweight

From the above table, it can be clearly seen that GFRP rebars have higher tensile strength compared to steel, which makes them strong in tension. However, their modulus of elasticity is lower, which means they are less stiff and may show more deflection. Steel rebars are heavy and prone to corrosion, especially in coastal environments. On the other hand, GFRP rebars are lightweight and completely resistant to corrosion, making them more suitable for marine conditions.

### 3.3 Methodology

The methodology of this study includes preparation of concrete specimens, reinforcement with steel and GFRP rebars, exposure to coastal conditions, and testing of specimens. The complete process is explained below:

#### 3.3.1 Preparation of Concrete Specimens

Concrete was prepared using cement, fine aggregate, coarse aggregate, and water in proper proportions. The mix design was done as per standard guidelines. The materials were mixed thoroughly to achieve uniform consistency. Concrete specimens such as cubes, beams, and slabs were cast using moulds. Proper compaction was done to remove air voids. After casting, the specimens were kept for 24 hours and then removed from moulds. They were cured in water for 7, 14, and 28 days.

#### 3.3.2 Reinforcement with Steel and GFRP

*Two types of reinforced concrete specimens were prepared:*

1. Specimens reinforced with steel rebars
2. Specimens reinforced with GFRP rebars

The reinforcement was placed properly inside the moulds before casting. Proper cover was maintained to ensure durability. The same size and arrangement of reinforcement were used for both steel and GFRP specimens for fair comparison.

#### 3.3.3 Exposure to Simulated Coastal Conditions

After curing, the specimens were exposed to simulated coastal conditions. For this purpose, saltwater (chloride solution) was used to represent marine environment. The specimens were either immersed in saltwater or subjected to wetting and drying cycles. This process helps in studying the effect of chloride attack on reinforcement. Steel reinforced specimens showed signs of corrosion after exposure, while GFRP specimens remained unaffected.

#### 3.3.4 Testing of Specimens

*After exposure, different tests were conducted to evaluate the performance of concrete specimens:*

**a) Compressive Strength Test:** Concrete cubes were tested in compression testing machine to determine compressive strength at different curing ages.



Figure 3.4: Compressive Strength Testing Using Compression Testing Machine

b) **Flexural Strength Test:** Beam specimens were tested under loading to study bending behavior, load carrying capacity, and deflection.



Figure 3.5: Flexural Strength Test

c) **Durability Test:** Durability was evaluated based on resistance to corrosion, crack formation, and overall condition of specimens after exposure to saltwater.

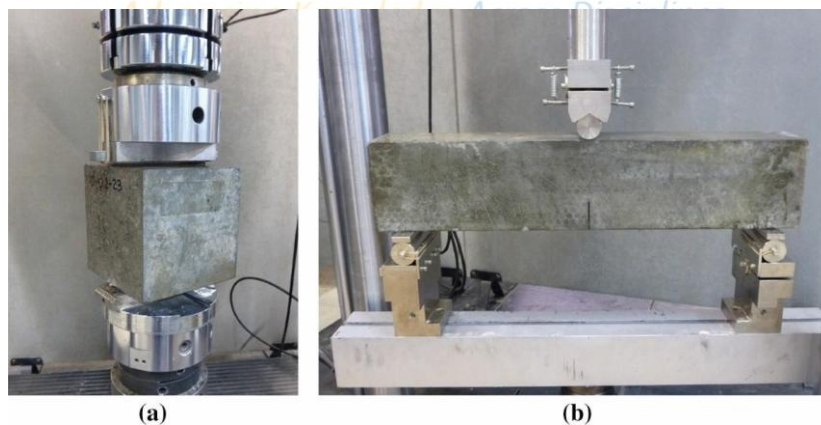


Figure 3.6: Durability Test

The methodology flowchart presented in Figure 3.7 clearly explains the complete step-by-step procedure followed in this study for evaluating the performance of steel and GFRP reinforced concrete under coastal conditions. In the first stage, all the required materials such as cement, fine aggregate, coarse aggregate, steel rebars, GFRP rebars, and water are carefully selected and tested to ensure their quality and suitability. After proper selection, the concrete mix is prepared according to the standard mix design to achieve the required strength and workability. In the next stage, concrete specimens such as cubes, beams, or slabs are cast using moulds. During casting, reinforcement is provided in two different forms: one set of specimens is reinforced with conventional steel rebars, and the other set is reinforced with GFRP rebars. Proper placement of reinforcement and adequate concrete cover are maintained to ensure accurate and fair comparison. After casting, the specimens are kept undisturbed for 24 hours and then removed from the moulds. The specimens are then subjected to curing, which is an important process to gain strength. They are immersed in clean water for a specified period, usually 7, 14, and 28 days. Proper curing helps in achieving the desired strength and durability of concrete. After curing, the specimens are exposed to simulated coastal conditions. This is done by immersing them in saltwater or subjecting them to alternate wetting and drying cycles to replicate the effect of chloride-rich marine environment.



6(a) Batching of Materials



6(b) Mixing of Ingredients



6(c) Reinforcement Cage



6(d) Beam Mould Ready for Casting



6(e) Pouring of Concrete



6(f) De moulding Under Progress



6(g) Test Beams Under Curing

Figure 3.7: Methodology showing preparation, reinforcement, exposure, and testing of concrete specimens.

Finally, various tests are conducted on the specimens to evaluate their performance. These tests include compressive strength test, flexural strength test, and durability assessment. The results obtained from steel reinforced specimens and GFRP reinforced specimens are compared in terms of strength, cracking behavior, corrosion resistance, and overall performance. This systematic methodology helps in understanding the effectiveness of GFRP rebars as a replacement for steel in coastal concrete structures.

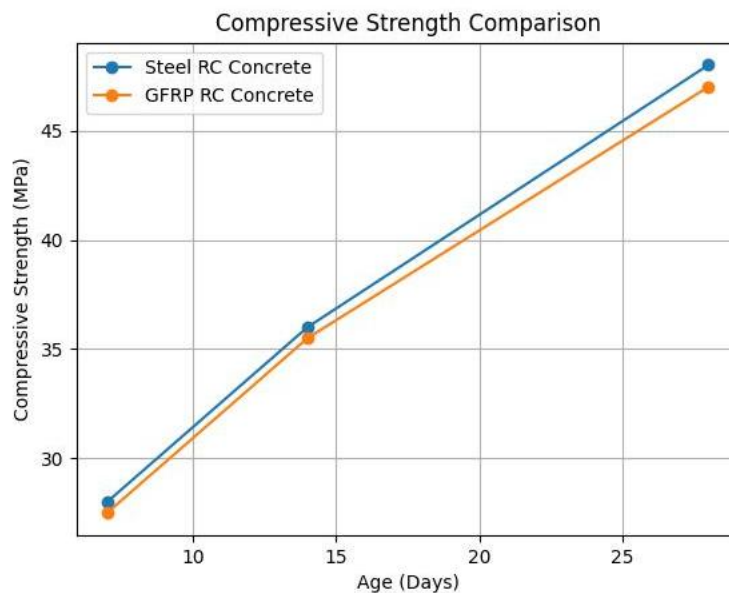
#### IV. RESULTS & DISCUSSION

##### 4.1 Compressive Strength Results

The compressive strength results of concrete specimens reinforced with steel and GFRP rebars are presented in Table 4.1 and Graph 4.1. The test was conducted at different curing periods of 7 days, 14 days, and 28 days to evaluate the strength development of concrete. From the results, it is observed that at 7 days, the compressive strength of steel reinforced concrete is 28 MPa, while GFRP reinforced concrete shows 27.5 MPa, which is almost equal. At 14 days, the strength increases to 36 MPa for steel and 35.5 MPa for GFRP, showing only a minor variation. At 28 days, both specimens achieve higher strength, with steel reaching 48 MPa and GFRP reaching 47 MPa, indicating no significant difference. From these results, it is clear that the compressive strength of concrete is mainly dependent on the quality of materials, mix design, and curing conditions, rather than the type of reinforcement used. The presence of either steel or GFRP rebars does not significantly influence the compressive strength values. Both types of reinforced concrete specimens successfully achieve the required target strength. Therefore, it can be concluded that replacing steel with GFRP rebars does not affect the compressive strength of concrete, and GFRP can be safely used as an alternative reinforcement without compromising compressive performance.

**Table 4.1: Compressive Strength Results**

Sr. No.	Age (Days)	Steel RC Concrete (MPa)	GFRP RC Concrete (MPa)	Observation
1	7 Days	28 MPa	27.5 MPa	Almost same strength
2	14 Days	36 MPa	35.5 MPa	Minor variation
3	28 Days	48 MPa	47 MPa	No major difference



**Graph 4.1: Compressive Strength Results**

**Observation:**

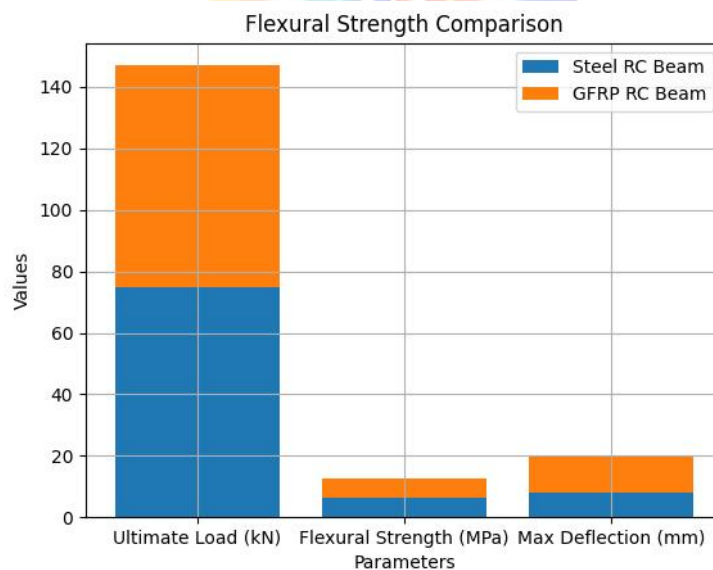
- Compressive strength depends on concrete, not reinforcement
- Difference between steel and GFRP is negligible
- Both achieve target strength

## 4.2 Flexural Strength Results

The flexural strength results of reinforced concrete beams using steel and GFRP rebars are presented in Table 4.2 and Graph 4.2. The test was conducted to evaluate the behavior of beams under bending load. From the results, it is observed that the ultimate load carrying capacity of steel reinforced beam is 75 kN, while the GFRP reinforced beam carries 72 kN, which is slightly lower but still comparable. The flexural strength of steel RC beam is 6.5 MPa, whereas GFRP RC beam shows 6.2 MPa, indicating that both have nearly equal strength under bending conditions. However, a significant difference is observed in the deflection values. The maximum deflection of the steel reinforced beam is 8 mm, while the GFRP reinforced beam shows a higher deflection of 12 mm. This is mainly due to the lower modulus of elasticity of GFRP rebars, which makes them less stiff compared to steel. As a result, GFRP beams tend to bend more under the same load. From the above results, it can be concluded that although the load carrying capacity and flexural strength of GFRP reinforced beams are almost similar to steel, the stiffness is lower, leading to higher deflection. Steel beams behave in a more rigid manner, while GFRP beams show more flexibility. Therefore, while using GFRP rebars, proper design considerations should be taken to control deflection and ensure serviceability of the structure.

**Table 4.2: Flexural Strength Results**

Sr. No.	Parameter	Steel RC Beam	GFRP RC Beam	Observation
1	Ultimate Load	75 kN	72 kN	Slightly lower in GFRP
2	Flexural Strength	6.5 MPa	6.2 MPa	Nearly equal
3	Maximum Deflection	8 mm	12 mm	GFRP shows more deflection



**Graph 4.2: Flexural Strength Results**

### Observation:

- Load capacity is almost similar
- GFRP beams deflect more
- Steel beams are stiffer

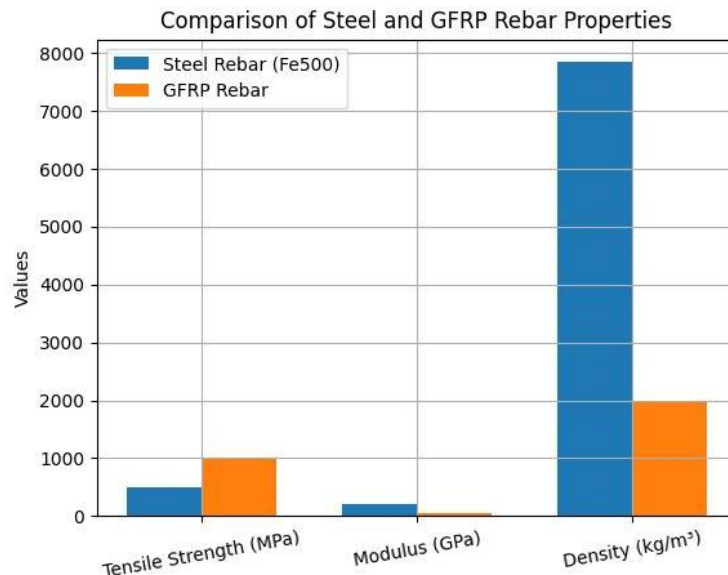
## 4.3 Material Strength

The material strength properties of steel rebars (Fe500) and GFRP rebars are presented in Table 4.3 and Graph 4.3. These properties play an important role in understanding the structural behavior of reinforced concrete elements. From the table, it is observed that the tensile strength of GFRP rebar is 1000 MPa, which is significantly higher than that of steel rebar, which is 500 MPa.

This indicates that GFRP has a higher capacity to resist tensile forces and can perform well in tension-controlled structural members. However, when considering the modulus of elasticity, steel has a much higher value of 200 GPa compared to GFRP, which has only 50 GPa. This shows that steel is much stiffer than GFRP, and hence steel reinforced members exhibit less deflection under load. On the other hand, GFRP, due to its lower stiffness, results in higher deflection, which must be considered during design. In terms of density, steel is much heavier with a density of 7850 kg/m<sup>3</sup>, whereas GFRP is lightweight with a density of about 2000 kg/m<sup>3</sup>. This makes GFRP easier to handle, transport, and install at construction sites. From these results, it can be concluded that GFRP rebars provide higher tensile strength and lower weight, making them advantageous in many applications, especially in coastal structures. However, due to their lower stiffness, proper design measures are required to control deflection. Overall, GFRP rebars show promising material properties and can be considered a suitable alternative to steel reinforcement in specific conditions.

**Table 4.3: Material Strength**

Property	Steel Rebar (Fe500)	GFRP Rebar
Tensile Strength	500 MPa	1000 MPa
Modulus of Elasticity	200 GPa	50 GPa
Density	7850 kg/m <sup>3</sup>	2000 kg/m <sup>3</sup>



**Graph 4.3: Material Strength**

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CONCLUSION

**Based on the experimental study and analysis carried out on reinforced concrete specimens using steel and GFRP rebars under coastal conditions, the following conclusions are drawn:**

- GFRP rebars show excellent resistance to corrosion, even after exposure to saltwater conditions, whereas steel rebars show clear signs of rusting and deterioration.
- The compressive strength of concrete is almost the same for both steel and GFRP reinforced specimens, which proves that the type of reinforcement does not affect compressive strength significantly.
- The flexural strength of GFRP reinforced beams is comparable to steel reinforced beams, although slightly lower due to difference in material properties.
- GFRP reinforced members show higher deflection compared to steel because of lower modulus of elasticity.
- Steel reinforced structures show ductile behavior (gradual failure with warning), while GFRP reinforced structures show brittle failure (sudden failure without warning).
- The crack width in GFRP reinforced beams is larger compared to steel, but no corrosion-related damage occurs in GFRP.
- Steel rebars undergo reduction in cross-section due to corrosion, which decreases structural strength over time.
- GFRP rebars maintain their original strength and shape even in aggressive coastal environments.

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