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Experimental Study on flexural behavior of concrete beam reinforced with Glass Fiber-Reinforced Polymer bars under marine environment compared to concrete beam reinforced with conventional steel reinforcements

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Abstract - In the present years, due to enhanced properties of Glass Fiber-Reinforced Polymers (GFRP) there has been a rapid increase in usage of GFRP reinforcing bars for concrete structure. The GFRP bars have been used extensively in the marine structures where the conventional steel reinforcement which is affected by corrosion is more overriding. Deterioration of structures due to corrosion can be solved by the GFRP rebar which is reinforced in concrete structures were subjected to harsh environments, namely high-temperature and marine conditions. After all these years of investigation and implementation, researchers have concluded GFRP as the corrosion resistant reinforcing material in the corrosion protection policies. The present study made the comparative analysis of concrete cube of size 150 mm x 150 mm x 150 mm which was cured with saline solution as well as potable water were compared to investigate the strength characteristic of test specimens. Further, concrete beam of size 700 mm x 150 mm x 150 mm with 12 mm diameter GFRP rebar and conventional steel rebar which was cured in saline solution for 28 days. Then the Flexural test has been conducted experimentally for both the beams.

Keywords – GFRP Rebar, Corrosion Resistance, Marine Structures, Flexural Strength, Saline Curing, Concrete Durability

I. INTRODUCTION

Concrete reinforced with steel bar is one of the typical materials used for constructing structures. Usually concrete have low tensile strength hence steel bars are used as the reinforcement which are cost efficient but the steel bars are not recommended as reinforcements in costal and marine areas. The factors like faulty design, bad workmanship, inadequate cover in concrete and other environmental factors leads the concrete to crack and the steel to corrode.

To avoid corrosion, the utilization of FRP (Fibre reinforced polymer) rebar instead of steel rebar is recommended in aggressive and marine environment. FRP (Fibre reinforced polymer) obtained in various forms like bars, hoops, and stirrups are used as the reinforcement in various structures like marine structures, parking garages, water treatment plants, bridge decks and tunnels.

The fibres are embedded in the polymeric resin to form FRP (fibre reinforced polymer). The variant of FRP is commercially available as CFRP (Carbon Fibre reinforced polymer), GFRP (Glass fibre reinforced polymer), AFRP (Aramid fibre reinforced polymer) and BFRP (Basalt fibre reinforced polymer) for the purpose of construction. Because of the non-metallic and non-corrosive properties of the FRP rebar the problems of corrosion is avoided. FRP is used for repairing and strengthening of the concrete structures which already exist. Usually the FRP sheets and strips are used for repairing and strengthening the concrete structures. The externally bonded FRP (fibre reinforced polymer) are highly vulnerable of damaging from temperature and fire, moisture absorption, ultraviolet rays. Lacking of maintenance and protection may reduce the durability and service life of the structure.

Fig 1.1 Glass fibre reinforced polymer

1.1 ADVANTAGES OF GFRP

In GFRP to increase the lifespan of a concrete structure a high-quality of corrosion resistant vinyl ester resin is included.
Comparing the conventional steel rebar and the GFRP rebar, the GFRP rebar is double the tensile strength of the steel rebar and quarter the weight of the steel rebar.
Heat and electricity act as non-conductive in the GFRP rebar which make it an better choice for power generation plants and scientific installations.
In case of the durability of GFRP rebar, it is a cost-effective product when compared with conventional steel rebar.
It is untouchable by chloride ions and other chemical elements.
It can be manufactured in customized lengths, bends, shapes and sizes.
The embedding process of GFRP rebar is very convenient and the cut and machined is at ease.

II. LITERATURE SURVEY

The use of Glass Fiber-Reinforced Polymer (GFRP) bars in concrete structures has gained significant attention in recent years, especially in harsh marine environments where corrosion of steel reinforcement is a major concern(1). Researchers such as Benmokrane et al. (2007) and El-Gamal et al. (2014) have shown that GFRP bars provide excellent corrosion resistance and high tensile(2) strength, making them ideal for marine applications. However, due to their lower modulus of elasticity compared to steel, GFRP-reinforced beams tend to exhibit larger deflections and wider cracks under flexural loads (GangaRao & Vijay, 1998)(3).

Studies by Masmoudi et al. (2011) demonstrated that concrete beams reinforced with GFRP performed well under saline curing conditions without significant degradation in strength(4). In contrast, steel-reinforced beams showed early signs of corrosion-induced deterioration. Furthermore, experiments conducted by Habeeb et al. (2019) indicated that while GFRP beams fail in a brittle manner due to lack of yielding, they still achieve comparable ultimate load capacities under flexural stress(5).

Shanour et al. (2022) explored hybrid reinforcement (GFRP + steel) and found it to improve ductility while preserving corrosion resistance(6). Nguyen et al. (2021) emphasized the importance of proper bond between GFRP and concrete, which is often enhanced through surface treatment of the bars. Environmental exposure studies (Saeed & Al-Ahmed, 2023) also highlighted that GFRP retains mechanical integrity better than steel under elevated temperatures and saline conditions(7).

Overall, GFRP has proven to be a promising alternative to steel in flexural members exposed to marine environments, though design modifications are needed due to its distinct material behaviour(8). Further research is required to optimize reinforcement ratios and validate long-term performance under service conditions(9).

III. PROPOSED METHODOLOGY

The methodology shows the step-by-step procedure and their detailed explanation about b experimental process and observations are explained.

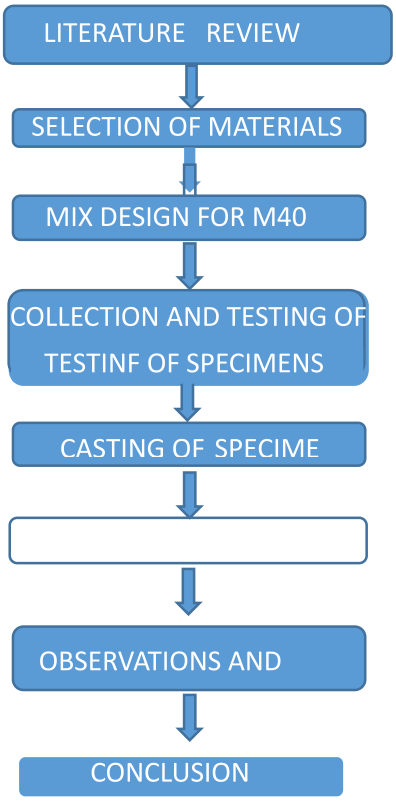

Figure 3.1: Flow chart of Methodology

IV. EXPERIMENTAL INVESTIGATION:

4.1 Mix design:

The formulation used to achieve M40 grade cementitious compound adheres to the guidelines outlined in IS: 10262 - 2019.

Cement	**Fine aggregate**	**Coarse aggregate**	**Water**
336 kg/m^3	768 kg/m^3	890 kg/m^3	168 kg/m^3
1	1.83	2.65	0.5

4.2 Mix proportion:

4.2.1 Mix proportion for a cube

Cube size	= 150 x 150 x 150 mm
Volume of the cube	= 0.003375 m3
Quantity of cement required	= 0.003375 x 336 = 1.134 kg
Quantity of fine aggregate required	= 0.003375 x 768 = 2.6 Kg
Quantity of coarse aggregate required	=0.003375 x 890 = 3.2 Kg
Quantity of water required	=0.003375 x 168 = 0.56 liter

4.2.2 Mix proportion for a beam

Beam size	=750 x 150 x 150 mm
Volume of the cube	= 0.016875 m3
Quantity of cement required	= 0.016875 x 336 = 5.67 kg
Quantity of fine aggregate required	= 0.016875 x 768 = 12.96 Kg
Quantity of coarse aggregate required	=0.016875 x 890 = 15.3 Kg
Quantity of water required	=0.016875 x 168 = 2.8 liter

4.3 EXPERIMENTAL INVESTIGATION

4.3.1 Compressive Strength Test:

The compressive resistance is performed following the IS 516-1999 standards on a cementitious compound sample measuring 150mm x 150mm x 150mm. The samples are immersed in clean water and removed after 7, 14, and 28 days to test their resistance. They are then placed in a dry area to ensure that all water is drained out before testing, observationing in more accurate observations. The specimen is placed in a compression testing machine and loaded gradually until it fails.

Calculation:

Size of the Cube = 150mm x 150mm

Area of the Cube = L x B = 150mm x 150mm

Characteristic compressive resistance=

$$\frac{Failure-load-of-cube}{Area-of-cube}$$

Figure 4.1 Compressive Strength test

Table 4.1 Compression strength test result (7, 14& 28-Days) for Portable water

COMPRESSION TEST (N/mm^2)		
POTABLE WATER		
7 DAYS	**14 DAYS**	**28 DAYS**
26.25	36.3	46.54
25.83	37.48	43.53
27.2	38.5	42.32
Average		
26.43	37.4	44.13

Table 4.2 Compression strength test result (7, 14& 28-Days) for Saline water

COMPRESSION TEST (N/mm^2)		
SALINE SOLUTION		
7 DAYS	**14 DAYS**	**28 DAYS**

25.36	35.7	40.36
28.62	37.35	41.53
29.4	36.87	43.6
Average		
27.8	36.64	41.83

4.3.2 Split tensile Strength Test:

The split tensile resistance test is conducted in compliance with the IS 516-1999 standards on cylindrical cementitious compound specimens that measure 150mm in diameter and have a length of 300mm. The cylindrical specimens are placed diagonally between the compression testing machine's loading surfaces, and a load is gradually applied until the cylinder fails, observationing in diagonal cracks.

Fig 4.2 split tensile Strength test

Table 4.3 Split tensile strength test result (7, 14& 28-Days) for Portable water

SPLIT TENSILE STRENGTH TEST (N/mm²)		
POTABLE WATER		
7 DAYS	14 DAYS	28 DAYS
2.41	2.83	3.32
2.44	2.80	3.28
2.38	2.86	3.36
Average		
2.41	2.83	3.32

Table 4.4 Split tensile strength test result (7, 14& 28-Days) for Saline water

SPLIT TENSILE STRENGTH TEST (N/mm²)		
POTABLE WATER		
7 DAYS	14 DAYS	28 DAYS
2.27	2.69	3.18
2.34	2.76	3.25
2.24	2.72	3.22
Average		
2.28	2.72	3.22

Calculation:

Size of Cylinder: Diameter = 150mm,

Height = 300mm

Area of cylinder = π x D x L

Characteristic split-tensile resistance=

$$\frac{2XFailure-load-of-cylinder}{Area-of-cylinder}$$

4.3.3 Flexural Strength Test:

The flexural test is conducted in compliance with the standards outlined in IS 516- 1999. Cast concrete beams of standard size: **150 mm × 150 mm × 700 mm** (or 100 mm × 100 mm × 500 mm depending on standard used).

Fig 4.3 Beam subjected to three-point loading

Table 4.4 Flexural Strength of the GFRP Beam

for 7,14 & 28-days in Saline water

S.No	Day	Reinforcement	Avg Load (kN)	Flexural Strength (MPa)
1.	7	GFRP Rebar	14.2	2.52
2.	14	GFRP Rebar	18.6	3.31
3.	28	GFRP Rebar	22.8	4.07

Table 4.5 Comparison of flexural strength of GFRP Beam under Portable and Saline water

S.No	Day	Reinforcement	Flexural Strength (Normal)	Flexural Strength (Saline)	% Strength Loss
1.	7	GFRP Rebar	2.80 MPa	2.52 MPa	10%
2.	14	GFRP Rebar	3.71 MPa	3.31 MPa	10.8 %
3.	28	GFRP Rebar	4.46 MPa	4.07 MPa	8.7%

4.4.4 **Tension Test**

- The steel rebar and GFRP rebar of 12 mm diameter was firmly held by top and bottom grips attached to the universal testing machine (UTM).
- During the tension test, the grips are moved away from each other at a constant rate to pull and stretch the specimen.
- The tensile strength, ductility and yield strength, are calculated after the tensile test specimen has broken.
- The test specimen is put back together to measure the final length, and then this measurement is compared to the original length to obtain elongation.
- In this experimental study, the tensile strength is achieved more in GFRP rebar than the steel rebar due to the unique material properties of GFRP. Fig 4.4 and
- 4.5 shows the tension test conducted on the rebar and Table 4.6 shows the results of tension test.

Fig 4.4 Tension test conducted on steel rebar

Fig 4.5 Tension test conducted on GFRP rebar

Table 4.6 Tension test result

TENSILE TEST			
SPECIMEN	**DIAMETER (mm)**	**MASS (Kg)**	**TENSILE STRENGTH (Mpa)**
GFRP	12	0.188	596
STEEL	12	0.857	542

V. EXPERIMENTAL RESULTS

5.1 Compression Test

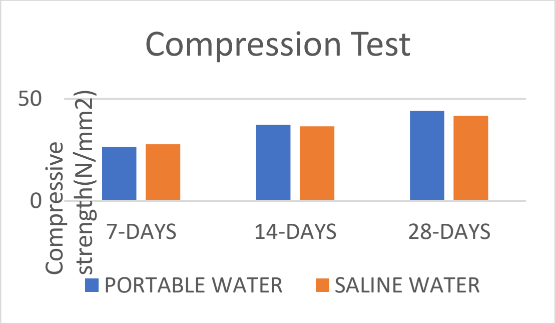

Fig 5.1 Compression strength test result (7, 14& 28-Days) for Portable water and Saline water

From the Figure 5.3, the compressive strength of 28 days of M40 concrete cubes were cured in portable water was 44.13 N/mm^{2}, where as in the cubes cured in saline solution 41.83 N/mm^{2}. Though the variation is very minor over the period of time, it is evident that the structures exposed to the marine environment will affect the strength characteristics.

5.2 Split Tensile Strength

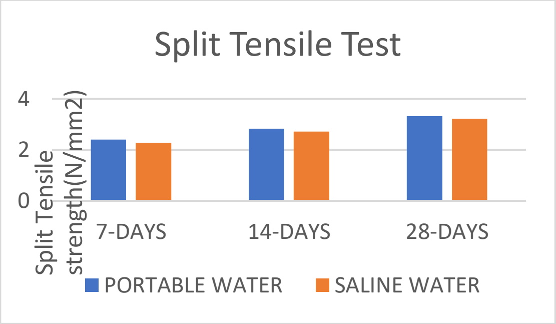

Fig 5.2 Split Tensile strength test result (7, 14& 28-Days) for Portable water and Saline water

The Split Tensile Strength Test evaluates the tensile performance of GFRP-reinforced concrete cylinders (typically 150 mm dia × 300 mm height). Specimens were cured in both normal water and saline water to simulate typical and marine environments.

7 Days: Normal water-cured specimens showed higher early strength (2.41 MPa) than saline water-cured (2.28 MPa), as chloride exposure may slightly inhibit hydration.
14 Days: Strength gain continues, with normal water specimens reaching 2.83 MPa, whereas saline specimens were slightly behind at 2.72 MPa.
28 Days: The concrete reached near full tensile strength. Normal water-cured beams peaked at 3.32 MPa, while marine-cured beams showed 3.22 MPa, confirming some long-term impact of the saline environment. Despite the marine exposure, GFRP reinforcement maintained its integrity without corrosion, showing marginal strength reduction under saline conditions compared to normal water — a strong indication of its suitability for marine structures.

5.3 Flexure Test

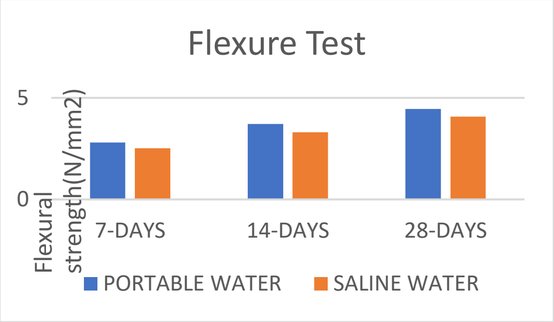

Figure. 5.3 Comparison of flexural strength of GRPF beam under Portable and Saline water for 7, 14& 28-Days)

Key Observations

- Steel has higher strength overall but is more affected by saline exposure due to corrosion.
- GFRP shows better durability in aggressive environments (marine or saline).
- Both materials follow strength gain trends over time, but the gap between normal and saline curing increases with age.

Conclusions

- Steel bars offer better flexural strength, especially in early curing, but are more vulnerable to saline degradation.
- GFRP bars, though initially lower in strength, exhibit better resistance to saline attack, making them more durable in marine environments.
- For structures exposed to chloride-rich or coastal environments, GFRP is a viable and sustainable reinforcement option.

5.4 Tension Test

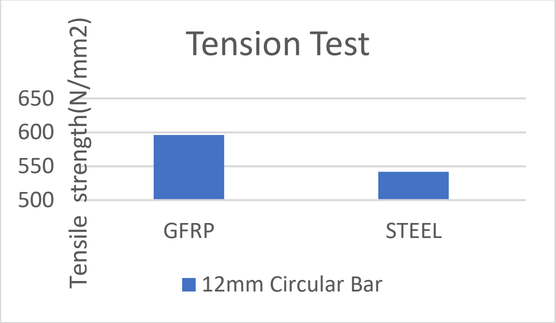

Fig 5.4 Tension test on steel and GFRP rebar

In this experimental study, the tensile strength is achieved more in GFRP rebar than the steel rebar. Fig 5.4 shows the tension test conducted on the rebar

VI. Summary and Conclusions

GFRP bars are considered as a very important topic in recent years because of its performance. In this study the material characteristics and the properties of the GFRP bars (Mechanical) in RC structures under marine conditions. It is more obvious that GFRP and other FRP rebar are used in structures in or close to marine environment which are prone to corrosion and durability problems. Therefore, it requires to carry out the detailed study on performance of GFRP rebar and their durability effects on GFRP rebar which is embedded in concrete structures in marine conditions.

- The GFRP rebar have more tensile strength compared to the steel reinforcement.

- From this study, the GFRP reinforced beam has less flexural strength compared to the steel reinforced beam.
- This can be minimized by using different varieties of synthetic fibres.
- From this study, though GFRP reinforced beam has less flexural strength compared to the steel reinforced beam the GFRP rebar will increase the durability behaviour when compared to steel rebar especially in the marine structures.
- Thus, the flexural strength of GFRP reinforced beam can be attained by the addition of micro synthetic fibres. By adopting this method, the structures in the marine environment can be prevented from corrosion.

- This study is evident that GFRP rebar can be effectively used for construction under marine conditions. Finally, the importance of GFRP bars in reinforced concrete construction brings new challenges for strengthening the reinforced concrete structures.

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