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Characterization of GFRP Material

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Abstract

GLASS FIBRE REINFORCED POLYMER (GFRP) composite materials have developed economically and structurally viable construction materials for buildings and bridges over the last 20 years. FRP composite materials used in structural engineering typically consist of glass, carbon encased in a matrix of epoxy, polyester, vinyl ester thermosetting resins that have fiber concentrations greater than 30% by volume. They have been used in structural engineering in a variety of forms: from structural profiles to internal reinforcing bars for concrete members to strips and sheets for external strengthening of concrete and other structures. Depending on the form of the FRP product used in structural engineering, the FRP material is supplied either as a ready-to-use structural component such as a wide flange profile or a reinforcing bar, or it is supplied in its constituent forms as dry fiber and liquid polymer resin and formed and cured in situ to create a structural component.

Objective: *Finding the mechanical properties of GFRP samples by conducting some laboratory test and comparing it with steel samples.*

Conclusion: *No corrosion effect has been detected on GFRP conservative estimates indicate fiber glass reinforced concrete structures will last longer than 100 years. It is the unique physical properties of GFRP that makes it suitable for applications where conventional steel would be unsuitable.*

Keywords*: - Reinforcing fibres, Polymer resigns.*

INTRODUCTION

The traditional material used in the strengthening of concrete structures is steel. Because of its drawbacks of low corrosion resistance and handling problems involving excessive size and weight, there is a need for the engineering community to look for alternatives. Due to lightweight, high strength and good fatigue and corrosion properties, Fiber Reinforced Plastics (FRP) have been intensively used in the repair and strengthening of aerospace structures. Though the study of using FRP to strengthen reinforced concrete structures just started in the 1990s, the technology is currently widely used.

Several studies have been conducted on the use of Glass or Carbon FRP sheets as flexural strengthening reinforcement of concrete beams. The researchers showed the behavior in terms of load deflection, load-strain, failure patterns and structural ductility. All beams showed a considerable increase in ultimate load capacity (from 40 to 200%) with a good energy absorption capability.

The advantageous properties of fibre-reinforced polymer (FRP), such as high strength-to-weight ratio and corrosion and fatigue resistance, create an interest in engineers. As given in Table 1, the ranges of properties for three FRP systems based on three different fibers (glass, carbon and aramid) are compared to those of conventional reinforcing steel. In addition, to use in new construction, the results of field and laboratory investigations show the effectiveness of FRP bars as reinforcement for strengthening and rehabilitation applications. As an example, a strengthening method consisting of the use of near-surface-mounted FRP bars has been proposed for concrete and masonry structures.

For wide acceptance and implementation in construction, a full characterization of the mechanical properties of FRP bars is needed. In particular, it is necessary to define the mean value and distribution of the tensile strength of FRP bars for reinforced concrete, which engineers can use for design purposes and composite manufacturers for quality control and optimization purposes. Various factors affect the tensile strength of FRP bars. The most significant factors are fiber type and fiber-volume fraction that is defined as the ratio of the volume of fiber to the overall volume of the bar over the unit length. Bar manufacturing process, quality control and the rate of thermoset resin curing also affect tensile strength.

Table 1: Comparison of mechanical properties of FRP materials and steel

	Steel	GFRP	CFRP	AFRP
NOMINAL YIELD STRESS (MPA)	276–517	NA	NA	NA
TENSILE STRENGTH(MPA)	482–689	482–1585	600–3688	1724–2537
ELASTIC MODULUS (MPA)	200	35–51	103–579	41–125
Yield strain (%)	1.4–2.5	NA	NA	NA
Ultimate strain (%)	6–12	1.2–3.1	0.5–1.9	1.9–4.4

MATERIALS USED

To produce an GFRP composite material, two primary raw material constituents are required, reinforcing Glass fibers and a polymer resin matrix.

Reinforcing Fibers

The fiber phase of a GFRP composite material consists of thousands of individual micrometer-diameter individual filaments. In the large majority of fiber forms used in FRP products for structural engineering, these fibers are indefinitely long and are called continuous. Continuous fibers are used at a relatively high volume percentage (from 20 to 60%) to reinforce the polymer resin: thus, the term fiber-reinforced polymer (FRP).

1) Glass Fibers: Glass fibers are used in a multitude of GFRP products for structural engineering, from GFRP reinforcing bars for concrete to GFRP strengthening fabrics to GFRP structural profile shapes. Silica dioxide (SiO_2) is the largest single compound in all glass formulations, constituting from 50 to 70% by weight of the glass. Different grades of glass fiber are identified by letter nomenclature. A borosilicate glass known as E-glass (electrical glass), because of its high electrical resistivity, is used to produce the vast majority of glass fiber used in FRP products for structural engineering. A-glass (window glass) and C-glass (corrosion resistant, also known as AR-glass or alkali-resistant glass) are used to produce specialized products for use in structural engineering. S-glass (structural or high-strength glass) is used to produce the high-performance fibers used primarily in the aerospace industry.

Table 2: Approximate Properties of Common Grades of Glass Fibers

Grade of Glass Fiber	Density [g/cm^3(lb/in^3)]	Tensile Modulus [GPa(Msi)]	Tensile strength [MPa(ksi)]	Max. Elongation (%)
E	2.57(0.093)	72.5(10.5)	3400(493)	2.5
A	2.46(0.089)	73 (10.6)	2760(400)	2.5
C	2.46(0.089)	74 (10.7)	2350(340)	2.5
S	2.47(0.089)	88 (12.8)	4600(667)	3.0

Table 3: Approximate Properties of Common Grades of Carbon Fibers

Grade of carbon fiber	Density [g/cm^3 (lb/ in^3)]	Tensile Modulus [GPa (Msi)]	Tensile Strength[MPa (ksi)]	Max. Elongation
Standard	1.7 (0.061)	250 (36.3)	3700 (537)	1.2
High strength	1.8 (0.065)	250 (36.3)	4800 (696)	1.4
High modulus	1.9 (0.068)	500 (72.5)	3000 (435)	0.5
Ultrahigh modulus	2.1 (0.076)	800 (116.0)	2400 (348)	0.2

2) Carbon Fibers: Carbon fibers are used in structural engineering applications today in FRP strengthening sheets and fabrics, in FRP strengthening strips, and in FRP prestressing tendons. Carbon fiber is a solid semi-crystalline organic material consisting on the atomic level of planar two-dimensional arrays of carbon atoms. The two-dimensional sheet like an array is usually known as the graphitic form; hence, the fibers are also known as graphite fibers (the three-dimensional array is well known as the diamond form). Carbon fiber is produced in grades known as standard modulus, intermediate modulus, high strength, and ultrahigh modulus (SM, IM, HS, UHM). See above **table 3.**

3) Aramid Fibers: Aramid fibers were used to produce first-generation FRP prestressing tendons in the 1980s in Europe and Japan; however, few manufacturers still produce aramid fiber FRP reinforcing bars or tendons. Aramid fabrics are occasionally used in FRP strengthening applications to wrap columns and as sparse-volume weft (fill) fibers in unidirectional glass or carbon fabrics for FRP strengthening. Aramid fibers consist of aromatic polyamide molecular chains. They were first developed and patented by DuPont in 1965 under the trade name Kevlar.

A combination of their relatively high price, difficulty in processing, high moisture absorption (up to 6% by weight), low melting temperatures [around 425 C (~800 F)], and relatively poor compressive properties have made them less attractive for FRP parts for structural engineering applications.

Polymer Resins

The term polymer is used to describe an array of extremely large molecules, called macromolecules, that consist of repeating units, or chains, in which the atoms are held together by covalent bonds. The term polymer is generally used to describe an organic material of this type; however, it can also be used to describe an inorganic material. The term polymer resin, or simply resin, is used in the composites industry to refer to the **primary polymer ingredient in the non-fibrous part of the FRP material that binds the fibers together**. This non-fibrous part is also known as the **matrix or binder**.

1) Unsaturated Polyester Resin: Polyester resin is widely used to make pultruded FRP profiles for use in structural engineering and is also used to make some GFRP rebars. When greater corrosion resistance is desired in FRP parts, higher-priced vinyl ester resins are generally recommended, although the corrosion resistance of some polyester resins may be as good as that of vinyl ester resins. Polyester resins can also be used for GFRP strengthening for structures. However, epoxy resins are preferred at this time for GFRP strengthening applications because of their adhesive properties, low shrinkage, and environmental durability.

2) Epoxy Resins: Epoxy resins are used in many GFRP products for structural engineering applications. Most carbon fiber reinforced precured FRP strips for structural strengthening are made with epoxy resins. In addition, epoxy resin adhesives are used to bond precured FRP strips to concrete (and other materials) in the FRP strengthening process.

Epoxy resins are known to have excellent corrosion resistance and to undergo significantly less shrinkage than polyester or vinyl ester resins when cured.

3) Vinyl ester Resins: Developed in the last 20 years, vinyl ester resins have become attractive polymer resins for GFRP products for structural engineering due to their good properties, especially their corrosion resistance and their ease of processing (Blankenship et al. 1989).

A vinyl ester resin is a hybrid of an epoxy and an unsaturated polyester resin and is sometimes referred to as an epoxy vinyl ester resin or a modified epoxy resin. It is an unsaturated polymer that is produced from an epoxy and an acrylic ester monomer. When it is dissolved in styrene, it reacts with the styrene monomer in the same way as an unsaturated polyester does and cures by free-radical chain polymerization with a peroxide catalyst. See below **table 4.**

METHODOLOGY

Tests on GFRP bars

1) Determination of flexural properties of plastics

Apparatus: Universal testing machine capable of operating at the different speed and record the load and extension during the test accurately, flexural test feature, suitable micrometers for measuring the dimensions of the test specimen to the accuracy of 0.01mm,vernier caliper/steel rule for setting test span length.

Procedure

Test specimen

- Molded specimen of size 12.7mm ×12.7mm×6.4mm is mostly commonly used.
- The sample from sheet, finished and semi finished product are cut and machined on counter cutter into the size of 12.7mm×12.7mm×thickness of products.
- At least five No's of good test specimens shall be prepared and tested.
- Conditioning: pre-condition the test specimens in the environmental chamber at atmospheric condition as specified by standard. in a number cases it is taken as 27±2ºC and 65±5%RH.

Table 4: Approximate Properties of Thermosetting Polymer Resins

	Density [g/cm^3 (lb/in^3)]	**Tensile Modulus [GPa(Msi)]**	**Tensile Strength [MPa(ksi)]**	**Max. Elongation (%)**
Polyester	1.2 (0.043)	4.0(0.58)	65(9.4)	2.5
Epoxy	1.2 (0.043)	3.0(0.44)	90(13.1)	8.0
Vinylester	1.12(0.041)	3.5(0.51)	82(11.9)	6.0
Phenolic	1.24(0.045)	2.5(0.36)	40(5.8)	1.8
Polyurethane	Varies	2.9(0.42)	71(10.3)	5.9

Fig 1: flexural test of GFRP bar

Fig 2: Flexure test of GFRP bar

- Take five good test specimen and write specimens no.
- Measure width and thickness of specimen to the accuracy of 0.01mm by micrometer
- Calculate the span length (distance between two specimen) span length is generally taken and times of specimen thickness.
- Calculate the test speed using the following formula

$$R=ZL^2/6d$$

Where, Z = rate of straining of outer fiber i.e., 0.01mm/mm min

L = span support length (mm)

D = depth of beam

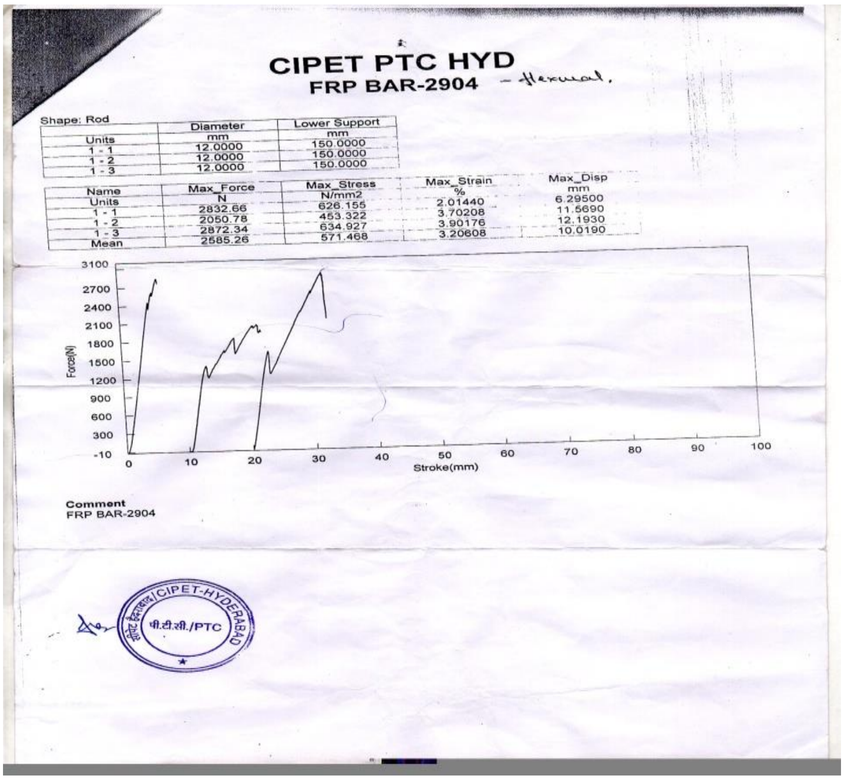
R = speed test in mm/min

Alternatively the speed of testing may also be calculated by following formula's = h/2 min.

Where, V = speed of loading nose in mm/min.

h= thickness of the specimen.

- Place the specimen span support of test fixture in such a way that overhang is equal in both side.
- **Electrode:** Electrode geometry, its area and electrode composition material effect test result. Break down voltage decrease with increasing of area.
- Rate rice of test voltage: it affect result rise of voltage higher is break down voltage.
- **Mechanical stress:** molded in stress in specimen reduce the dielectric strength.
- **Processing:** containing voids, bubbles, flow line, etc. show low dielectric strength.



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FRP BAR-2904 – Flexural.

Shape: Rod

	Diameter	Lower Support
Units	mm	mm
1 - 1	12.0000	150.0000
1 - 2	12.0000	150.0000
1 - 3	12.0000	150.0000

Name	Max_Force	Max_Stress	Max_Strain	Max_Disp
Units	N	N/mm2	%	mm
1 - 1	2832.66	626.155	2.01440	6.29500
1 - 2	2050.78	453.322	3.70208	11.5690
1 - 3	2872.34	634.927	3.90176	12.1930
Mean	2585.26	571.468	3.20608	10.0190

2) Determination of filler content in plastics materials (loss on ignition)

Apparatus

Crucible of silica or platinum of suitable size to accommodate test sample of 2-5gm

- Analytical weighting balance: analytical weighting balance capable of weighting crucible and sample to an accuracy of 0.1 mg
- Muffle furnace: muffle furnace capable of maintaining temp of 850±10ºC is used
- Desiccators: desiccators with cacl2 as drying agent is used for cooling the crucible
- Tongue: a steel tongue of sufficient length is used for handling crucible in hot condition

Procedure

Test specimen: Cut FRP rod in small pieces with the help of knife/saw in sufficient amount (approx 10-15gm)

Samples: No of sample to be tested 02

Conditioning: unless otherwise specified no condition is required

- Switch ON the muffle furnace and set the test temperature as 550º C±50º C
- Take the crucible clean it properly
- Now weigh the empty crucible and record as W1
- Take 2-3 grams material in crucible and weigh it again and record as W2
- After reaching set temperature of 550º C keep the material inside muffle furnace using steel and allow it to heat for one hour

- After one hour of treatment, remove the crucible from furnace using steel long and keep inside desecator.
- Allow to cool to the room temperature
- After cooling take the weight of the crucible containing residue and record as W3

Fig 3: Determination of Filler content Machine

Fig 4: Determination of Filler content

Observations, formula and calculation

Material: GFRP BARS

Test temperature: 850ºC

Sample 1

Mass of empty crucible = W1=30.8926gm

Mass of crucible + material = W2 = 34.1307

Mass of crucible + residue = W3=33.4771

Sample 2

Mass of empty crucible = W1 = 34.1607gm

Mass of crucible + material W2 = 37.4302gm

Mass of crucible + residue= W3 = 36.8619gm

- The quantity of filler is calculated byusing following formula

Filler content = ((W3W1)/(W2W1))×100

Where, W1 = wt of empty crucible

W2 = wt of crucible +material

W3 = wt of crucible +residue

For sample 1 the filler content of the material is **79.8 %.**

For sample 1 the filler content of the material is **82.6 %.**

Result and Conclusion: The filler content of the material is **81.20** %

3) Determination of tensile properties of plastics

Apparatus

- Tensile tester or universal machine with tensile test fixture. machine shall be capable of operating at different test speed and record the load and extension accurately.

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- Dial micrometer: dial gauge micrometer for measuring width & thickness of the specimen.
- Vernier or steel rule for fixing intial position (grip length) of the machine.

Procedure

Test specimen

- Different types of dumbbell shaped molded test specimens from thermoplastic and thermo set are used. The type of sample are classified based on the type of material.
- Test specimens from the sheet, finished and semi finished products etc. are cut and prepared by punching press and cutting dies (for soft plastics) and using contour cutter and material templates for hard & rigid plastic.
- Film samples are cut in the form of strip of 10mm wide and 150mm long.
- At least five good test specimen shall be taken and tested.

Conditioning: Pre-condition the test specimen in the environmental chamber at standard atmospheric condition as specified by standard. in a number of cases it is taken as 27°±2° C and 65±5%RH.

Number of cases it is taken 27+_2 C and 65+5% RH.

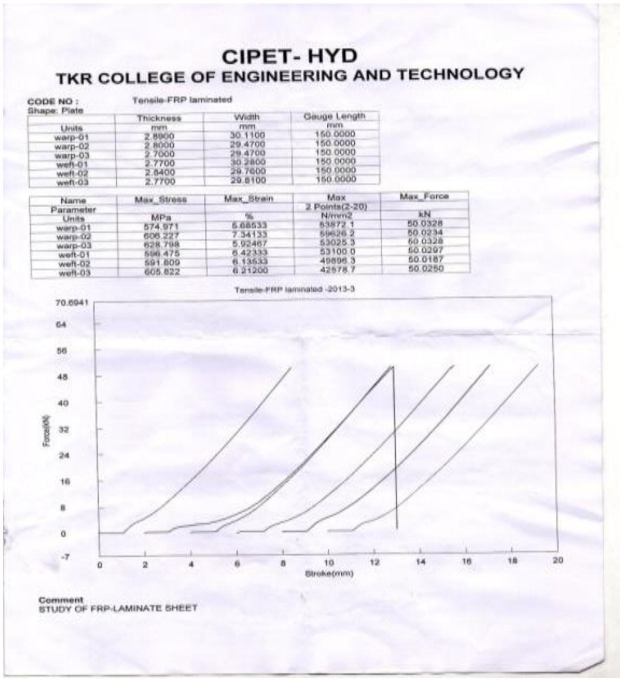
Fig. 5: Tensile test of GFRP laminate

Observation, Formula and Calculation

Material : GFRP laminate.

Test method : Tensile test.

Gauge length : 150 mm.



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CODE NO : Tensile-FRP laminated
Shape: Plate

	Thickness	Width	Gauge Length
Units	mm	mm	mm
warp-01	2.8900	30.1100	150.0000
warp-02	2.8000	29.4700	150.0000
warp-03	2.7000	29.4700	150.0000
weft-01	2.7700	30.2800	150.0000
weft-02	2.8400	29.7600	150.0000
weft-03	2.7700	29.8100	150.0000

Name	Max_Stress	Max_Strain	Max	Max_Force
Parameter			2 Points(2-20)	
Units	MPa	%	N/mm2	kN
warp-01	574.971	5.68533	53872.1	50.0328
warp-02	606.227	7.34133	59626.2	50.0234
warp-03	628.798	5.92467	53025.3	50.0328
weft-01	598.475	6.42333	53100.0	50.0297
weft-02	591.809	6.13533	49896.3	50.0187
weft-03	605.822	6.21200	42578.7	50.0250

Tensile-FRP laminated -2013-3

Comment
STUDY OF FRP-LAMINATE SHEET

Fig. 6: GFRP Tensile Test

REPORT

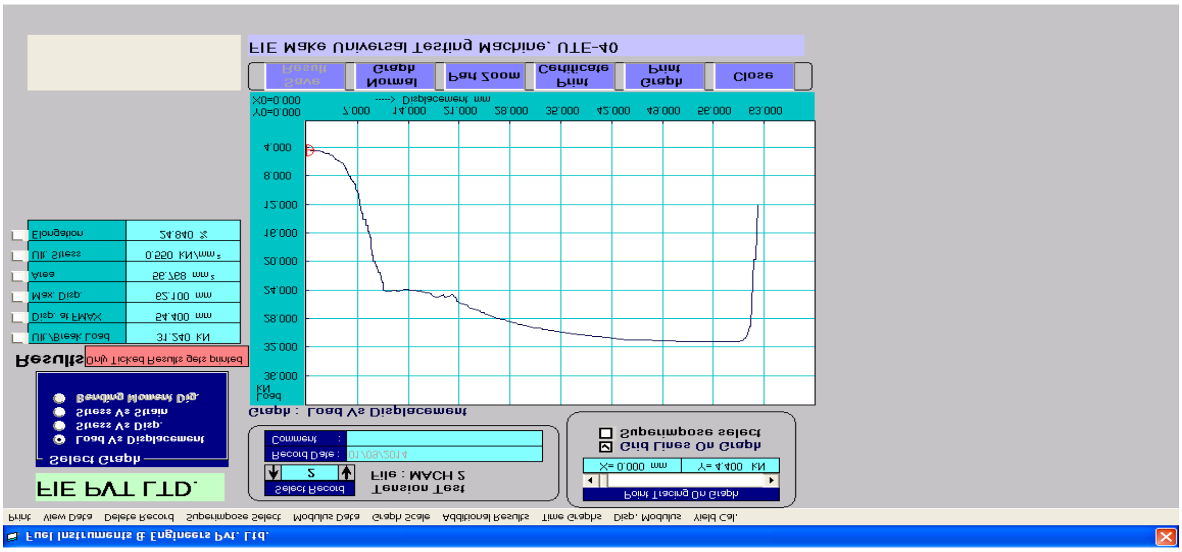

Fig. 7: Mild Steel Tensile Test Report

Result & Conclusion

- Tensile strength at = **600.68 N/mm²**
- Percentage elongation at = **6.28%**

4) Determination of water absorption Test

Aim: To determine the water absorption of GFRP bars.

Apparatus

1. Balance—an analytical balance capable of reading 0.0001 g.
2. Oven, capable of maintaining uniform temperatures of 50 6 3°C (122 6 5.4°F) and of 105 to 110°C (221 to 230°F).

Procedure:

- Take the test specimen, i.e., GFRP bar and place it in the oven for drying up to 2 hrs.
- After the drying find the initial weight of sample by using weigh balance.
- Note the initial weight of sample, i.e., (W1).
- In next step place the sample in a beaker containing water for 24 hrs.
- After the 24 hrs find the final weight of the sample in weight balance.
- Note the final value of sample, i.e., (w2).
- After finding the final weight find the water absorption of sample by using the formula.

Observation

Sample 1

Initial weight w1= 33.2899 gr.

Final Weight W2 = 33.52186 gr.

Sample 2

Initial weight w1= 32.4721 gr.

Final Weight W2 = 32.6027 gr.

Calculation

Formula: (W2 –W1) / W1

Percentage of water absorption: (W2–W1)/W1X100.

Percentage of water absorption of sample 1 is = **0.68 %**

Percentage of water absorption of sample 2 is = **0.4%**

Result

Water absorption of GFRP sample is = **0.54 %**

CONCLUSION

GFRP has a very important role to play as reinforcement in concrete structures that will be exposed to harsh environmental conditions where traditional steel reinforcement could corrode.

No corrosion effect has been detected on GFRP conservative estimates indicate fiberglass-reinforced concrete structures will last longer than 100 years. Properly reinforced GFRP concrete slabs exposed to heavy fatigue loads (like driveways, bridge decks) will have less cracking and are projected to last up to 20 times longer than similar structures reinforced with conventional black steel.

It is the unique physical properties of GFRP that makes it suitable for applications where conventional steel would be unsuitable. GFRP bars are a competitive reinforcing option in reinforced concrete members subjected to flexure and shear. GFRP has compelling physical and mechanical properties, corrosion resistance and electromagnetic transparency.

The list of GFRP reinforcement is particularly attractive for structures that operate in aggressive environments, such as in coastal regions, or for buildings that host magnetic resonance imaging (MRT) units or other equipment sensitive to electromagnetic fields. GFRP has more tensile strength and flexural strength when compared with steel and required less maintenance cost.

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