

Flexural Performance Evaluation Of Glass Fiber Reinforced Polymer Bars (GFRP) In Doubly Reinforced Beams: An Experimental Approach

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Abstract

using the primary goal of evaluating their efficacy as a sustainable substitute for conventional steel reinforcement, this experimental study investigates the flexural performance of double-reinforced concrete beams strengthened using Glass Fibre fiber-reinforced polymer (GFRP) bars. Recent years have seen a significant increase in interest in the use of GFRP bars in concrete buildings due to their inherent benefits, which include increased durability, reduced material weight, and corrosion resistance. Five examples were manufactured for this investigation; two included only GFRP bars, two included hybrid bars, and one had only steel bar beams for comparison. The beams are full-scale, with dimensions of 152 and 230 mm in cross-section and 3000 mm in length. With a factored load of 2.5 kips/ft, the beam specimens were constructed as standard doubly reinforced beam designs, with 5#4 bars in tension and 2#4 bars in compression. T-Rod International produced the GFRP bars utilized in this investigation. To assess their flexural behavior, including load-deflection response, cracking patterns, and ultimate load capacity, beam specimens were put through three-point bending tests. The efficiency of GFRP bars in doubly reinforced beams in comparison to traditional steel reinforcement is assessed through the analysis of experimental data. Deflection, ultimate strength, and failure mechanisms are the main provisions being examined. GFRP bars exhibit brittle behavior and a 54% greater tensile strength than steel bars. Steel-reinforced beams have a 30% greater ultimate load capacity than pure GFRP-reinforced beams, whereas hybrid GFRP-reinforced beams have an 18% lower ultimate load capacity. In GFRP and hybrid samples, the maximum mid-span deflection caused by the ultimate load is significantly greater than in steel samples.

Keywords: double-reinforced beam, glass fiber reinforced polymer (GFRP),

maximum load capacity, tensile strength, and sustainable substitute.

Introduction

Civil engineers plan, design, build, operate, and maintain physical infrastructure. Roads, bridges, water supplies, sewers, and other kinds of buildings are all considered public and private infrastructure [1]. The infrastructure is expected to last between 50 and 100 years. One of the biggest issues facing engineers today is the problem of aging infrastructure, particularly reinforced concrete [2]. The corrosion of the reinforcing steel is one of the main causes of the degradation of reinforced concrete structures. In the past, corrosion-related bridge failures have proved fatal [3–4]. Examples are the 1983 Mianus River and the 135 Mississippi River Bridge in Minneapolis, Minnesota [5]. The nation's annual expenses and gross domestic product are directly impacted by the deterioration of its infrastructure. The US Department of Commerce's Census Bureau estimates that the direct costs of highway bridge corrosion are \$6.43 billion a year [6]. Regarding the environmental and climatic issues of the building sector, the steel industry is one of the largest global producers of carbon dioxide. Approximately 1.83% of CO₂ is released with every tonne of steel produced, which accounts for 7-8% of world emissions. Construction reinforcement accounts for 44% of steel consumption. This means that steel rebar alone is responsible for a staggering 1.5% of worldwide carbon emissions. Engineers are looking for alternatives to steel reinforcement, which has been used for a long time. Examples include zinc-coated steel and stainless steel. Fiber-reinforced polymer (FRP) composites, such as glass, carbon, and basalt, are now being utilized in major building projects. In order to improve the performance of a reinforced concrete structure, a lot of research has focused on the use of various materials for strengthening and repair [7–10]. Among other things, employing Glass Fibre Reinforced Polymers (GFRP) bars to strengthen our future infrastructure makes sense because of its excellent mechanical qualities, low weight, non-corrosive, non-magnetic, and high tensile strength. The phrase "glass fiber reinforced" describes a composite material made by mixing glass fibers with a polymer matrix. A polymer matrix is usually an epoxy, vinyl ester, or polyester thermosetting resin. Alumino-borosilicate glass is a more common glass fiber used as a GFRP [11-12].

Table: Shows the Components of GFRP Bar

Property	Matrix		
	Polyester	Epoxy	Vinyl Ester
Density (kg/m ³)	1200.0-1400.0	1200.0-1400.0	1150.0-1350.0
Tensile Strength (MPa)	34.50-104	55.0-130.0	73-81
Longitudinal Modulus (GPa)	2.10-3.450	2.750-4.100	3.00-3.50
Poisson’s Coefficient	0.350-0.390	0.380-0.400	0.360-0.390
Thermal Expansion Coefficient (10 ⁻⁶ / C)	55.0-100.0	45.0-65.0	50.0-75.0
Moisture content (%)	0.150-0.600	0.080-0.150	0.140-0.300

GFRP bars may significantly increase the lifespan of reinforced concrete structures and reduce the cost of upkeep, replacement, and repair since they are non-corrosive. In contrast to conventional steel-reinforced concrete, glass fiber-reinforced plastic (GFRP) presents special design challenges, although being a feasible alternative [13–15]. One of the most difficult challenges is to identify its brittle mechanism of failure [16–17]. The design philosophy for flexure-prone parts, such as beams, is drastically changed by the difference in the failure modes of GFRP and steel. According to the Canadian National Building Code, the top concrete must crumble after the bottom steel reinforcement for a ductile collapse to occur (CSA A23.3-04). GFRP is believed to be more brittle than steel concrete, nevertheless, indicating a different mode of collapse. It is believed that GFRP concrete is more brittle than steel concrete, indicating a different mode of collapse. Finding out more about the load capacities, fracture patterns, deflections, and failure processes of GFRP-

reinforced beams is the primary goal of the study. The behavior of GFRP-reinforced concrete beams was investigated at Rutgers University. According to the author, the deflection of GFRP beams is three times larger than that of steel beams under any given load. They concluded that GFRP beams exhibit a considerable degree of flexure cracking and that the design strategy may be determined by the deformation serviceability. When examining the load-deflection curve both before and after breaking, bilinear curve analysis performs better. They concluded that there may be a chance to use this material for construction purposes [18]. The pre-and post-cracking deflection behavior of concrete beams reinforced with fiber-reinforced plastic rebar has also been the subject of several studies. The writers devote great attention to detail as they carefully examine concrete beams reinforced with steel and GFRP. The most significant factors that differ between specimens are concrete compressive strength, shear reinforcement type and distribution, and reinforcing bar type and size [19–21]. To highlight the significance of creating and promoting the terrestrial environment, several researchers have worked on using various trash in a variety of construction materials [22–27].

This work aims to compare GFRP-reinforced beams to steel-reinforced beams by conducting an experimental analysis of the flexural performance and ductility of GFRP-reinforced beams. In order to solve the problems of corrosion and the depletion of steel raw materials, as well as to lessen the impact on the environment and guarantee long-term viability, guidelines for the construction industry to use GFRP with confidence in the field must also be developed.

The next stage is to build and test the five full-scale beams that are reinforced with steel and GFRP, two of which are made entirely of GFRP. One beam is made entirely of steel with steel tension and compression bars, and it acts as a control sample. The other two beams are hybrid reinforced with GFRP tension bars and steel compression bars. The beams were 152 x 230 x 3000 mm in size.

Materials and Method

Thus, the investigation of the flexural performance of beams doubly reinforced with GFRP bars will be the primary emphasis of the research to be done in this area. The following steps are taken to achieve this goal: The following justifies the use of the research strategy that follows:

Literature Review: All previous research on GFRP bars, double-reinforced beams, and flexural performances is thoroughly examined before talking about the results of the current study and identifying any gaps in the literature.

Experiment Design: The trials use five doubly reinforced beams. One beam is a control sample of pure steel reinforced, two beams are reinforced with GFRP bars, and two beams are reinforced with hybrid (both GFRP and steel) bars. The doubly reinforced beam configuration, which is frequently utilized in buildings and bridges, is the kind of beam specimen that is chosen.

Properties of the Material: When the concrete grade is prefixed earlier by the maximum compressive strength of concrete used in construction, the tensile strength of the steel and GFRP bars is determined.

Specimen Preparation: To ensure an adequate connection between the reinforcements and the concrete, the beam specimens are pre-cast and cured.

Testing Procedure: To evaluate the beam specimens' flexural performance which includes their ultimate load capacity, fracture patterns, and load-deflection response they are put through a third-point bending test.

Data Analysis: The test findings were then explained and contrasted to assess the flexural performance of GFRP-reinforced beams in comparison to steel-reinforced beams.

Results and Discussion: In connection with the study's goals and the section on the literature review, this study also discusses the consequences of employing GFRP bars in double-reinforced beams.

Table: Sources of used materials

S. No.	Materials	Sources
1	Coarse Aggregates	Dara Adam Khel, Kohat
2	Fine Aggregate	Lawrencepur sand
3	Cement	Kohat cement

4	GFRP	T-Rod int.
5	Steel reinforcement	FF Steel

Material Collection

GFRP and steel were purchased from the local market during this project phase, while the necessary materials (cement, fine and coarse aggregates, and aggregates) were supplied from easily accessible local areas. Our priority for the project was to employ materials that were readily available locally. The fine aggregates came from Lawrencepur sand, and the coarse aggregates came from Dara Adam Khel near Kohat. T-Rod International provided the GFRP, while Kohat Cement provided the cement.

Test Specimen Casting

We moved on to the main component of our study, which was casting and testing the beams, after completing the mix design and choosing the reinforcing bars. The beams were intended to sustain an ultimate design load of 2.5 kip/ft and a floor live load of 80 lb/ft. The needed steel area and cross-sectional dimensions were calculated using ACI 318-19 guidelines. Specifically, beams having a cross-sectional area of 6" by 9" and a length of 10 feet were intended to be double-reinforced. We cast five beams in total for testing:

Beam B1: A beam that is entirely strengthened with steel

Beams B2 and B3 are hybrid beams that have steel compression bars and GFRP tension bars.

Beams B4 and B5 are entirely GFRP-reinforced beams that have GFRP-made compression and tension bars.

All beams were strengthened with #3 stirrups spaced 4.5 inches center-to-center to provide sufficient shear strength. There were 5#4 tension bars and 5#4 compression bars in each beam.

To thoroughly evaluate the performance of hybrid and fully GFRP-reinforced beams in contrast to conventional steel-reinforced beams under particular loading circumstances, this design was selected.

Controlled Samples

A single steel-reinforced reinforced concrete beam with the necessary size was cast.

Samples of GFRP

Two GFRP-reinforced reinforced concrete beams with the necessary size were cast.

Samples of Hybrids

Two hybrid reinforced concrete beams with steel and GFRP reinforcement were cast to the necessary size.

Material Properties

During this stage of the project, both coarse and fine aggregates are subjected to a number of quality assurance assessments. The assessments were carried out in compliance with the particular ASTM guidelines.

The aggregates are put through the following tests: • Sieve Analysis (ASTM C-136).

- Specific Gravity (ASTM C 127)
- Absorption of water (ASTM C 128)
- The moisture content test (ASTM C 70)

The tests performed on the GFRP, and steel are:

- Tensile strength of GFRP (ASTM C 1557).
- Tensile strength of Steel (ASTM C 1557).

Mix Design

ACI 211. 19, Specimen ASTM C 192-82 Reapproved 1990 Specific Guide for Procedure of Choosing the Proportions of Normal, Heavy Weight, and Mass Concrete, is the guide that is used to construct the concrete mix design in this phase. The following are the qualities that the project wants the concrete to have: After 28 days, the cube should reach a compressive strength of 4000 psi. By weight, the concrete mix design ratio is 1:2.25:3.0, and by volume, it is 1:2.7:3.5. When it comes to cement and water, the ideal ratio is 0.57.

Experimental Validation of Mix Design

Six concrete cylinders were formed during this research phase to verify the specified mix design. Three of the six cast samples were cured for 14 days, while the remaining three were cured for 28 days. The cylinders were split into two groups. A Universal Testing Machine (UTM) was used for each of these tests. The approved concrete mix design was found to be suitable for usage based on the favorable findings of the UTM testing. Given these encouraging outcomes, the mix design that was supplied was suitable for the subsequent concrete beam casting. The accompanying table and bar chart display the results of the concrete cylinders.

Table: Compressive Strength of Cylinders

Age (days)	Cylinder 1 (psi)	Cylinder 2 (psi)	Cylinder 3 (psi)	Average compressive strength (psi)	Targeted compressive strength (psi)
14	3250	3188	3378	3272	3600
28	4058	3889	3948	3965	4000

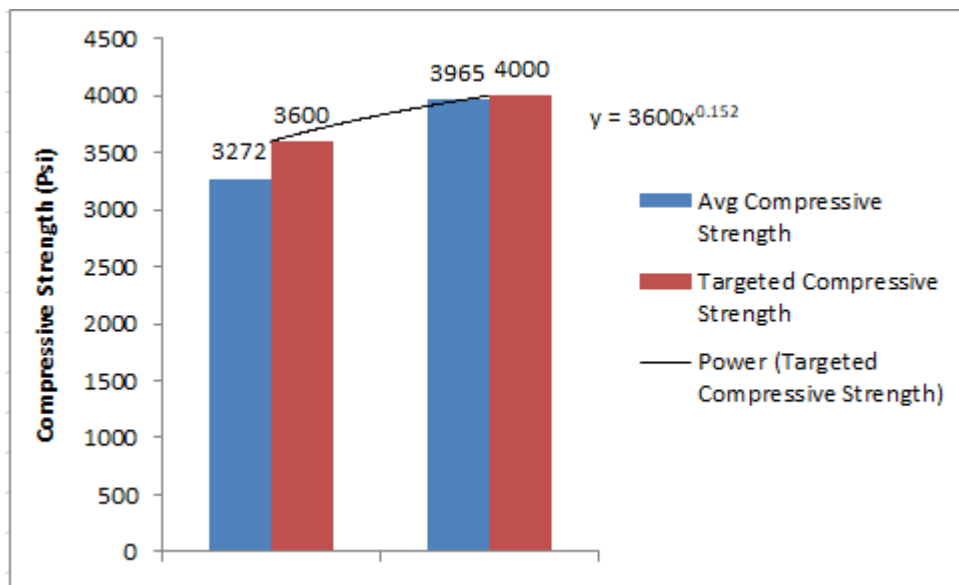


Figure: 14 and 28 days compressive strength values of concrete

Longitudinal GFRP bars

The main focus of this inquiry is on the characteristics and capabilities of the GFRP bars, which are produced by the Pakistani company T-Rods International Company Karachi. Numerous articles exist regarding the mechanical characteristics of these GFRP bars, and it is reasonable to conclude that they differ significantly from steel reinforcement bars in terms of their mechanical attributes. In comparison to steel, GFRP bars have a yield strength that is around three and a half times more, a stiffness of about $\frac{1}{4}$, and an elastic modulus that ranges from 50,000 to 60,000 micro Pascals, whereas steel has an elastic modulus of 200,000 micro Pascals. Additionally, GFRP bars have a substantially larger elastic strain capacity (0.02) than steel bars (0.002). Research has shown that GFRP bars are regarded as fragile materials. The linear shape of the stress-strain curve that these bars exhibit serves as the foundation for this conclusion.

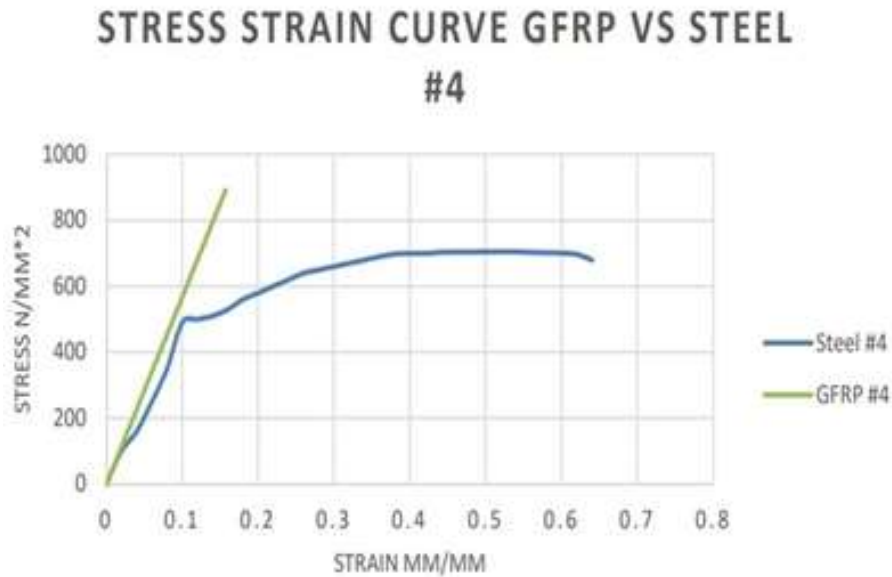


Figure: Stress-Strain Curves of GFRP and Steel Bars

Table: Shows the mechanical properties of different diameters of GFRP bars

S. No.	No. of Bars	Bar Length (m)	Weight of bar (gm)	Load (Tons)	Load (KN)	Tensile Strength (N/mm ²)	Strain (%)
1	#8	1.00	970	33.75	331	650	1.34
2	#6	1.00	570	21.41	210	739	1.49
3	#5	1.00	388	14.47	142	710	1.57
4	#4	1.00	210	11.72	115	891	1.64
5	#3	1.00	150	7.14	70	985	1.79
6	#2	1.00	51	4.28	42	1312	1.94

Each manufacturer provides six different types of longitudinal bars with nominal diameters #8, #6, #5, #4, #3, #2. The direct tensile tests were conducted using test equipment that complied with ASTM DT205-06 requirements.

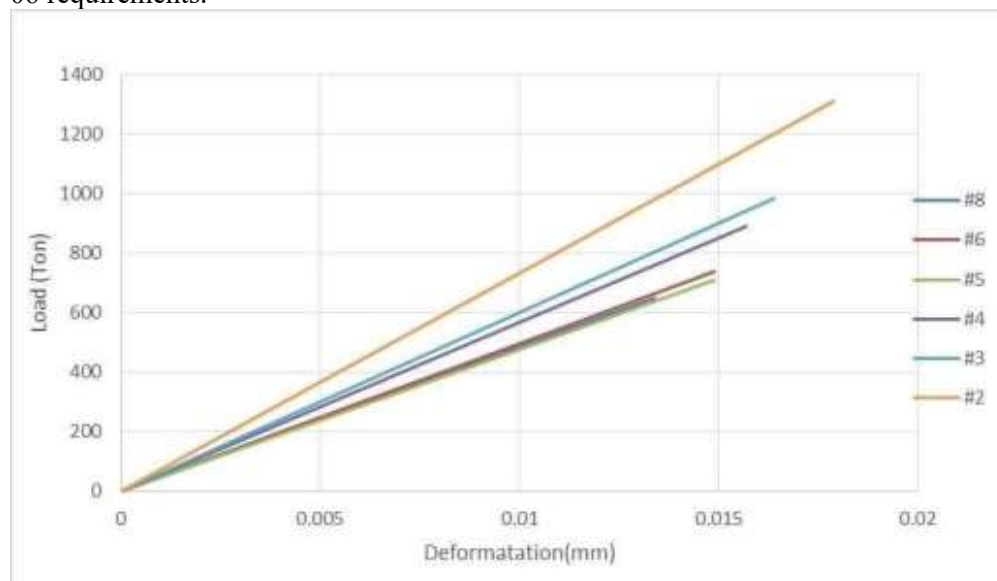


Figure: Stress-strain curves of different diameters of GFRP bars

Tensile load (N) divided by nominal area yields the ultimate, which is determined (mm^2). Divide the maximum strength by the maximum elongation to obtain the elastic modulus. The cross-sectional area of a bar directly relates to both its ultimate strength and its modulus of elasticity.

Transverse Reinforcement

Since our project only used GFRP to support the beams, GFRP bars had to be bent into stirrups. The manufacturer should supply the GFRP bars bent as they cannot be bent on location. Stirrup bars were 6 mm in diameter. Their purpose was to provide concrete with the least amount of cover possible. However, when GFRP is bent 90 degrees, its ultimate strength drops to 40% less than that of a straight GFRP bar. For this reason, we employ grade 60 steel for shear and transverse reinforcement.

Casting of Test Specimens

We moved on to the main component of our study, which was casting and testing the beams, after completing the mix design and choosing the reinforcing bars. The beams were intended to sustain an ultimate design load of 2.5 kip/ft and a floor live load of 80 psf. ACI 318-19 guidelines were followed in determining the necessary steel area and the cross-sectional dimensions. In particular, the beams, which had a 6" by 9" cross-sectional area and a 10-foot length, were intended to be double-strengthened. We cast five beams in total for testing:

Beam B1: A beam that is entirely strengthened with steel.

Beams B2 and B3 are hybrid beams that have steel compression bars and GFRP tension bars.

Beams B4 and B5 are entirely GFRP-reinforced beams that have GFRP-made compression and tension bars. All beams were strengthened with #3 stirrups spaced 4.5 inches center-to-center to provide sufficient shear strength. There were five #4 tension bars and five #4 compression bars in each beam.

This arrangement was selected to thoroughly evaluate the performance of both hybrid and fully GFRP-reinforced beams about conventional steel-reinforced beams under the given loading circumstances.

Control Samples

One reinforced concrete beam incorporating steel reinforcement was cast off the required dimensions.

GFRP Samples

Two reinforced concrete beams incorporating GFRP reinforcement were cast of the required dimensions.

Hybrid Samples

Two Hybrid reinforced concrete beams incorporating GFRP and steel reinforcement were cast of the required dimensions.

Experimental Results

The experimental findings and analysis of the flexural behavior of doubly reinforced concrete beams using Glass Fibre fiber-reinforced polymer (GFRP) bars are presented in this section. The purpose of this study was to assess the potential of GFRP reinforcement in concrete construction, specifically its stiffness, ductility, failure modes, ultimate loads, crack patterns, flexural performance, and initial cracking moment. Two GFRP-reinforced beams, two hybrid beams with GFRP tension and steel compression reinforcement, and one steel-reinforced beam were among the five beams with different reinforcement configurations that we built and tested in order to accomplish this goal.

This section, which is separated into two main sections, presents the experimental data about these five beams: Analysis of Failure Modes and Experimental Discussion. The behavior and characteristics of the two main failure modes seen in the beams—tension failure and concrete crushing failure—are examined in the section on failure mode analysis. The results for the different beams are compared in the Experimental Discussion section, emphasizing the behavioral variations across steel-reinforced, hybrid, and GFRP-reinforced beams. The outcomes of this experimental program offer important new information on the behavior of GFRP-reinforced beams and their prospective applications.

Tensile Tests of GFRP Bars

Glass fiber broke and ruptured, causing glass fiber rebar to behave brittlely and collapse suddenly. Before the fall, there was no warning. The glass fibers were completely separated from each other along their free length. Stress and strain for the material have a linear relationship till failure. This puts the failure mode of the bars with different diameters in the GFRP group into visual form.

The results, which include the elasticity, strain, and load capacity, are tabulated. The computed stress-strain curves are shown in the figure.

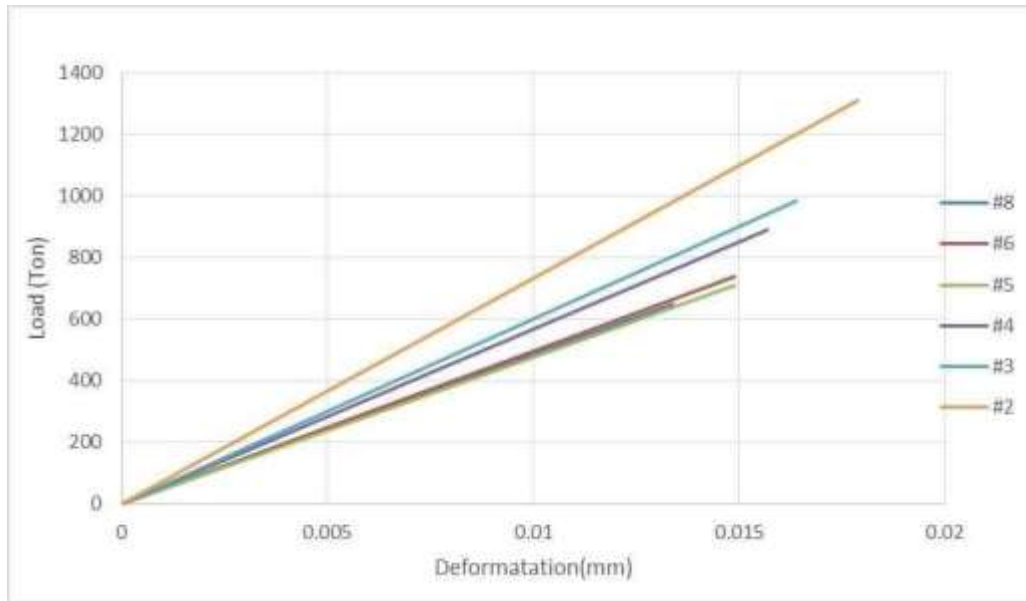


Figure: The Stress-Strain curve of GFRP

Tensile Testing of Steel Reinforcement

The figure demonstrates the tensile behavior of steel bars. The stress-strain curve behaves linearly up to yielding, and then plastically failure occurs with continuous stress to the maximum tensile strength.



Figure: Shows the Stress-Strain Curves of Steel Bars

Pure GFRP Beams Failure Mode

The primary cause of the failure mode was the GFRP reinforcement's brittle tensile breaking. The

compression crushing in the compression zone, which suggests excessive deformation, came next. Eventually, the beam also showed a sharp increase in deflection and, therefore, a decrease in stiffness. This failure pattern differs from the more ductile behavior often exhibited by steel-reinforced beams, demonstrating the need for extra care in the design of GFRP-reinforced beams to ensure their ductility and serviceability.

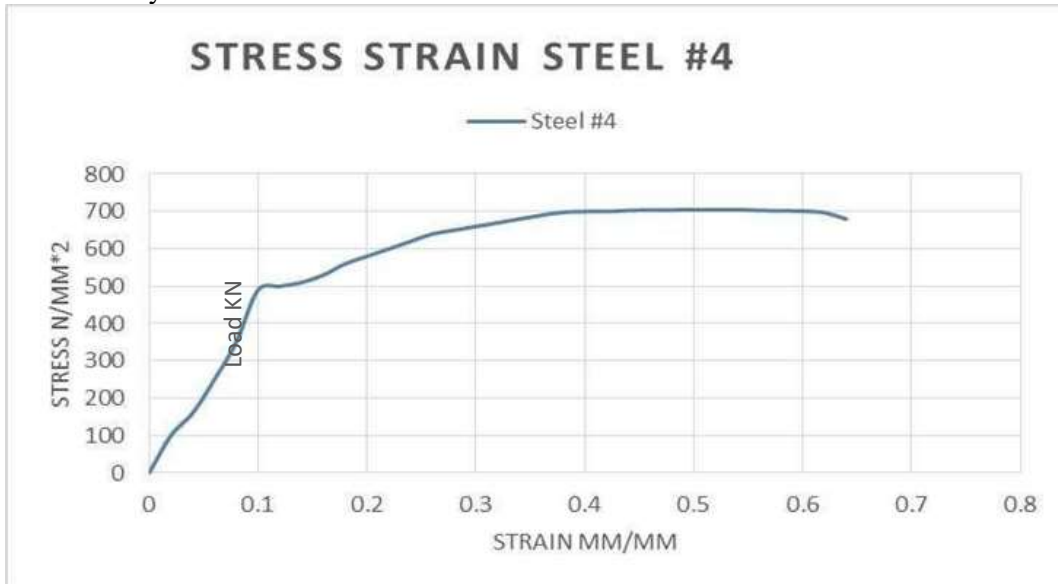


Figure: Load-Deflection Curves of GFRP Reinforced Beam

Hybrid Beams Failure Mode

A distinct failure mechanism was demonstrated using hybrid beams, which had GFRP reinforcement in tension and steel reinforcement in compression. The failure occurred while the GFRP reinforcement was under strain, whereas the steel reinforcement was under compression. The usage of both materials is also shown by this failure mode: GFRP provides strength, while steel is ductile. The hybrid beams must be carefully engineered to achieve desired architectural qualities like ductility and serviceability because of the development of concrete crushing principally in the compression zone and the snapping off of the GFRP reinforcement in the tension zone. Although it must be done ideally, the failure mode mentioned above suggests that it is possible to successfully balance the hybrid beam's strength and ductility during design.

The load-deflection curves of hybrid beams are

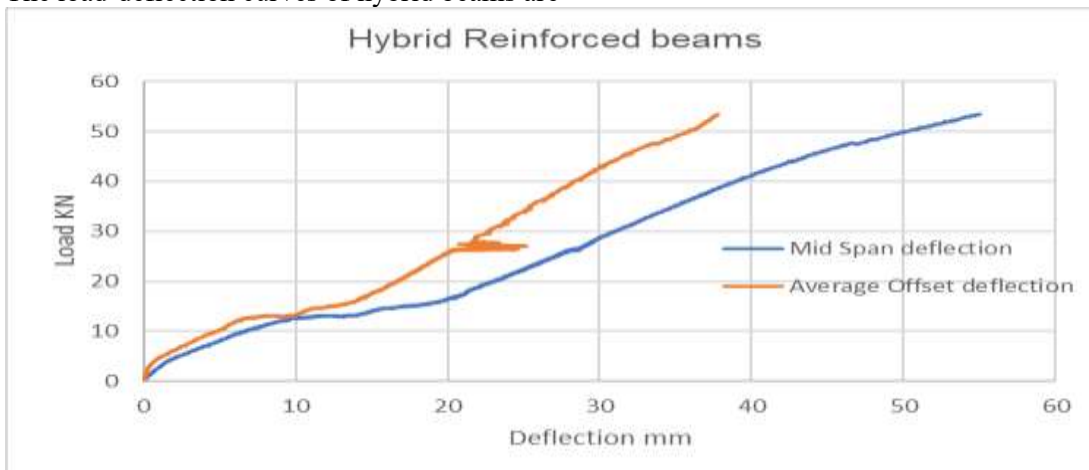


Figure: Load-Deflection Curves of Hybrid Reinforced Beam

Steel Beam Failure Mode

The steel beams that were constructed using steel under both compressive and tensile force conditions had a typical type of failure. The failure was demonstrated by the way the steel reinforcement behaved under tension and compression, leading to severe deformation and rupture. Concrete crushing in the compression zone and steel reinforcement failure in the tension zone as a result of pullout were two other failure scenarios that were noted. However, compared to the hybrid and GFRP beams, the steel beams showed less deformation, suggesting a more delicate manner of failure. Steel-reinforced beams, where the steel reinforcement serves two purposes, exhibit this failure process. The failure mechanism emphasizes the significance of designing steel-reinforced beams with sufficient ductility and toughness, especially in situations when seismic or dynamic loads are anticipated.

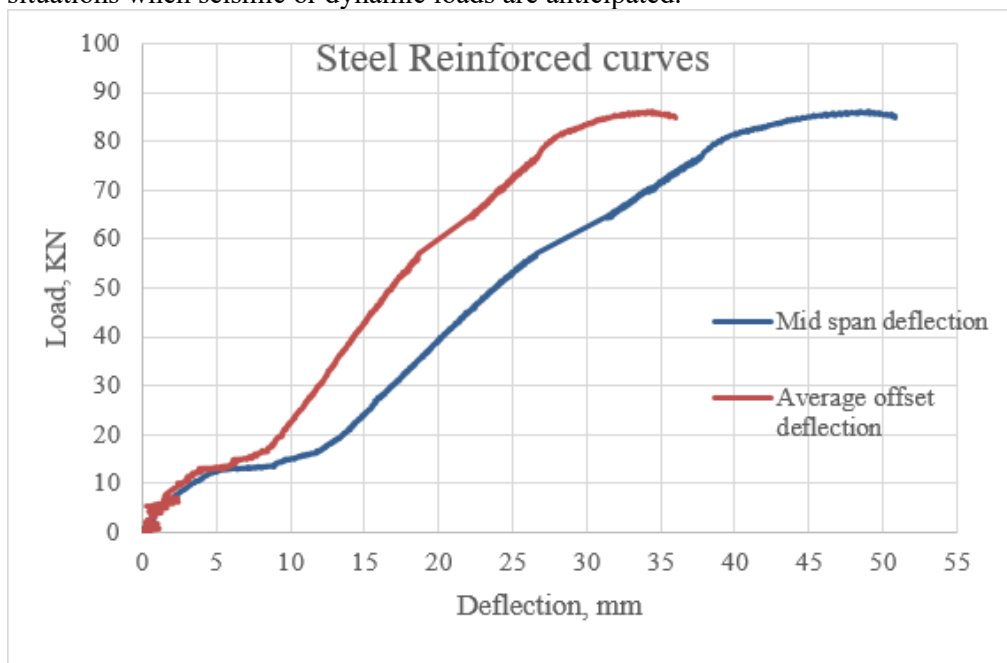


Figure: Load-Deflection Curves of Steel Reinforced Beam

Experimental Discussion

The experimental program's complete findings, including tensile, pull-out, and flexural testing, are shown in this section. Examining the flexural bond behavior of steel and GFRP reinforcements in Reinforced Concrete (RC) members was the main goal of this work. This was accomplished by using concrete with constant strength throughout the experiment, which allowed precise comparisons of each specimen's ultimate load capabilities with various reinforcing materials. The detailed observations and information gathered throughout these tests offer important new perspectives on how steel and GFRP reinforcements behave in RC members, illuminating their flexural strength, bond properties, and potential for structural application. The results of this study offer meaningful contributions to the existing body of knowledge, enhancing our understanding of the performance of GFRP reinforcements in concrete structures and informing the development of innovative, sustainable, and resilient infrastructure solutions.

Tensile Behavior

A comparison is made between the mechanical characteristics and tensile strength of GFRP bars and steel bars. The following results have been determined.

Table: Shows Tensile behavior of GFRP Bars

S. No.	No. of bars	Bar length (m)	Weight of bar (g/m)	Load (Tons)	Load (KN)	Tensile Strength (N/mm ²)	Strain (%)
1	#8	1.00	970	33.75	331	650	1.34
2	#6	1.00	570	21.41	210	739	1.49

3	#5	1.00	388	14.47	142	710	1.57
4	#4	1.00	210	11.72	115	891	1.64
5	#3	1.00	150	7.14	70	985	1.79
6	#2	1.00	51	4.28	42	1312	1.94

The tensile strength of GFRP bars is approximately two times greater than steel bars. The GFRP bar shows linear behavior with brittle failure. The specimen of the GFRP bar failed through the rupture of fibers.

Flexure Behavior

Load Capacity of Reinforced Beams

By gradually adding load until the beams collapsed, an assessment was conducted to ascertain how well the reinforced beams performed in terms of their ability to support loads. The GFRP parametric beams, on the other hand, could sustain a maximum load of 55 KN before failing at 15 KN. The total maximum load for the beams made of both materials was 70 KN, and the first break showed up at 24 KN. In contrast, the steel-reinforced beam had the highest maximum load of 89 KN; nonetheless, the beam's mid-span cracks started to form at an initial load of 38 KN. To put it more directly, the GFRP-reinforced beams were more deformed than the steel-reinforced beams. This puts the beams at risk for a variety of performance problems. Furthermore, the GFRP-reinforced beams have a substantially lower cracking load than the steel-reinforced beams. Furthermore, when it comes to reinforced beams, the significance of material selection cannot be emphasized enough.



Figure: Shows the Flexure Behavior of GFRP and Steel

Conclusions and Recommendations

Conclusions

- The tensile strength of GFRP bars is significantly greater than that of steel bars; nevertheless, adequate preparation of the GFRP specimen in compliance with the requirements is necessary to get a satisfactory result.
- GFRP-reinforced concrete sections exhibit significant deformability due to the non-ductile nature of GFRP bars, which causes excessive flexural cracking at comparatively low stresses. In particular, GFRP and hybrid beams exhibit substantially reduced cracking loads, with cracks appearing at just 14 KN and

18 KN, respectively, in comparison to 24 KN in steel-reinforced beams.

- Steel bars exhibit tensile behavior, whereas GFRP bars exhibit brittle behavior.
- In comparison to its steel-reinforced counterparts, the GFRP-reinforced beam and the hybrid beam had a lower ultimate load capacity of 32% and 23%, respectively, due to the incompatibility of concrete and GFRP material, even though they all had the same reinforcing area in doubly reinforced beams.
- Some of the beam specimens' crack widths fall within the allowed range according to the maximum crack width formula recommended by ACI 440.1R-15.
- The GFRP reinforced concrete section exhibits significant deformability, but the GFRP bars lack ductility.
- Although they come at a high initial cost, the fact that they are simple to transport and require little to no maintenance because they are non-corrosive still qualifies them as a decent substitute for steel bars. In light of lifespan costs, the GFRP bar can be compared favorably to steel as a reinforcing material.

Recommendations

- GFRP bars should be utilized more often as reinforcing materials since they can sustain a significant applied load and also aid in preventing corrosion and the associated high maintenance costs.
- In order to ensure a safe and regulated failure mechanism, it is crucial to design over-reinforced sections in the construction industry that let the concrete compress before the GFRP bars burst. The designer's greatest choice is the concrete's compression failure.
- The designer's greatest choice is the concrete's compression failure.
- The CSA, ACI, and ASA requirements for the design guidelines should be adhered to by the designer.
- Limits should be established for the design purpose and additional validation of the deflection deformability factor should be necessary.
- Limits should be established for the design purpose and additional validation of the deflection deformability factor should be necessary.
- GFRP is perfect for subterranean buildings like water retention and sewage tanks, as well as shoreline and offshore constructions, despite having lower flexure strength than steel due to its non-corrosive nature and longevity.

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List of Acronyms

GFRP Glass Fiber Reinforced Polymer.

RC Reinforced Concrete.

S Steel.

G GFRP.

ACI American Concrete Institute.

ASTM American Society for Testing Materials.

CSA Canadian Standards Association

NACE National Associate of Corrosion Engineers

CMD Concrete Mix Design

SEI Structural Engineering Institute

RCB Reinforced Concrete Beam