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(RESEARCH ARTICLE)

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Evaluation of glass fiber-reinforced polymer bars for application in sections of reinforced concrete

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Abstract

In order to evaluate the effectiveness and acceptability of glass fiber reinforced polymer (GFRP) bars as a substitute for conventional steel reinforcement, this study looks into their use in reinforced concrete sections. To assess the mechanical qualities of GFRP bars, the research includes mix design, casting, and extensive testing, such as flexural and tensile tests. Furthermore, a comprehensive study of GFRP-integrated reinforced concrete building sections is carried out, looking at factors like primary stresses, bending stresses, shear stresses, and deflection. Additionally, using ANSYS software, a comparative study of beam-column junctions using GFRP and RCC sections is conducted to evaluate structural performance under various loading circumstances. The results demonstrate how GFRP bars can improve building projects' structural integrity, toughness, and sustainability

Keywords: Glass Fiber Reinforced Polymer (GFRP); Reinforced concrete; Structural analysis; Beam-column joints; ANSYS; Mechanical properties

1. Introduction

1.1. History

A significant development in civil engineering is the design of structural sections made of Glass Fiber Reinforced Polymer (GFRP), which provides a robust and lightweight substitute for conventional building materials. The use of fiberglass reinforcement polymers (GFRP) in structural design dates back to the mid-1900s, when scientists and engineers first started investigating the material's potential as a reinforcement. For a variety of applications, GFRP's remarkable strength-to-weight ratio, resistance to corrosion, and longevity made it a desirable option.

The mechanical qualities of GFRP have been further improved throughout time by developments in material formulas and production techniques, which have made it possible for it to be widely used in a variety of construction projects. In infrastructure projects where weight reduction, corrosion resistance, and long-term durability are critical considerations, the usage of GFRP in section design has grown significantly. The design of sections made of glass fiber reinforced polymer (GFRP) is a monument to the advancement of engineering methods toward more effective and ecologically friendly solutions, as sustainability and innovation continue to propel the building sector.

1.2. Introduction

The search for materials that combine strength, durability, and versatility in a seamless manner has prompted the investigation of creative solutions in the fields of structural engineering and building. Glass Fiber Reinforced Polymer is one such innovative substance that has become more well-known recently (GFRP BARS). This composite material has

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completely changed the way structural elements are designed and built, especially load-bearing sections used in a variety of applications. It is made up of high-strength glass fibers embedded in a polymer matrix.

Glass fiber reinforced polymer, which offers a distinct combination of properties that make it an appealing option for engineers and architects, is a departure from conventional materials like steel or concrete when designing sections. Because to GFRP BARS's intrinsic qualities—such as its excellent strength-to-weight ratio, resistance to corrosion, and flexibility in meeting a variety of design specifications—it has emerged as a leader in contemporary construction methods.

The main features of GFRP BARS bar as a material are examined in this introduction, along with its uses in structural section design. In the quest for resilient and effective constructions, GFRP BARS has become a dependable and sustainable solution for everything from bridges to buildings, upending accepted wisdom and establishing new benchmarks. We will explore the material's remarkable benefits as we go through the complexities of GFRP BARS design, illuminating its revolutionary influence on the state of structural engineering today.

1.3. Glass fiber reinforced polymer bars

GFRP BARS rods do not show plastic behavior (yielding) before breaking under tensile strain. A linear elastic stress-strain relationship holds true for the tensile behavior of GFRP BARS rods made of a single fiber material all the way up to failure. In general, reinforced concrete sections are made to guarantee stress-controlled behavior brought on by steel giving before concrete fractures. Steel yield indicates component failure and gives ductility. The non-ductile nature of FK reinforcement necessitates reassessing this methodology.

The component fails suddenly and catastrophically when the FRP stiffener fails. Nevertheless, there is little indication of an approaching failure in the form of crack propagation or significant deflections because FRP stiffeners experience high elastic strains prior to failure [6]. In either scenario, the rebar experiences plastic deformation before the concrete fractures, and the members lack the ductility often observed in tension-controlled concrete beams reinforced with steel rebar. For GFRP BARS, compression-controlled behavior is marginally preferred. Increased deflection by a rod .The bending elements show some inelastic behavior prior to failure because the concrete fractures before the GFRP BARS rebar tensile failure. Therefore, as long as the strength and serviceability requirements are satisfied, both compression and tension control sections are appropriate in GFRP BARS bar reinforced flexure designs. Higher strength reserves are needed by components to make up for their decreased ductility. Therefore, compared to traditional reinforced concrete structures, a larger margin of safety against failure is advised.

1.3.1. Definition

Fiberglass, or glass fiber reinforced polymer, or GRP, is a composite material made of tiny glass fibers mixed with a matrix of polymer resin. Because of its special qualities, this composite material has a lot to offer and may be used in a lot of different industrial and engineering applications.

1.3.2. Overview OF Glass Fiber Reinforced Polymer (GFRP)

High-strength glass fibers are embedded in a polymer resin to generate glass fiber reinforced polymer (GFRP), a material with exceptional strength and durability. Glass fibers for glass fiber reinforced polymer (GFRP) can be derived from a variety of glass kinds, such as S-glass, E-glass, and others, each having unique qualities appropriate for particular uses. Thermosetting or thermoplastic resins, which offer various qualities including increased strength, flexibility, and chemical resistance, can make up the polymer resin matrix. The result of combining these components is a high-strength, lightweight, and corrosion-resistant material that can be tailored to match the unique needs of many industries.

1.3.3. Glass Fibers

In Glass Fiber Reinforced Polymer (GFRP) composites, glass fibers serve as the main source of reinforcement. They are in charge of giving the material its strength and stiffness. Glass fibers come in various varieties, and there are several important processes in the manufacturing process. The purpose of this project is to design the mix for Glass Fiber Reinforced Polymer (GFRP) bars. The beams will then be cast, and testing will include tensile and flexural tests. Furthermore, the goal of the study is to analyze a Reinforced Concrete (RCC) building from top to bottom while including glass fiber reinforced polymer bars. Aspects like bending stresses, shear stresses, main stresses, and deflection will all be looked at in this examination. In addition, the project will compare beam-column joints made of Glass Fiber Reinforced Polymers (GFRP) to RCC sections. ANSYS software will be used to evaluate a number of variables, such as main stresses, bending stresses, shear stresses, and deflection.

2. Literature review

[1] Hibretu Kaske Kassa et.al (2022), "A Study on Using Glass Fiber-Reinforced Polymer Composites for Shear and Flexural Enhancement of Reinforced Concrete Beams" focuses on the experimental assessment of the flexural strengths of glass fiber-reinforced polymers (GFRP) in concrete construction at different percentages of fiber content. Flexural tests were carried out at 7, 21, and 28 days after casting on C-25 concrete mixes with 50mm glass fiber additions at 0.25%, 0.50%, and 0.75% by total concrete weight, in accordance with ASTM standards. According to the results, flexural strength tends to rise with increased glass fiber content; gains range from 2.5% to 13.60% when compared to control beams. Additionally, ductility gets better as fiber content rises. Results point to GFRP's potential to improve structural capacity beyond its conventional use as plaster reinforcement. It outperforms regular concrete in terms of strength and ultimate load-carrying capacity. According to the study's findings, fiber-reinforced concrete successfully enhances and maintains structural integrity by lowering the chance of collapse via flexural strength and preventing the spread of cracks. Overall, adding glass fiber to concrete greatly increases its flexural strength, demonstrating its promise for structural applications.

[2] Vasant S. Nagre et.al (2021), "flexural and bond response of rcc beam and cube by using glass fiber reinforced polymer bar" The purpose of this article is to present the results of an experimental study that looked at the flexural and bond characteristics of Glass Fiber Reinforced Polymer (GFRP) material in structural concrete. Because GFRP is more corrosion resistant than steel reinforcement, this material may find use in water-retaining structures. GFRP bars in a range of sizes were used, with an emphasis on replacing steel bars completely and partially. M25 grade concrete was used to cast the concrete beams and cubes. And following 28 days of water curing, the flexural strength and bond strength were evaluated. The results reveal that 50% GFRP replacement may achieve a sufficient level of flexural strength, and the second beam performs similarly to 100% steel reinforcement. Interestingly, pullout tests showed a notable increase in binding strength. According to the study, a combination of 50% glass fiber reinforced polymer (GFRP) and 50% steel reinforcement may be a viable substitute for conventional steel reinforcement, especially when considering costs.

[3] Md. Akter Hosen et.al (2017), "Glass Fiber Reinforced Polymer (GFRP) Bars for Enhancing the Flexural Performance of RC Beams Using Side-NSM Technique" This study examines the impact of glass fiber-reinforced polymer (GFRP) bars used in the side near-surface mounted (SNSM) strengthening technique on the flexural capacity of reinforced concrete (RC) beams. After being strengthened with various levels of reinforcement and bond lengths, nine RC beams were put through four-point bending tests. The results demonstrate a notable improvement in the flexural responses, with greater ultimate and first cracking loads, enhanced ductility, and enhanced energy absorption capacities.

and rigidity in contrast to specimens under control. By exhibiting a tri-linear load-deflection response, the SNSM-GFRP bars addressed serviceability issues and decreased deflection. Furthermore, the method demonstrated a flexural failure mechanism akin to that of control specimens, suggesting a decreased vulnerability to debonding. It was discovered that the length of the bond affected performance more than the strength of the reinforcing. There was good agreement between the experimental and predicted results for beam width, flexural fracture spacing, and deflection. Overall, the study highlights how well SNSM-GFRP strengthening maximizes the structural capacity of RC beams and provides insightful information for initiatives aimed at structural improvement and rehabilitation.

[4] S. M. Hasanur Rahman et.al (2017), Six large-scale glass fiber-reinforced polymer (GFRP) continuous T-beam test findings are provided in this research. Four GFRP RC beams are designed to attain the same theoretical ultimate load as the reference beam, one GFRP RC beam is designed to meet the serviceability criteria at the service load level predicted for the reference beam, and one steel RC beam serves as the reference in the test specimens. The test variables consisted of the lateral reinforcement spacing in the flange and the expected percentage of moment redistribution. and how the shear reinforcement is arranged. The test findings demonstrated that in GFRP RC beams with T-sections, moment redistribution occurred from the hogging to the sagging moment area, and that the moment redistribution % was increased by a small stirrup spacing. Furthermore, by increasing the stiffness of the sagging moment zone, reducing the lateral reinforcement spacing in the flange increased the moment redistribution.

[5] Trupti Amit Kinjawadekar et.al (2023), "A Critical Review on Glass Fiber-Reinforced Polymer Bars as Reinforcement in Flexural Members" In order to understand the applications of GFRP reinforcement in flexural members, this research examines a variety of GFRP-reinforced beam properties. This well-liked composite material is widely utilized in many types of buildings. Nonetheless, one obstacle that may lower the caliber of reinforced concrete constructions is the deterioration of steel reinforcing bar as a result of corrosion. Because of its resistance to corrosion, the glass fiber-reinforced polymer (GFRP) bar is crucial in this regard. To determine how GFRP-reinforced flexural members will react in shear and bending, the researchers conducted a number of tests and numerical analyses. This paper critically

examines the response of flexural members reinforced with glass fiber-reinforced polymer (FRP) bars, drawing on research conducted over the past ten years. This review will help in understanding how the FRP bar behaves as the alternating reinforcing material. The traditional ductility characterizations may not be appropriate to estimate the ductility of GFRP-reinforced concrete components because the GFRP bar has a high strength and no yield point. Thus, in order to comprehend the behavior of such systems, a thorough investigation is required. In order to understand the applications of GFRP reinforcement in flexural members, this research examines a variety of GFRP-reinforced beam properties.

[6] R Venkata Suraj Reddy et.al (2023), "Design of concrete beam reinforced with GFRP bars as per ACI codal provisions" In accordance with ACI 440.1R-15, this study offers design guidelines for concrete beams reinforced with glass fiber reinforced polymer (GFRP) bars. Glass fiber reinforced polymer rods are lighter and more corrosion resistant than standard steel reinforced rods, which is one of their key advantages. However, because the elongation at break is modest and the elasticity of fiber reinforced polymer (FRP) bars is linear until failure, the bending failure mode of FRP reinforced concrete (FRP-RC) beams is brittle rather than ductile. The chosen failure mode for FRP-RC elements is concrete crushing compression failure, which provides multiple warnings prior to failure.

Put another way, an over-reinforced construction is preferred to an under-reinforced structure for fiber-reinforced polymer (FRP) beams, in contrast to the standard design practice for steel-RC (reinforced concrete) beams. Furthermore, compared to the steel RC member, the FRP RC member bends more and breaks wider due to the reduced stiffness of the FRP rod. These elements restrict the range of applications for FRP. This is an illustration of a rectangular beam design that complies with ACI guidelines and includes tension reinforcement.

[7] M Talha Junaid et.al (2019) "Experimental Study on the Effect of Matrix on the Flexural Behavior of Beams Reinforced with Glass Fiber Reinforced Polymer (GFRP) bars" Results from this experimental work on the impact of various concrete types on the deflection and flexural behavior of beams reinforced with glass fiber-reinforced polymer (GFRP) bars are presented. The four types of concrete that were employed were fiber reinforced concrete (FRC), geopolymer concrete (GPC), ordinary Portland concrete (OPCC), and fiber reinforced geopolymer concrete (FRGC). Static four-point bending tests were performed on eight beams in total. The criteria that were examined were strain development, deflection, and load capabilities in both concrete and rebar. Whereas failure types and patterns of cracking were also noted. Comparable flexural and deflection properties are shown by all tested beams. According to the findings, GFRP reinforced systems performed better with GPC and FRGC beams than with regular concrete. Regardless of the kind of concrete, the ACI 440-R1-06 formulae can be utilized as they provided conservative estimates for the flexural capacity and deflection of the members. Lastly, the flexural strengths of the beams are not correspondingly increased by an increase in the $\rho f/\rho b$ ratio, according to results from flexural capacity adjusted for concrete strength, cross-section, and reinforcement ratio of GFRP ($\rho f/\rho b$).

3. Methodology

3.1. General

The objective of this study's technique is to find out how adding GFRP BARS as a natural reinforcement affects reinforced concrete beams that are subjected to combine shear and bending pressures. In order to gain a thorough grasp of the mechanical properties of GFRP BARS and its potential advantages in improving the performance of reinforced concrete structures, the first phase entails a detailed examination of pertinent literature. The physical and mechanical characteristics of the glass fiber, such as its aspect ratio, modulus of elasticity, and tensile strength, are then evaluated in laboratory settings. Then, using a mix design that includes different percentages of GFRP BARS in place of some conventional steel reinforcement, the reinforced concrete beams are cast.

In order to evaluate the glass fiber-reinforced concrete beams' structural behavior under combined bending and shear, a number of tests are carried out utilizing an experimental configuration that mimics actual circumstances. Displacement sensors and strain gauges are positioned carefully to track and document the beams' reaction to loading. Furthermore, the beams' structural performance is modeled and simulated using the finite element analysis (FEA) program ANSYS. In order to forecast the response of the reinforced concrete beams, a comprehensive three-dimensional model of the beams must be created, together with material parameters and simulated loads.

In order to assess how well GFRP BARS works as a natural reinforcement to enhance the structural integrity of reinforced concrete beams subjected to combined bending and shear, data from both experimental and numerical assessments are compared and analyzed. Insights into the intricate behavior of the beams are largely provided by the ANSYS program, which is a useful adjunct to the experimental findings. By offering important insights for resilient and sustainable building techniques, this integrated approach seeks to advance knowledge of the possible uses and constraints of GFRP BARS in improving the performance of reinforced concrete buildings.

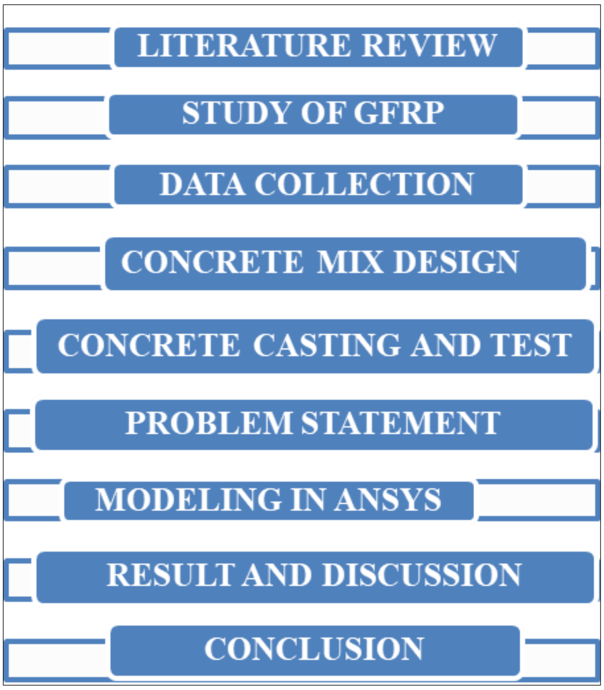

Figure 1 Flowchart

3.1.1. Material test results, which will be ascertained at the lab

Specific gravity of cement — 3.15

- Specific gravity of FA — 2.64
- Specific gravity of CA — 2.84
- Aggregate are assumed to be in saturated surface dry condition.
- Fine aggregates confirm to Zone II of IS – 383

3.2. Process for Designing Concrete Mix for M25 Grade Concrete

3.2.1. Step 1 — Determination of Target Strength

Himsworth constant for 5% risk factor is 1.65. In this case standard deviation is taken from IS: 456 against M 20 is 4.0.

$$f_{target} = f_{ck} + 1.65 \text{ x } S = 25 + 1.65 \text{ x } 4.0 = 31.6 \text{ N/mm}^2$$

Where,

S = standard deviation in N/mm^2 = 4 (as per table -1 of IS 10262- 2009)

3.2.2. Step 2 — Selection of water / cement ratio:-

From Table 5 of IS 456, (page no 20)

Maximum water-cement ratio for Mild exposure condition = 0.55

Based on experience, adopt water-cement ratio as 0.5. 0.5<0.55, hence OK.

3.2.3. Step 3 — Selection of Water Content

From Table 2 of IS 10262- 2009,

Maximum water content = 186 Kg (for Nominal maximum size of aggregate — 20 mm)

Table 3. 1 Correction in water content

Estimated water content = 186+ (3/100) x 186 = 191.6 kg /m^3

3.2.4. Step 4 — Selection of Cement Content

Water-cement ratio = 0.5

Corrected water content = 191.6 kg /m^3 Cement content =

From Table 5 of IS 456,

Minimum cement Content for mild exposure condition = 300 kg/m^3

383.2 kg/m^3 > 300 kg/m^3, hence, OK.

This value is to be checked for durability requirement from IS: 456.

In the present example against mild exposure and for the case of reinforced concrete the minimum cement content is 300 kg/m^3 which is less than 383.2 kg/m^3. Hence cement content adopted = 383.2 kg/m^3.

As per clause 8.2.4.2 of IS: 456 Maximum cement content = 450 kg/m^3.

3.2.5. Step 5: Estimation of Coarse Aggregate proportion: -

From Table 3 of IS 10262- 2009,

For Nominal maximum size of aggregate = 20 mm, Zone of fine aggregate = Zone II

And For w/c = 0.5

Volume of coarse aggregate per unit volume of total aggregate = 0.62

- **Note 1:** For every ±0.05 change in w/c, the coarse aggregate proportion is to be changed by 0.01. If the w/c is less than 0.5 (standard value), volume of coarse aggregate is required to be increased to reduce the fine aggregate content. If the w/c is more than 0.5, volume of coarse aggregate is to be reduced to increase the fine aggregate content. If coarse aggregate is not angular, volume of coarse aggregate may be required to be increased suitably, based on experience.
- **Note 2:** For pump able concrete or congested reinforcement the coarse aggregate proportion may be reduced up to 10%.

Hence, Volume of coarse aggregate per unit volume of total aggregate = 0.62 x 90% = 0.558 Volume of fine aggregate = 1 – 0.558 = 0.442

3.2.6. Step 6: Estimation of the mix ingredients

- Volume of concrete = 1 m3
- Volume of cement = (Mass of cement / Specific gravity of cement) x (1/100)
- = (383.2/3.15) x (1/1000) = 0.122 m3
- Volume of water = (Mass of water / Specific gravity of water) x (1/1000)
- = (191.6/1) x (1/1000) = 0.1916 m3
- Volume of total aggregates = a – (b + c) = 1 – (0.122 + 0.1916) = 0.6864 m3
- Mass of coarse aggregates = 0.6864 x 0.558 x 2.84 x 1000 = 1087.75 kg/m3
- Mass of fine aggregates = 0.6864 x 0.442 x 2.64 x 1000 = 800.94 kg/m3

Concrete Mix proportions for Trial Mix 1

Cement = 383.2 kg/m^3 Water = 191.6 kg/m^3

Fine aggregates = 800.94 kg/m^3

Coarse aggregate = 1087.75 kg/m^3

W/c = 0.5

For trial -1 casting of concrete in lab, to check its properties It will satisfy durability & economy.

For casting trial -1, mass of ingredients required will be calculated for 4 no's cube assuming 25% wastage

Volume of concrete required for 4 cubes = 4 x (0.15^3 x1.25) = 0.016878 m^3 Cement = (383.2 x 0.016878) kg/m^3 = 6.47 kg

Water = (191.6 x 0.016878) kg/m^3 =3.23 kg

Coarse aggregate = (1087.75 x 0.016878) kg/m^3 =18.36 kg Fine aggregates = (800.94 x 0.016878) kg/m^3 = 13.52 kg

3.2.7. Step 7: Correction due to absorbing / moist aggregate

Since the aggregate is saturated surface dry condition hence no correction is required.

3.2.8. Step 8: Concrete Trial Mixes: - Concrete Trial Mix 1:

The mix proportion as calculated in Step 6 forms trial mix1. With this proportion, concrete is manufactured and tested for fresh concrete properties requirement i.e. workability, bleeding and finishing qualities.

In this case, Slump value = 25 mm Compaction Factor = 0.844

So, from slump test we can say,

Mix is cohesive, workable and had a true slump of about 25 mm and it is free from segregation and bleeding.

Desired slump = 50-75 mm

So modifications are needed in trial mix 1 to arrive at the desired workability.

3.3. Recommended mix proportion of ingredients for grade of concrete

M25: From Compressive Strength vs. c/w graph for target strength 31.6 MPa we get,

W/c = 0.44

Water content = 197.4 kg/m^3

Cement content = (197.4/0.44) = 448.6 kg/m^3 Volume of all in aggregate

= 1 – [{448.6/(3.15 x 1000)} + (197.4/1000)] = 0.660 m^3

A reduction of 0.05 in w/c will entail and increase of coarse aggregate fraction by 0.01. Coarse aggregate fraction = 0.558 +.01 =.568

Volume of fine aggregate = 1 – 0.568 = 0.432

Mass of coarse aggregate = 0.660 x 0.568 x 2.84 x 1000 = 1064.65 kg/m^3

Mass of fine aggregate = 0.660 x 0.432 x 2.64 x 1000 = 752.71 kg/m^3

3.4. Dosage of plasticizer

The typical dosage of superplasticizers, which include approximately 40% active material in liquid form, is one to three liters per cubic meter of concrete in order to improve the workability of the mix. Superplasticizers are employed at substantially higher dosages—5 to 20 liters per cubic meter of concrete—when utilized to lower the water content of the mix. The volume of the liquid superplasticizer needs to be considered when calculating the water/cement ratio and mix proportions in general.

It is important to note that the amount of solids in commercial superplasticizers varies, therefore any performance comparison should be based on the amount of solids rather than the entire mass. Practically speaking, comparisons must to be based on the cost of a particular outcome. The water to cement ratio of the mixture determines how effective a superplasticizer is at a particular dosage. In particular, the percentage of water reduction that preserves a consistent workability at a given dosage of superplasticizers is significantly larger at low water/cement ratios of 0.40, where the reduction was measured to be 23%, and only 11% at high ratios of 0.55.

There are virtually no issues choosing an admixture-cement combination to generate high workability normal-strength concrete when superplasticizers are employed in extremely low dosages. At high dosages, the situation is very different since there is not enough cement and superplasticizer used separately to meet criteria; instead, the superplasticizers must be compatible with the cement utilized. FDN-A, B, AND C A dry powdered additive is called superplasticizer. One method used to manufacture it is sulphonating refined naphthalene with sulfuric acid, followed by formaldehyde condensation, neutralization, and filtering. It is mostly used for various high-strength concrete, steel concrete, prestressed concrete, big formwork concrete, slip-forming concrete, etc. and complies with GB8076-1997.

3.5. Material properties and test procedure

3.6. Cement

3.6.1. Material properties of cement

Physical Properties of Cement

Different blends of cement used in construction are characterized by their physical properties. Some key parameters control the quality of cement. The physical properties of good cement are based on:

- Fineness of cement
- Soundness
- Consistency
- Strength
- Setting time
- Heat of hydration
- Loss of ignition
- Bulk density
- Specific gravity (Relative density)

Chemical Properties of Cement

The raw materials for cement production are limestone (calcium), sand or clay (silicon), bauxite (aluminum) and iron ore, and may include shells, chalk, marl, shale, clay, blast furnace slag, slate. Chemical analysis of cement raw materials provides insight into the chemical properties of cement.

Tricalcium aluminate (C3A)

Low content of $\mathbf{C_3A}$ makes the cement sulfate-resistant. Gypsum reduces the hydration of $\mathbf{C_3A}$, which liberates a lot of heat in the early stages of hydration. C_3A does not provide any more than a little amount of strength.

Type I cement: contains up to 3.5% SO3 (in cement having more than 8% C3A)

Type II cement: contains up to 3% SO3 (in cement having less than 8% C3A)

Tricalcium silicate (C3S)

C_3S causes rapid hydration as well as hardening and is responsible for the cement's early strength gain an initial setting.

Dicalcium silicate (C_2S)

As opposed to tricalcium silicate, which helps early strength gain, dicalcium silicate in cement helps the strength gain after one week.

Ferrite (C_4AF)

Ferrite is a fluxing agent. It reduces the melting temperature of the raw materials in the kiln from 3,000°F to 2,600°F. Though it hydrates rapidly, it does not contribute much to the strength of the cement.

Magnesia (MgO)

The manufacturing process of Portland cement uses magnesia as a raw material in dry process plants. An excess amount of magnesia may make the cement unsound and expansive, but a little amount of it can add strength to the cement. Production of MgO-based cement also causes less CO2 emission. All cement is limited to a content of 6% MgO.

Sulphur trioxide

Sulfur trioxide in excess amount can make cement unsound.

Iron oxide/ Ferric oxide

Aside from adding strength and hardness, iron oxide or ferric oxide is mainly responsible for the color of the cement.

Alkalis

The amounts of potassium oxide (K_2O) and sodium oxide (Na_2O) determine the alkali content of the cement. Cement containing large amounts of alkali can cause some difficulty in regulating the setting time of cement. Low alkali cement, when used with calcium chloride in concrete, can cause discoloration. In slag-lime cement, ground granulated blast furnace slag is not hydraulic on its own but is "activated" by addition of alkalis. There is an optional limit in total alkali content of 0.60%, calculated by the equation Na_2O + 0.658 K_2O.

Free lime

Free lime, which is sometimes present in cement, may cause expansion.

Silica fumes

Silica fume is added to cement concrete in order to improve a variety of properties, especially compressive strength, abrasion resistance and bond strength. Though setting time is prolonged by the addition of silica fume, it can grant exceptionally high strength. Hence, Portland cement containing 5-20% silica fume is usually produced for Portland cement projects that require high strength.

Alumina

Cement containing high alumina has the ability to withstand frigid temperatures since alumina is chemical-resistant. It also quickens the setting but weakens the cement.

4. Modeling and analysis

4.1. GRPF

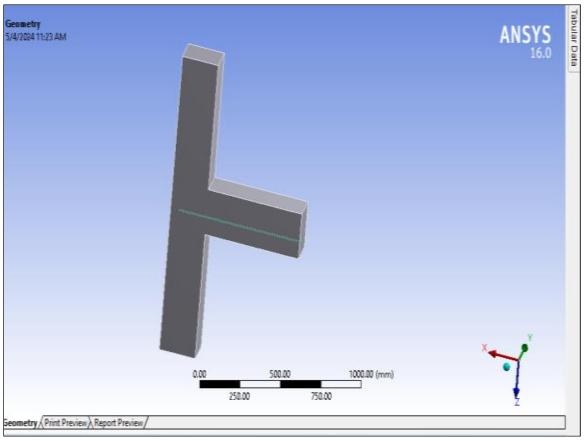

Figure 1 Geometry

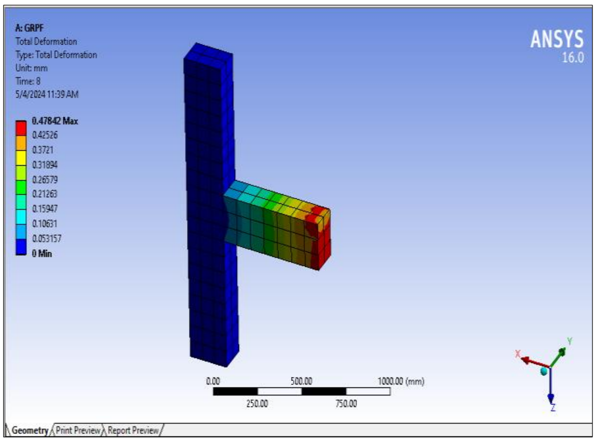

Figure 2 Total deformation

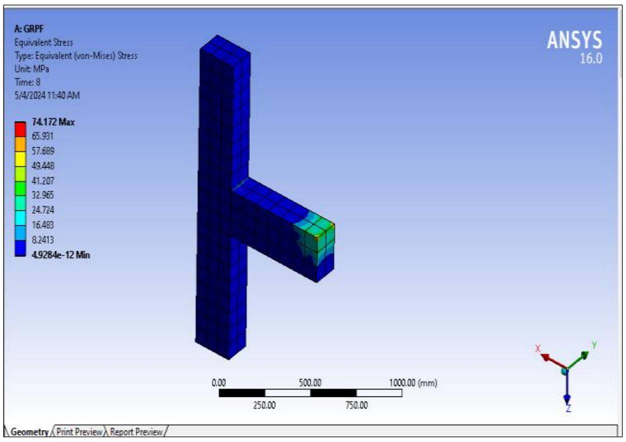

Figure 3 Equivalent Stress

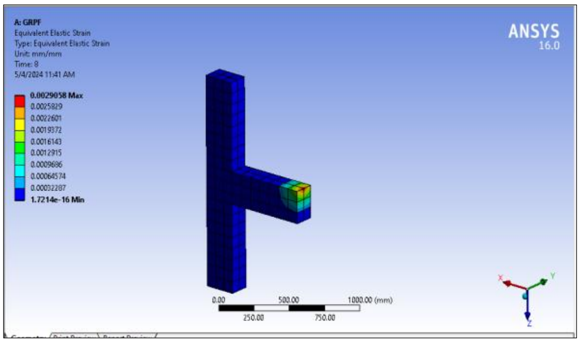

Figure 4 Equivalent Elastic Strain

4.2. Steel

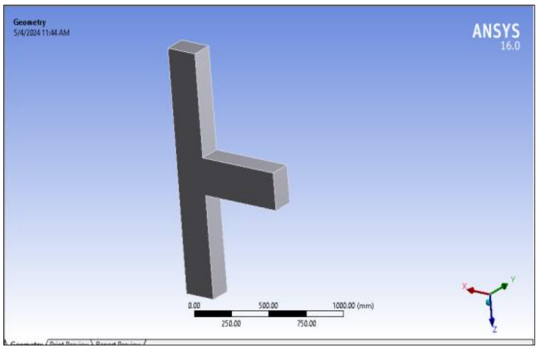

Figure 5 Geometry

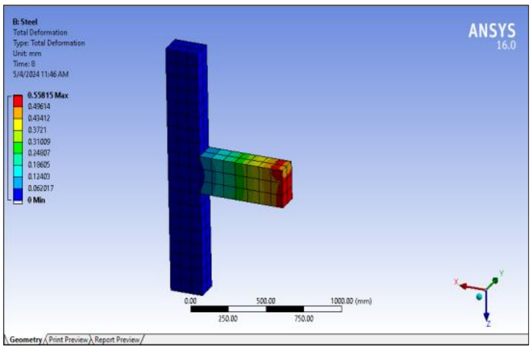

Figure 6 Total deformation

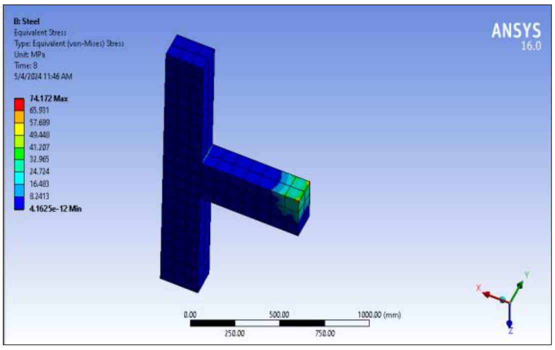

Figure 7 Equivalent Stress

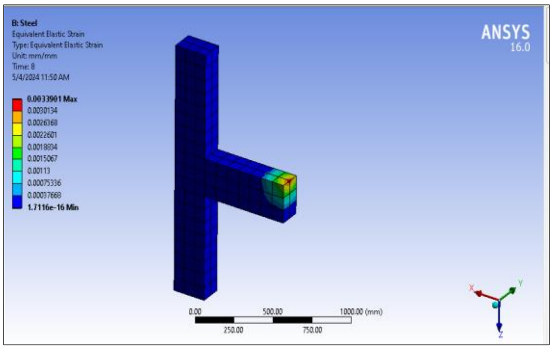

Figure 8 Quivalent Elastic Strain

5. Results and discussion

5.1. Flexural Beam test

*5.1.1. Plain Concrete beam 150*150*700mm*

Table 1 Beam Compressive Strength

Day	Beam sample	Strength	Avg-strength
3	1	350 kg.	350 kg.
7	2	510 Kg	510 kg.
28	3	760 Kg	760kg

We examined three samples of plain concrete beams on separate days, as seen in the graph above. Each beam sample's strength is expressed in kilograms (kg). The first beam sample tested on day three weighed 350 kg. The second beam sample's strength was 510 kg on day 7. Ultimately, the third beam sample's strength was 760 kg on day 28. Thus, the following is the plain concrete beams' average strength: The first sample weighed 350 kg, the second sample weighed 510 kg, and the third sample weighed 760 kg.

5.1.2. Steel RF concrete beam (steel bar used = 8 mm)

Table 2 Strength

Day	Sample	Strength	Avg strength
	1	1440kg	
3	2	1443 kg	1437 kg
	3	1428 Kg	
	I	1928 kg	
7	2	1930 kg	1932 kg
	3	1940 kg	
	1	2897 kg	
28	2	2910 kg	2874 kg
	3	2905 kg	

The graph shows that three samples of 8mm steel-barred reinforced concrete beams were tested on different days. The strength of each sample is expressed in kilograms (kg). The first sample demonstrated a strength of 1440 kg on day 1.

Day 3: 1443 kg was the weight recorded by the second sample, and 1428 kg by the third sample. By day seven, the third sample had reached 1940 kg, while the second sample had improved to 1930 kg. At last, on day 28, the third sample reached 2905 kg, while the second sample peaked at 2910 kg. The following formula is used to determine the average strengths: 1437 kg, 1932 kg, and 2874 kg, respectively.

5.1.3. GRPF bars Dia = 8mm

Table 3 Compressive Strength

Day	Sample	Strength	Avg strength
3	1	1196 Kg	1195kg
	2	1200 Kg	
	3	1190Kg	
	1	1600Kg	
7	2	1610kg	
	3	1605Kg	1605 kg
	1	2387 kg	
28	2	2390kg	
	3	2400kg	2392kg

We examined three samples on various days, as shown by the GRPF bars in the above graph. Each sample's strength is expressed in kilograms (kg). Day 3 results showed that the first sample weighed 1196 kg, whereas the second sample weighed 1200 kg. On day seven, the third sample's strength was recorded at 1190 kg. Day 1 saw considerable improvements in the first sample, which weighed 1600 kg, and the second sample, which weighed 1610 kg. The third sample peaked at 1605 kg on day 28. Finally, on the first day, the first sample showed an amazing strength of 2387 kg, but the second and third samples showed extraordinary strength of 2390 kg and 2400 kg respective. Each group's average strengths are 1195 kg, 1605 kg, and 2392 kg.respectively.

5.2. Modulus of Rupture

5.2.1. Plain concrete beam

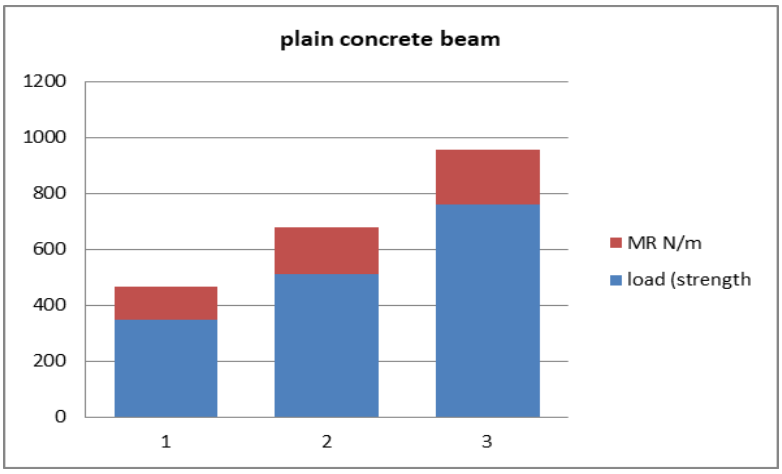

Figure 9 Plain Concrete Beam Strength

We find a relationship between the loads (strength) applied to each sample and the resulting flexural strength measured in mega pascals (N/mm2) based on the graph for plain concrete beams. The flexural strength of the three samples increases from 116 N/mm^2 to 194 N/mm^2 when the load increases from 350 kg to 760 kg. This implies that the concrete beams get stronger and more resilient to bending pressures as more weight is placed on them. As a result, plain concrete beams' load and flexural strength have a positive relationship, indicating that they can bear higher loads without cracking.

5.2.2. Steel RF concrete beam

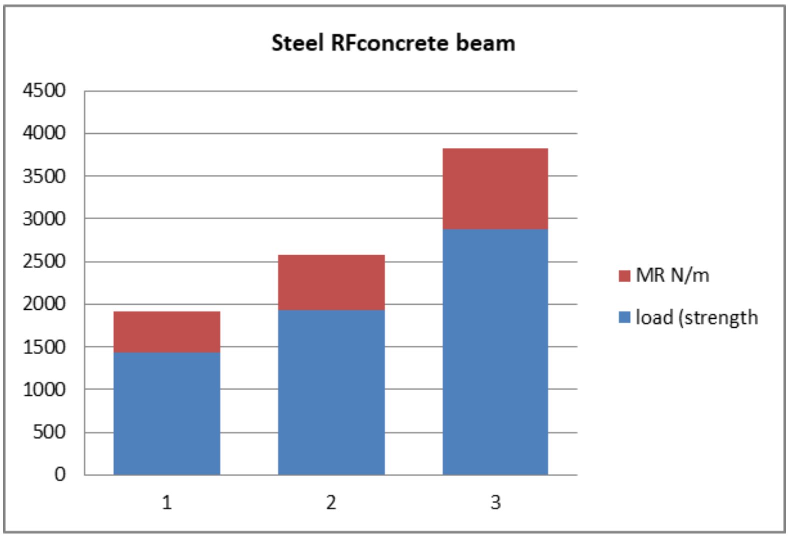

Figure 10 Steel RF Concrete Beam Strength

The applied load and the resulting flexural strength (MR) exhibit a clear link, as seen by the above graph that shows the data for Steel RF concrete beams. The flexural strength of the samples evaluated on days 3, 7, and 28 increased from 479 to 958 N/mm^2 in tandem with the rising load from 1437 to 2874 units.

5.2.3. GFRP

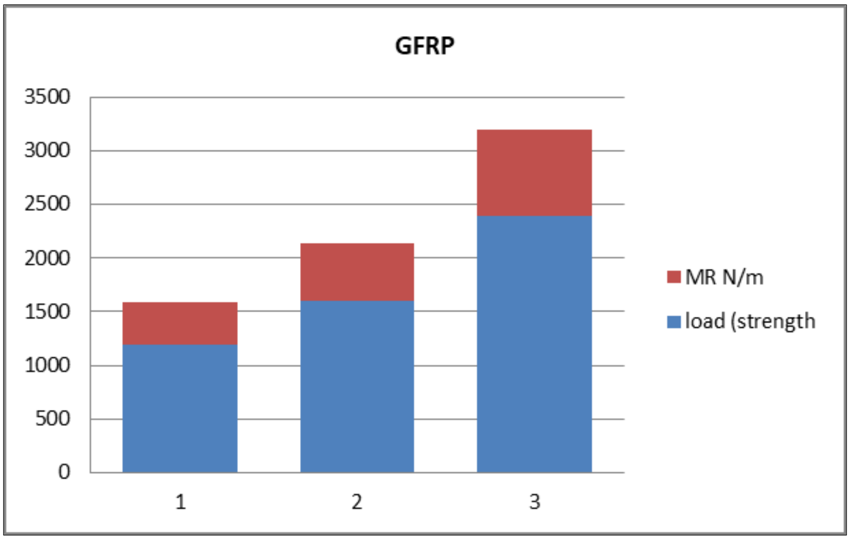

Figure 11 GRPF Concrete Beam Strength

According to the GFRP sample graph above, there is a noticeable correlation between the applied load and flexural strength (MR). Flexural strength improves from 398 to 797 N/mm^2 throughout samples tested on days 3, 7, and 28 when load increments from 1195 to 2392 units are applied. Higher loads correspond to greater flexural strength, highlighting the material's capacity to withstand bending pressures. This tendency is persistent.

5.3. Bar bending test

5.3.1. Steel bar bend test (8mm dia)

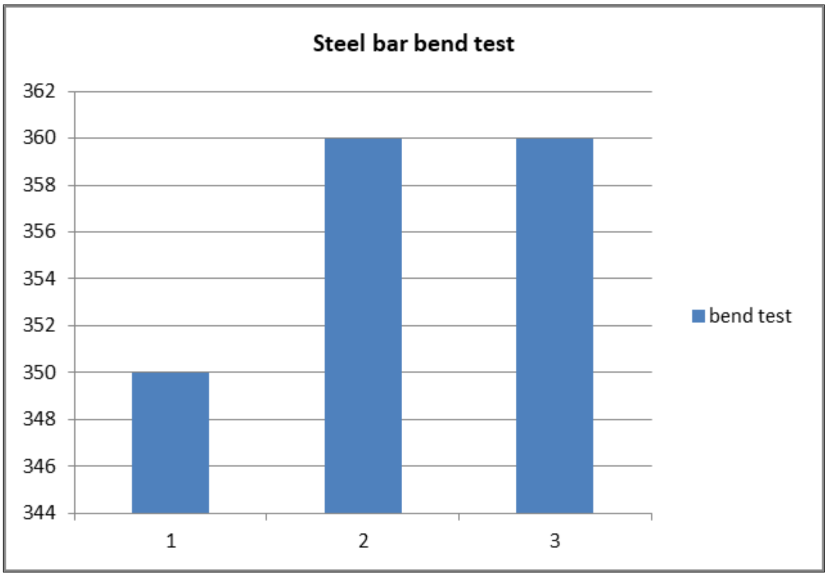

Figure 12 Steel Bar Bend Test

The presented data shows three samples with different weights: 350 kg, 360 kg, and 360 kg, respectively, as shown in the above graph. Most likely, the load or strength applied to each sample is represented by these weights. Sample 1 stands out with a slightly lower weight than samples 2 and 3, suggesting consistency. Samples 2 and 3 have similar weights.

5.3.2. Glass RF polymer Bar (8mm dia)

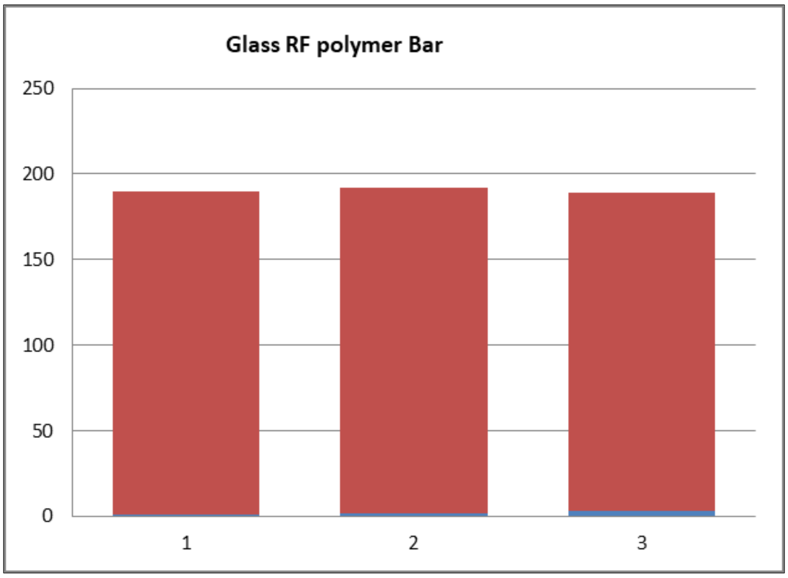

Figure 13 Glass RF polymer Bar

According to the statistics above, samples 1, 2, and 3 of Glass RF polymer Bar with an 8mm diameter have weights of 189 kg, 190 kg, and 186 kg, in that order. These weights most likely correspond to the force or load that was applied to every sample in the experiment or testing. The weight consistency between samples points to homogeneity in the material properties or experimental design.

5.4. Tensile strength

5.4.1. Steel bar

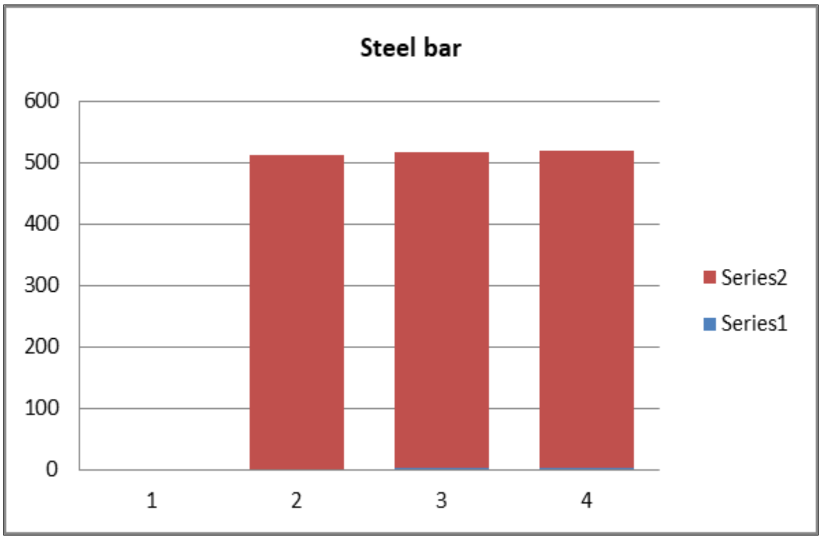

Figure 14 Steel Bar

5.4.2. GRPF

The graph shows that the strengths of the three steel bar samples are as follows: sample 1's strength is 510 N/mm2, sample 2's strength is 515 N/mm2, and sample 3's strength is 517 N/mm^2. This data suggests a positive association with sample, as there is a consistent increase in strength across the samples.

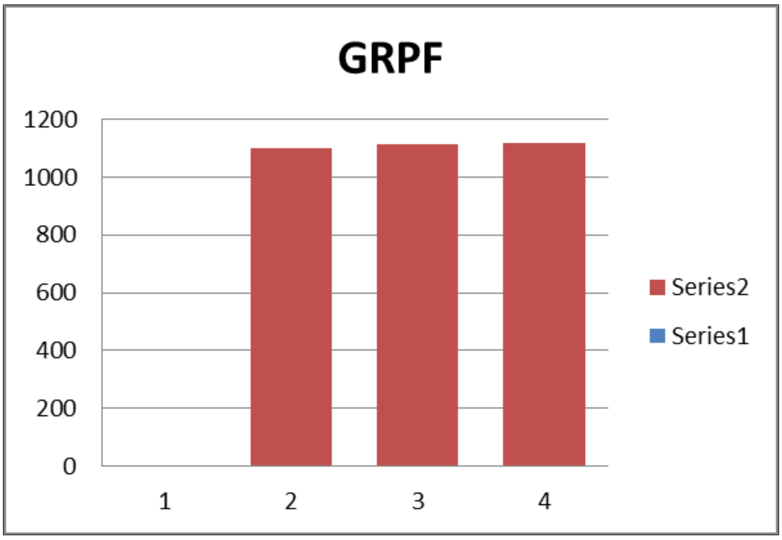

Figure 15 GRPF

According to the GRPF sample graph above, there is a definite upward trend in strength from sample 1 to sample 3. The strengths of samples 1 and 2 and 3 are 1100 N/mm^2, 1110 N/mm^2, and 1115 N/mm^2, respectively. This steady increase in strength points to a positive link between sample number and strength, suggesting possible enhancements or differences in the material qualities among the samples.

5.5. Comparison between Steel and GFRP

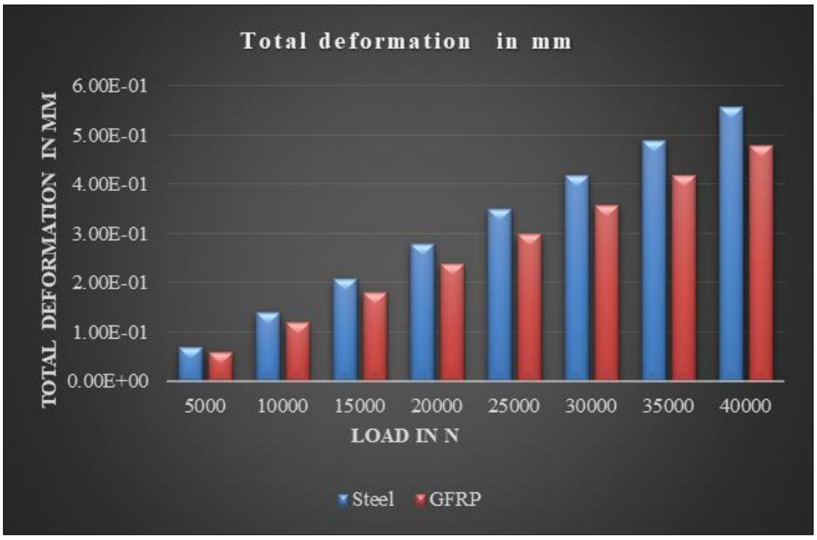

Figure 16 Comparison between Steel and GRPF Deformation

The GRPF sample graph above shows that the strength of the trend from sample 1 to sample 3 is unquestionably increasing. Samples 1, 2, and 3 have strengths of 1100 N/mm², 1110 N/mm², and 1115 N/mm², in that order. This consistent rise in strength indicates a positive correlation between sample size and strength, implying potential improvements or variations in the material properties between the samples.of Form

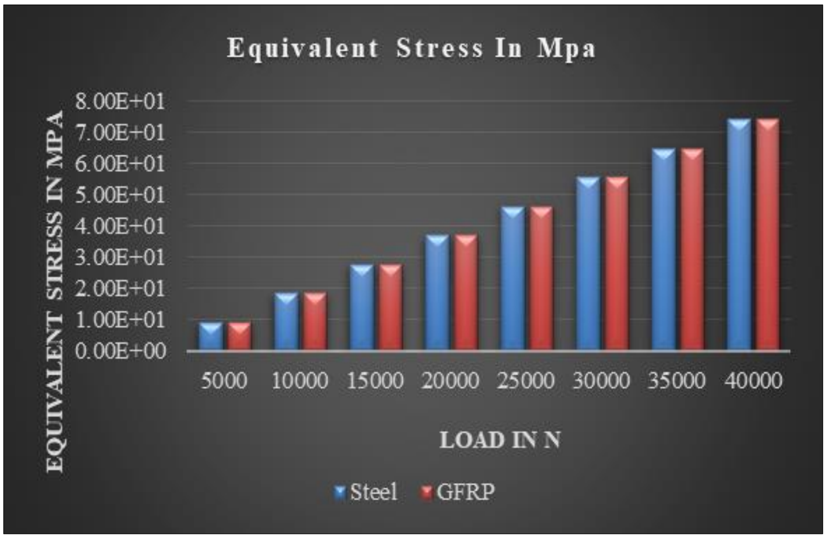

Figure 17 Equivalent Stress

The graph displays the equivalent stress values in megapascals (MPa) for steel and glass fiber reinforced polymer (GFRP) for two distinct materials under a range of load circumstances, from 5000 N to 40000 N. The stress a material experiences under complicated loading conditions is represented by equivalent stress, which condenses them into a single stress number. The result indicates that despite their different material compositions, steel and GFRP can tolerate similar amounts of stress because they both exhibit identical equivalent stress values across all load levels. This implies that in situations where great strength is required, GFRP may be a good substitute for steel.

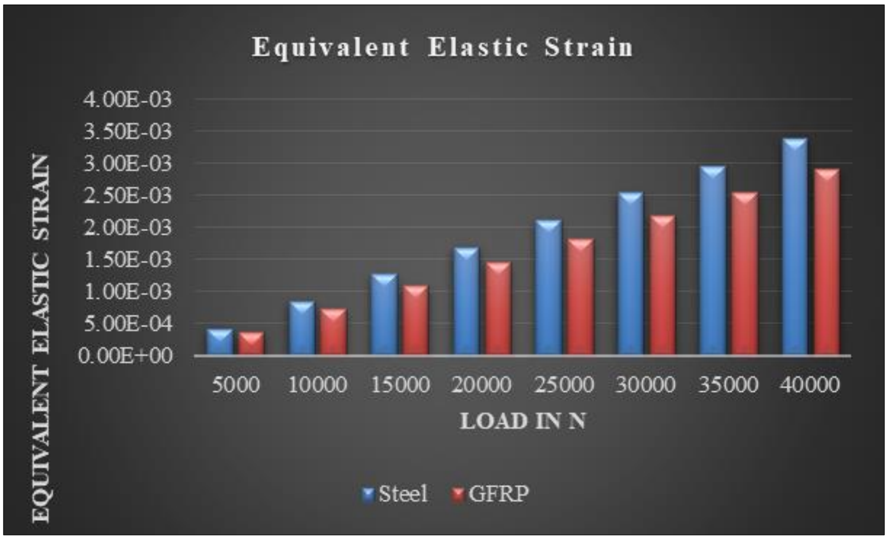

Figure 18 Equivalant Elastic Strain

Data on equivalent elastic strain under various loads for glass fiber reinforced polymer (GFRP) and steel are shown in the graph. Both materials see a proportionate rise in strain as the load increases from 5000 N to 40000 N, with steel constantly exhibiting greater values than GFRP. This suggests that steel is less resilient than GFRP because it deforms more under the same pressure. The information illustrates how the mechanical qualities of GFRP and steel vary, which can be important information for engineers to consider when choosing materials for engineering or building projects that demand a certain level of strength and elasticity.

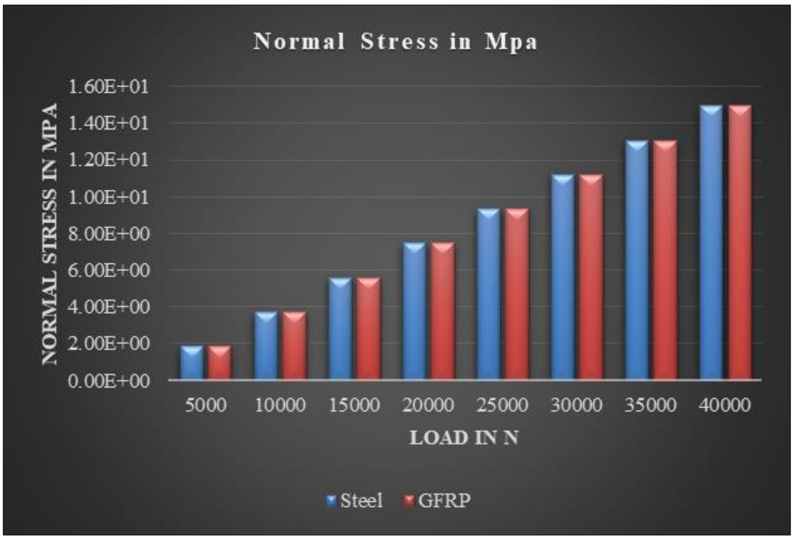

Figure 19 Normal Stress

The graph shows the normal stress (in megapascals, MPa) that glass fiber reinforced polymer (GFRP) and steel encounter under different loads (in newtons, N). As the load increases, both materials exhibit steady increases in stress while keeping constant stress levels. This implies that the forces that steel and GFRP can withstand before failing are comparable. The table makes comparison easier by showing that both materials show equal stress resistance for the specified loads, which qualifies them as viable substitutes in engineering applications where strength is essential.

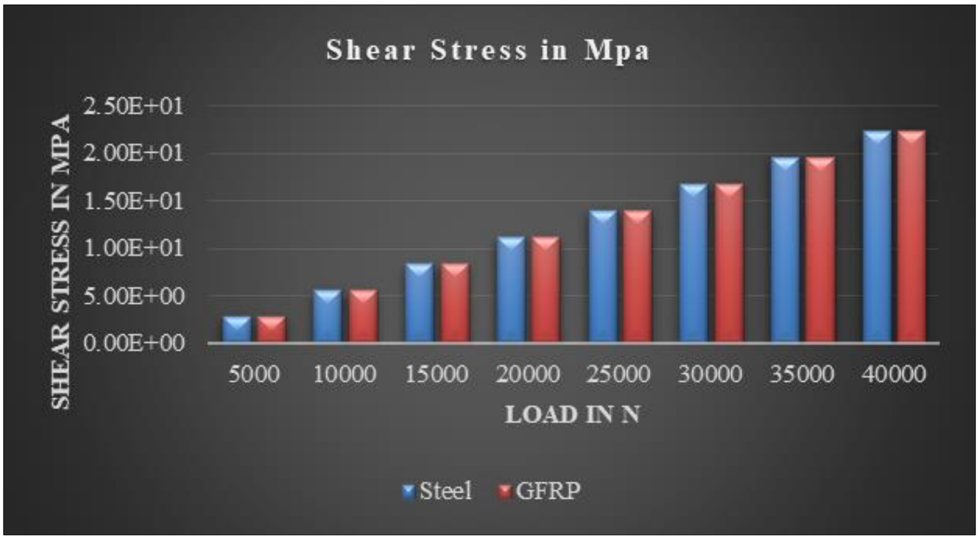

Figure 20 Shera Stress in Mpa

The graph shows the normal stress (in megapascals, MPa) that glass fiber reinforced polymer (GFRP) and steel encounter under different loads (in newtons, N). As the load increases, both materials exhibit steady increases in stress while keeping constant stress levels. This implies that the forces that steel and GFRP can withstand before failing are comparable. The table makes comparison easier by showing that both materials show equal stress resistance for the specified loads, which qualifies them as viable substitutes in engineering applications where strength is essential.

Figure 21 Testing Machine of GRPF

Figure 22 Tensile test of GRPF bars

Figure 23 Flexure strength test

6. Conclusion

Significant discoveries and insights into the structural behavior and performance of glass fiber reinforced polymer (GFRP) bars in reinforced concrete sections are provided by this study, which compares GFRP to conventional building materials like steel in a number of construction-related areas. The flexural and tensile tests, along with the mix design and casting process, were crucial in providing crucial information about the mechanical attributes and performance characteristics of GFRP bars. The outcomes demonstrated GFRP's resistance to applied loads and deformations, suggesting that it could be a good substitute for traditional steel reinforcement in reinforced concrete constructions.

Additionally, the thorough examination of reinforced concrete building sections with GFRP bars showed encouraging results for main stresses, bending stresses, shear stresses, and deflection. These results demonstrate how GFRP can improve the structural integrity and performance of elements made of reinforced concrete, opening the door for a broader use of GFRP in building techniques.

Using ANSYS software, a comparative study of beam-column junctions with GFRP and RCC sections provided important insights into the behavior of the structure under various loading scenarios. The findings showed that the performance of the GFRP and RCC sections was equivalent, indicating that GFRP can be a suitable replacement for steel reinforcement in important structural components. Overall, the study highlights how GFRP bars, which have advantages including corrosion resistance, lightweight characteristics, and ease of installation, have the potential to completely transform conventional reinforcement techniques in reinforced concrete construction.

The information provided here advances our knowledge of and use of GFRP in structural engineering, which has implications for enhancing the efficiency, sustainability, and durability of building projects. The incorporation of GFRP reinforcement has potential for tackling major difficulties and boosting the future of infrastructure development as the construction industry continues to look for creative solutions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Junaid, M. T., Elbana, A., Altoubat, S., & Al-Sadoon, Z. (2019). Experimental study on the effect of matrix on the flexural behavior of beams reinforced with Glass Fiber Reinforced Polymer (GFRP) bars. Composite Structures, 222. https://doi.org/10.1016/j.compstruct.2019.110930

[2] Adam, M. A., Said, M., Mahmoud, A. A., & Shanour, A. S. (2015). Analytical and experimental flexural behavior of concrete beams reinforced with glass fiber reinforced polymers bars. Construction and Building Materials, 84(June), 354–366. https://doi.org/10.1016/j.conbuildmat.2015.03.057

[3] Venkata Suraj Reddy, R., Srinivasa Reddy, V., Seshagiri Rao, M. V., Shrihari, S., Kadhim, S. I., & Awasthi, M. (2023). Design of concrete beam reinforced with GFRP bars as per ACI codal provisions. E3S Web of Conferences, 391, 4–11. https://doi.org/10.1051/e3sconf/202339101213

[4] Xue, W., Peng, F., & Zheng, Q. (2016). Design Equations for Flexural Capacity of Concrete Beams Reinforced with Glass Fiber–Reinforced Polymer Bars. Journal of Composites for Construction, 20(3), 1–11. https://doi.org/10.1061/(asce)cc.1943-5614.0000630

[5] Rovira, J., Almerich, A., Molines, J., & Martin, P. (2011). Develpoment and Applications of Glass Fiber. August, 1–6.

[6] Alsayed, S. H., Al-Salloum, Y. A., & Almusallam, T. H. (2000). Performance of glass fiber reinforced plastic bars as a reinforcing material for concrete structures. Composites Part B: Engineering, 31(6–7), 555–567. https://doi.org/10.1016/S1359-8368(99)00049-9

[7] Adam, M. A., Said, M., Mahmoud, A. A., & Shanour, A. S. (2015). Analytical and experimental flexural behavior of concrete beams reinforced with glass fiber reinforced polymers bars. Construction and Building Materials, 84, 354–366. https://doi.org/10.1016/j.conbuildmat.2015.03.057

[8] Kinjawadekar, T. A., Patil, S., & Nayak, G. (2023). A Critical Review on Glass Fiber-Reinforced Polymer Bars as Reinforcement in Flexural Members. Journal of The Institution of Engineers (India): Series A, 104(2), 501–516. https://doi.org/10.1007/s40030-023-00729-6

[9] Rahman, S. M. H., Mahmoud, K., & El-Salakawy, E. (2017). Behavior of Glass Fiber–Reinforced Polymer Reinforced Concrete Continuous T-Beams. Journal of Composites for Construction, 21(2), 1–12. https://doi.org/10.1061/(asce)cc.1943-5614.0000740

[10] Zhou, Z., Meng, L., Zeng, F., Guan, S., Sun, J., & Tafsirojjaman, T. (2023). Experimental Study and Discrete Analysis of Compressive Properties of Glass Fiber-Reinforced Polymer (GFRP) Bars. Polymers, 15(12). https://doi.org/10.3390/polym15122651

[11] Hosen, M. A., Johnson Alengaram, U., Jumaat, M. Z., Ramli Sulong, N. H., & Darain, K. M. U. (2017). Glass Fiber Reinforced Polymer (GFRP) Bars for Enhancing the Flexural Performance of RC Beams Using Side-NSM Technique. Polymers, 9(5). https://doi.org/10.3390/polym9050180

[12] Nagre, V., Gandhe, G., & Tupe, D. (2021). Flexural and bond response of rcc beam and cube by using glass fiber reinforced polymer bar.

[13] Tobbi, H., Farghaly, A. S., & Benmokrane, B. (2012). Concrete columns reinforced longitudinally and transversally with glass fiber-reinforced polymer bars. ACI Structural Journal, 109(4), 551–558. https://doi.org/10.14359/51683874

[14] Kassa, H. K., Melesse, G., & Yabasa, G. (2022). A Study on Using Glass Fiber-Reinforced Polymer Composites for Shear and Flexural Enhancement of Reinforced Concrete Beams. Advances in Civil Engineering, 2022. https://doi.org/10.1155/2022/5995103

[15] Junaid, M. T., Elbana, A., Altoubat, S., & Al-Sadoon, Z. (2019). Experimental study on the effect of matrix on the flexural behavior of beams reinforced with Glass Fiber Reinforced Polymer(GFRP)bars.CompositeStructures,222. https://doi.org/10.1016/j.compstruct.2019.110930