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An Experimental Investigation on Steel and GFRP RC Beams using Polypropylene Fiber

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ABSTRACT
This research focuses on the performance of concrete beams partially/fully reinforced with glass fiber-reinforced polymer bars with Polypropylene fiber Reinforced Concrete. This study reported the test results of 11 reinforced concrete beams with dimensions 100 × 150mm and a 1500-mm clear span length subjected to a two-point loading system. The tested beams were divided into five groups; i.e., CB, SP, GP, GP-T. and GP-C. Experimental work has been conducted to determine material properties and standard cubes have been tested in compression for flexural strength. The beams are designed so as to satisfy the flexural criteria. The flexural behaviour of 11 beams 1500mm x 100mm x 150mm were tested under loading frame of 1000KN capacity. The experimental results showed that different types of flexural reinforcement beams enhance the ultimate load compared to the conventional RC beams.

I.INTRODUCTION

In contemporary civil engineering, reinforced concrete beams constitute fundamental structural elements, crucial for bearing compressive loads in buildings and infrastructure. Traditionally, these beams employ a composite of Portland cement concrete for compression resistance and embedded steel rebars for tensile and shear load resilience. However, a significant challenge arises from the susceptibility of steel rebars to corrosion, limiting their longevity and necessitating costly protective measures such as coatings. Recent advancements in materials technology have spurred the development of alternatives to traditional steel reinforcement, notably Fiber-Reinforced Polymers (FRP). Among these, Glass Fiber-Reinforced Polymer (GFRP) stands out due to its corrosion resistance, mechanical properties comparable to steel, and favorable characteristics such as light weight and immunity to electromagnetic fields. These attributes make GFRP bars particularly suitable for applications in harsh environments like marine structures, where conventional steel rebars are prone to accelerated corrosion. The adoption of GFRP reinforcement in concrete beams offers promising solutions to mitigate corrosion-related issues while enhancing structural performance. However, challenges remain, including the brittle nature of GFRP materials which affects the ductility and flexural behaviour of reinforced concrete beams. Understanding these behaviours and their implications is critical for optimizing the use of GFRP bars in structural applications, ensuring reliability and longevity comparable to conventional steel reinforcement.

Alongside advancements in reinforcement materials, the incorporation of polypropylene fibers into concrete has gained attention for its ability to enhance material properties and durability. Polypropylene fibers, derived from the textile industry, are cost-effective and characterized by low specific gravity. When added to concrete mixes, these fibers act as micro-reinforcements, improving crack resistance and reducing plastic and thermal shrinkage cracking. This enhancement not only enhances the structural integrity of concrete elements but also prolongs their service life by minimizing the ingress of harmful agents that could lead to deterioration and corrosion. The combined use of GFRP bars and polypropylene fibers represents a holistic approach to addressing the shortcomings of traditional concrete reinforcement methods, offering potential improvements in structural performance, durability, and sustainability.

This paper investigates the flexural behaviour of GFRP-reinforced concrete beams, exploring the influence of reinforcement direction and stress distribution. By comprehensively analysing these aspects, the study aims to contribute insights into maximizing the effectiveness and durability of GFRP reinforcement in civil infrastructure. Through empirical research and theoretical analysis, this work seeks to inform engineering practices and advance the field towards sustainable and resilient construction materials.

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II.LITERATURE REVIEW

1. Trupti Amit Kinjawadekar, Shantharam Patil, Gopinatha Nayak et.al(2023):- "A Critical Review on Glass Fiber-Reinforced Polymer Bars as Reinforcement in Flexural Members."
   The literature review focuses on the application of Glass Fiber-Reinforced Polymer (GFRP) bars in reinforced concrete structures. Through experimental testing and numerical analyses, the review assesses the behaviour of GFRP-reinforced flexural members, including their performance under shear and bending, bond strength, crack patterns, and load-deflection characteristics. In this study, the effort is made to appreciate response of concrete structural members reinforced with GFRP under flexure. Various properties of glass FRP-reinforced flexural members are studied. A brief review of various properties of GFRP-reinforced flexural members will help to understand the response of these rebars

   Conclusion
   The behaviour of the beam in flexure can be enhanced using steel rebar in combination with GFRP reinforcement in terms of increased capacity for carrying the load, higher deflection compared to GFRP-reinforced beam. In the post-cracking stage, GFRP bar, along with the steel bar, is taking more load, and the beam fails in shear. Therefore, shear reinforcement needs to be taken care of.

2. Mohamed S. Moawad and Ahmed Fawzi (2021):-" Performance of concrete beams partially/ fully reinforced with glass fiber polymer bars." This research focuses on the performance of concrete beams partially/fully reinforced with glass fiber-reinforced polymer bars with 50% of GFRP bars were used to reinforce partially concrete beams at flexural zone. While 100% of GFRP bars were used to reinforce fully concrete beams at flexural and compression zones with different concrete compressive strength. This study reported the test results of 6 reinforced concrete beams with dimensions 150 × 200mm and a 1700-mm clear span length subjected to a four-point loading system. The tested beams were divided into three groups; the first one refers to the glass fiber-reinforced polymer bar effect. The second group is referring to the effect of concrete compressive strength, while the third group is referring to the effect of the GFRP bar volume ratio.

   Conclusion
   Using longitudinal GFRP bars as a full or partial replacement of longitudinal steel bar reinforcement led to an increase in the failure load capacity and the average crack width, while a decrease in ductility was reported with a lower number of cracks. Increasing the concrete compressive strength is more compatible with GFRP bar reinforcement and enhanced the failure performance of beams compared with normal compressive strength concrete

3. Jianwei Tu , Quan Zhao , and Kui Gao et.al (2021) :-" The Design of Concrete Beams Reinforced with GFRP Bars Based on Crack Width."
   in this paper for GFRP-RC beams based on the flexure crack width. The state when the maximum flexure crack width in the tensile zone reaches the limit of 0.5 mm specified by ACI 440.1R-15 was used as the design limit state. The concrete compressive strain at the extreme compression fiber of concrete under the design limit state was obtained by four-point bending tests of eight full-scale GFRP-RC beams and finite element analysis. Based on the concrete compressive strain under the design limit state and cross-sectional analysis, a design method for calculating the longitudinal reinforcement ratio of GFRP-RC beams under the design limit state is proposed. This design method is proven to be feasible by the experimental and the finite element results.

   Conclusion
   GFRP-RC beams based on the design method proposed in this paper have the flexural capacity coefficient of about 2.5, which means the beams have a very high factor of safety and reserve strength. Generally, the stress of the tensile bar material is no more than 30% of the ultimate strength, which makes it safe against creep failure too, thereby ensuring its long-term performance

4. Piotr Dybel, Milena Kucharska, Izabela Rzadzka et.al (2020):- "Analysis of flexural strength of beam elements reinforced with GFRP bars."
   a composite reinforcement made with fibre-reinforced polymer (FRP) can be a suitable alternative to the traditional reinforcing steel due to its mechanical and physical properties. the purposes of this paper, an analysis of the flexural strength of concrete elements reinforced with FRP bars with varying reinforcement ratios was conducted. The tests were performed on six beam elements reinforced with glass fibre-reinforced polymer (GFRP) bars. The beams with dimensions of 0.15x0.2x2.5 m were subjected to 4-point bending. This study aimed to assess the influence of the reinforcement ratio on the flexural strength of concrete beams reinforced with composite bars and to verify the failure mechanisms against the guidelines presented in the standard ACI 440.1R-06.

   Conclusion
   The reinforcement ratio has a significant impact on the failure mechanism and the flexural strength of beam elements reinforced with GFRP bars. An increase in the reinforcement ratio results in an improvement in the flexural strength of the specimen and is likely to change the failure mechanism - from rebar rupture to concrete crushing. The guidelines of ACI 440.1R-06 correctly estimate the flexural strength of the beam elements reinforced with GFRP bars.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 07, July-2024

5. Divya S Dharan, Aswathy Lal et.al (2016):-"Study The Effect Of Polypropylene Fiber In Concrete."
   India leading developing country in world. In future high strength high performance concrete required for construction work. Fiber-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. The character of fiber-reinforced concrete changes with varying concretes fiber materials, geometries, distribution, orientation, and densities. Polypropylene fiber is a lightweight synthetic fiber. It prevents crack formation and provides reinforcement to the concrete structure. In this project work polypropylene fibers (Blended type) of different percentage (0.5%, 1%, 1.5%, and 2%) added in concrete. Tests on workability, compressive strength, flexural resistance, split tensile strength.

Conclusion
Compressive strength of 1.5% of blended length polypropylene fiber reinforced concrete has found to be 17% increase in strength, when compared to that of Conventional concrete. Strength enhancement in split tensile strength is 22%, flexural strength is 24%and modulus of elasticity is 11% compared to that of Conventional concrete. The experimental studies proved to be the best method or way in providing strong and durable concrete. It is observed 1.5% fiber in concrete yields max. strength

III.OBJECTIVES

1. To determine the load carrying capacity at first crack and at failure of the beams.
2. To determine the deflection at mid span at failure of the beams.
3. To observe the cracking behaviour of beams.
4. To determine the flexural behaviour of beams.

IV.TEST METHODOLOGY

4.1 Compressive strength test

Compressive strength test will be carried out as per IS 516:1959. After 7 days cubes were taken out from the curing tank and the cubes were taken to the laboratory and tested with the application of gradual loading on compressive testing machine. The test set up is shown in Fig 3.22 & failure of cube shown in fig 3.23. Compressive strength = load at failure / area of cross section in N/mm²

4.2 Flexural Strength Test

Flexural strength test will be carried out as per IS 516:1959. Beam specimens of size 1500x100x150mm will be used for testing. The bearing surfaces of the supporting and loading ends were wiped cleanly and any loose sand or other material were removed from the surface of the specimen, where they were made to contact with the machine. The specimen was then placed in the machine in such a manner that the load was applied to the uppermost surface as cast in the mould. The axis of the specimen was carefully aligned with the axis of the loading device. No packing was used between the bearing surfaces of the specimen and the testing machine. The testing machine shown in Fig 3.24.

Flexural strength= PL/bd2

4.3 Specimen Details

Specimen type	Size of specimen (mm)	Test	Number of specimens
Cubes (7days curing)	150x150x150	Compressive strength test for conventional concrete.	6(3+3) (three conventional +three polypropylene)
Cubes (28days curing)	150x150x150	Compressive strength test for conventional concrete.	6(3+3) (three conventional +three polypropylene)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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Details of beam test specimen

Specimen type	Size of specimen (mm)	Test	Number of specimens
Conventional beam	1500x100x150	Flexural strength test for two-point loading.	03
Steel reinforcement +polypropylene fiber.	1500x100x150	Flexural strength test for two-point loading.	02
GFRP bars reinforced beam +polypropylene fiber	1500x100x150	Flexural strength test for two-point loading.	02
2GFRP bars (in tension) +2steel bars +polypropylene fiber	1500x100x150	Flexural strength test for two-point loading.	02
2GFRP bars (in compression zone) +2steel bars +polypropylene fiber	1500x100x150	Flexural strength test for two-point loading.	02

Beam reinforcement details

Beam identity	Designation	Effective length (mm)	Beam size (mm)	Reinforcement details
B1	CB	1200	1500X100X 150	4#10mm (steel bars) @ top and bottom, 2L-6mm stirrups @ 150mm c/c
B2	SP	1200	1500X100X 150	4#10mm (steel bars) @ top and bottom, 2L-6mm stirrups @ 150mm c/c
B3	GP	1200	1500X100X 150	4#10mm (GFRP bars) @ top and bottom, 2L-6mm stirrups @ 150mm c/c
B4	GP-T	1200	1500X100X 150	2#10mm steel bar @ top and 2#10mm GFRP Bars @ bottom, 2L –6mm stirrups @ 150mm c/c
B5	GP-C	1200	1500X100X 150	2#10mm GFRP bar @ top and 2#10mm STEEL Bars @ bottom, 2L –6mm stirrups @ 150mm c/c

4.4 MIX DESIGN

For casting RC beams M20 grade concrete was used. Mix design was carried out to achieve M20 grade concrete using IS 10262-2019. Mix design calculation is given in the Appendix A. Compressive strength was determined using 28 DAYS curing method, for selecting the mixture proportion for concrete for further investigation. A total number of TWO trial mixes are used. From the compressive strength test results trial MIX1 is finalized for casting of RC beams.

Table 1: Various Mix proportions of M20 Grade concrete by weight

Sl. No	Material	MIX 1	MIX 2
1	Cement	328.3 Kg/m^3	339.65 Kg/m^3
2	Fine Aggregate	766.24 Kg/m^3	799.28 Kg/m^3
3	Coarse Aggregate	1208.15 Kg/m^3	1161.48 Kg/m^3
4	Water	197 Kg/m^3	197 Kg/m^3

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4.5 PREPARATION OF BEAMS

4.5.1 Casting of Conventional RC beams

In Conventional RC beams, longitudinal reinforcement is provided with 2 main bars of 10 mm dia at the bottom and 2 bars of 10mm dia at top as a main reinforcement and tied with vertical stirrups of 6mm dia at a spacing 150 mm c/c provided to support main reinforcement as shown in fig. The moulds were cleaned and one thin coat of oil was applied on all the internal surfaces of the mould for easy removal and getting a smooth surface without affecting shape while removing.

4.5.2 Casting of RC beams with Polypropylene fiber

In this type the beam reinforcement consists of 2 main bars of 10mm dia at bottom and 2 bars of 10mm dia at top tied with vertical stirrups of 6mm dia at a spacing of 150mm are provided as per beam design APPENDIX-B and m20 grade Mix I concrete with replacement of sand with 1% of polypropylene fibers by Volume of Fine aggregate. reinforcement detail in mould is as shown in fig

4.5.3 Casting of PFRC beams with GFRP bars

In this type of beam 2 specimens were prepared. the beam reinforcement is done by GFRP bars consists of 2 main bars of 10mm dia at bottom and 2 bars of 10mm dia at top and tied with vertical Steel stirrups of 6mm dia at a spacing of 150mm.as shown in fig.

4.5.4 Casting of PFRC beams with GFRP bars (in Compression)

In this type of beam reinforcement consists of 2 main bars of 10mm dia at top and 2 Steel bars of 10mm dia at bottom tied with vertical stirrups of 6mm dia at a spacing of 150mm are provided as per beam design APPENDIX-B and m20 grade Mix I concrete with replacement of sand with 1% of polypropylene fibers by Volume of Fine aggregate. reinforcement detail in mould is as shown in fig

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V.TEST RESULTS AND DISCUSSION

5.1 Slump Test for Normal Concrete:

Table 5.1: Result of Slump Test

Sl. No	**W/C**	**Height before the removal of slump cone h1 (mm)**	**Height after the removal of slump cone h2 (mm)**	**Slump (h2-h1) mm**
1	0.58	20	150	130
2	0.60	20	160	140

International Journal of Engineering Research & Technology (IJERT)
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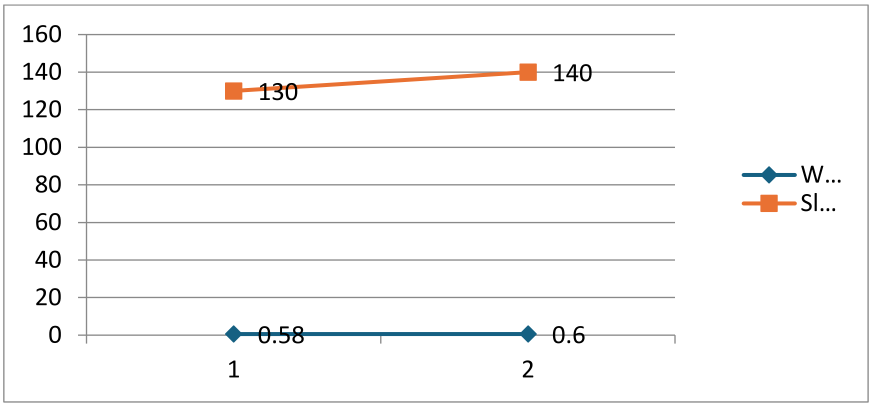
Graph of Slump Test

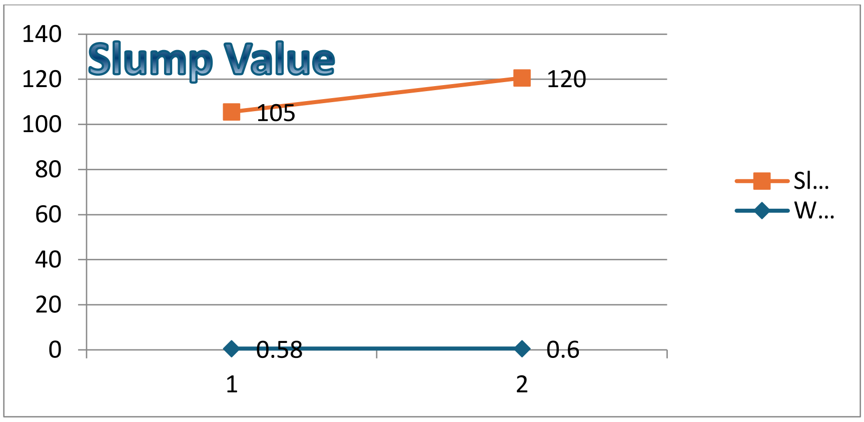


5.2 Slump Test Results of Polypropylene fiber reinforced concrete:

Table5.2: Result of Slump Test

Sl No	**W/C**	**Height before the removal of slump cone h1 (mm)**	**Height after the removal of slump cone h2 (mm)**	**Slump (h2-h1) mm**
1	0.58	20	125	105
2	0.60	20	140	120

Graph of Slump Test



5.3 Compression Test On Concrete

In this test we use cubical moulds of size 15cmX15cmX15cm. The cubes are then demoulded after 24 hours of casting. After completion of curing period of 7 and 28-days cubes shall be removed from water and keep it for drying. After that cubes are tests in Compression testing machine having capability of 3000 KN the load as apply at the rate of 315 KN/m. The load applied in such a way that two opposite sides are compressed. The load at which specimen fail is noticed

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 07, July-2024

Table5.3: Result of Compression Test on cubes after 7 & 28 days of Curing.

Sl No	Variations	7 days Compressive Strength (N/mm^2)	28 days Compressive Strength (N/mm^2)
1	Conventional concrete	14.75	22.3
2	Polypropylene fiber Reinforced concrete	15.94	25.5

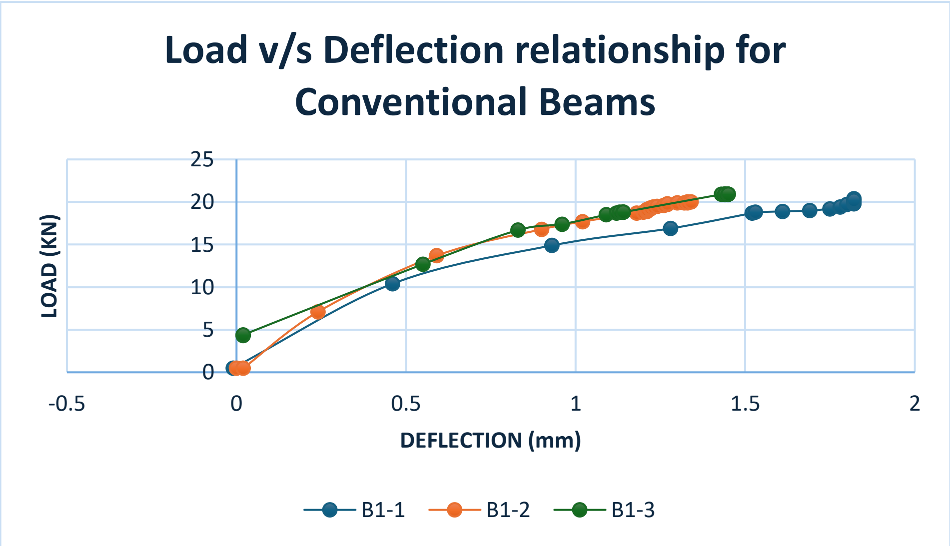
5.4 BEHAVIOR OF RC BEAMS UNDER FLEXURE

5.4.1 Conventional Beams with Steel Bars.

In Conventional RC beams, longitudinal reinforcement is provided with 2 main bars of 10 mm dia at the bottom and 2 bars of 10mm dia at top as a Distribution reinforcement bar and tied with vertical stirrups of 6mm dia at a spacing 150 mm c/c provided to support main reinforcement. The Load at First Crack, Ultimate Load of the Beam and the Deflection at First Crack are Observed.

Tabel 5.4: Load Deflection values for beam (B1-1, B1-2 and B1-3) at first crack

B1			B1-2			B1-3		
Load (KN)	Deflection (mm)	Remark	Load (KN)	Deflection (mm)	Remark	Load (KN)	Deflection (mm)	Remark
20.2	1.82	First Crack	20	1.34	First Crack	20.9	1.45	First Crack
42.6	-	Ultimate Load	46.7	-	Ultimate Load	45.4	-	Ultimate Load



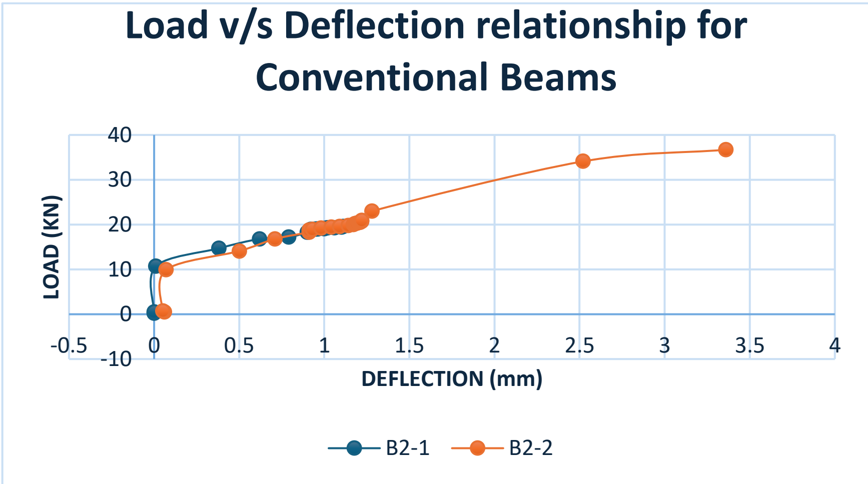
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 07, July-2024

5.4.2 PFRC Beams with Steel Bars

In this type, the beam reinforcement consists of 2 main bars of 10mm dia at bottom and 2 bars of 10mm dia at top tied with vertical stirrups of 6mm dia at a spacing of 150mm are provided as per beam design and m20 grade Mix I concrete with replacement of sand with 1% of polypropylene fibers by Volume of Fine aggregate. The Load at First Crack, Ultimate Load of the Beam and the Deflection at First Crack are Observed.

Tabel 5.5: Load Deflection values for beam (B2-1 and B2-2) at first crack

B2-1			B2-2		
Load (KN)	**Deflection (mm)**	**Remark**	**Load (KN)**	**Deflection (mm)**	**Remark**
19.6	1.11	First Crack	36.7	3.36	First Crack
46	-	Ultimate Load	43.3	-	Ultimate Load



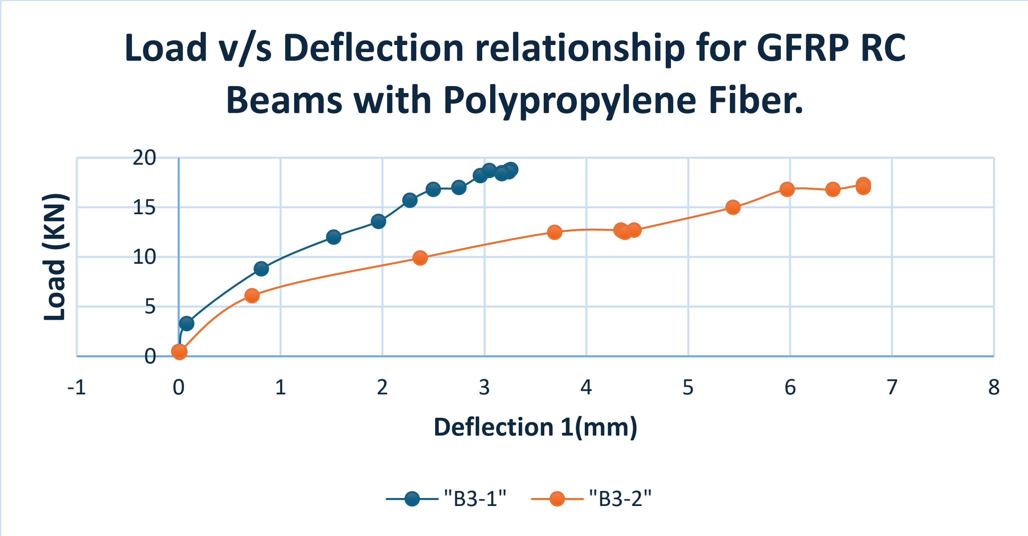
5.4.3 PFRC Beams with GFRP Bars

In this type of beam 2 specimens were prepared. the beam reinforcement is done by GFRP bars consists of 2 main bars of 10mm dia at bottom and 2 bars of 10mm dia at top and tied with vertical Steel stirrups of 6mm dia at a spacing of 150mm. The Load at First Crack, Ultimate Load of the Beam and the Deflection at First Crack are Observed.

Tabel 5.6: Load Deflection values for beam (B3-1 and B3-2) at first crack

B3-1			B3-2		
Load (KN)	**Deflection (mm)**	**Remark**	**Load (KN)**	**Deflection (mm)**	**Remark**
18.4	3.17	First Crack	17	6.72	First Crack
40.8	-	Ultimate Load	23.5	-	Ultimate Load

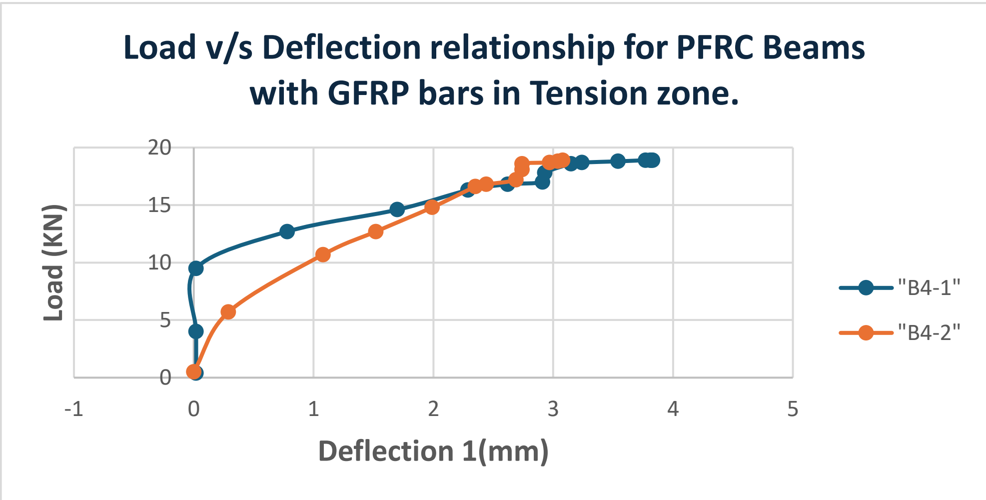
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 07, July-2024



5.4.4 PFRC Beams with GFRP Bars in Tension Zone [B4]
In this type of beam reinforcement consists of 2 main bars of 10mm dia at bottom and 2 Steel bars of 10mm dia at top tied with vertical stirrups of 6mm dia at a spacing of 150mm are provided as per beam design and m20 grade Mix I concrete with replacement of sand with 1% of polypropylene fibers by Volume of Fine aggregate. The Load at First Crack, Ultimate Load of the Beam and the Deflection at First Crack are Observed

Tabel 5.7: Load Deflection values for beam (B4-1 and B4-2) at first crack

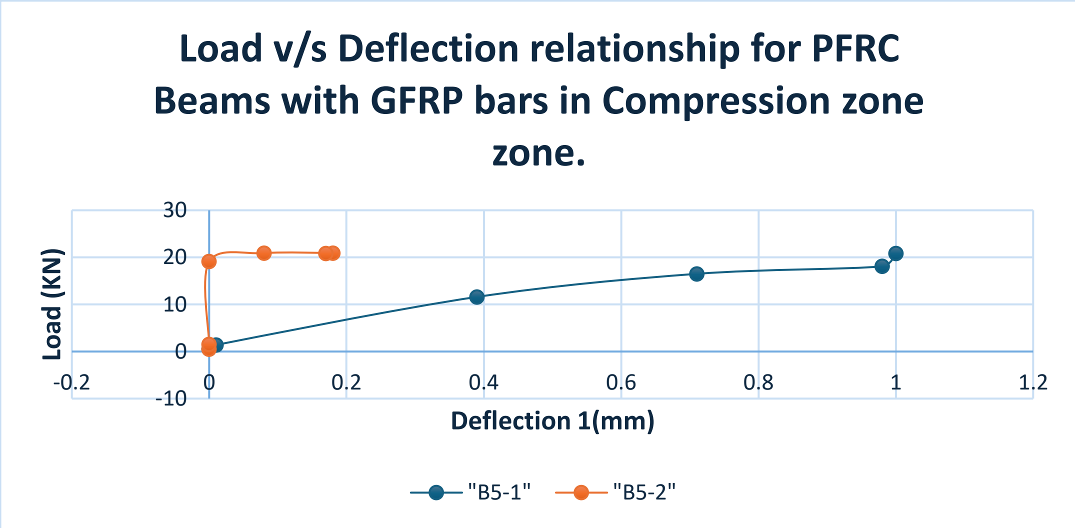
B4-1			B4-2		
Load (KN)	**Deflection (mm)**	**Remark**	**Load (KN)**	**Deflection (mm)**	**Remark**
18.9	3.83	First Crack	18.9	3.08	First Crack
48.6	-	Ultimate Load	41.3	-	Ultimate Load



5.4.5 PFRC Beams with GFRP Bars in Compression Zone [B5]
In this type of beam reinforcement consists of 2 main bars of 10mm dia at top and 2 Steel bars of 10mm dia at bottom tied with vertical stirrups of 6mm dia at a spacing of 150mm are provided as per beam design and m20 grade Mix I concrete with replacement of sand with 1% of polypropylene fibers by Volume of Fine aggregate. The Load at First Crack, Ultimate Load of the Beam and the Deflection at First Crack are Observed

Tabel 5.8: Load Deflection values for beam (B5-1 and B5-2) at first crack

B5-1			B5-2		
Load (KN)	**Deflection (mm)**	**REMARK**	**Load (KN)**	**Deflection (mm)**	**REMARK**
20.8	1	First Crack	20.8	0.17	First Crack
45.7	-	Ultimate Load	46.3	-	Ultimate Load



5.5 Comparison of First Crack, Ultimate Load and Deflection For The Set of Beams

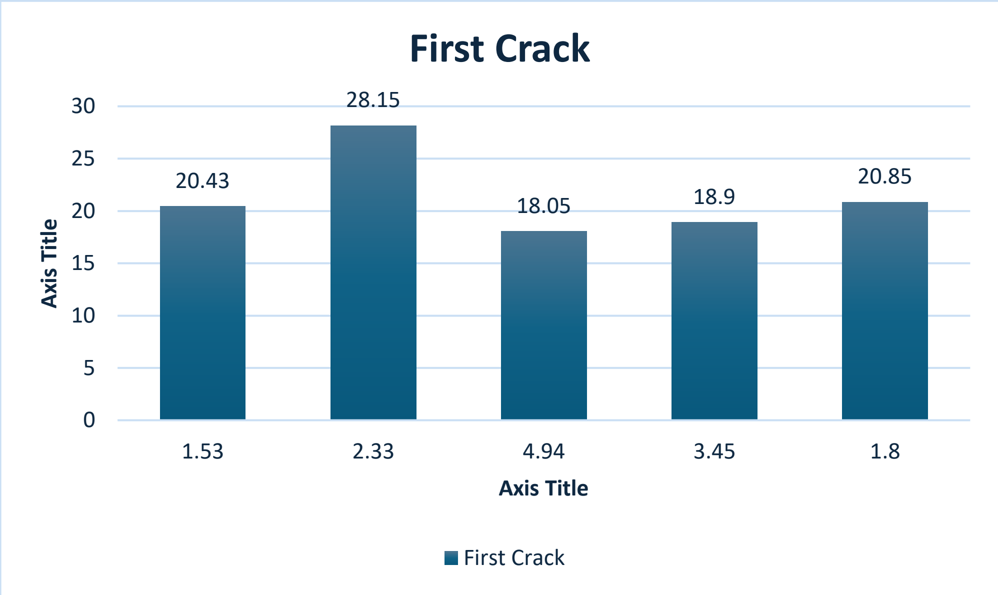
5.5.1 Beam Test Results and Discussion

Table 5.9: Beam Test Results and Discussion

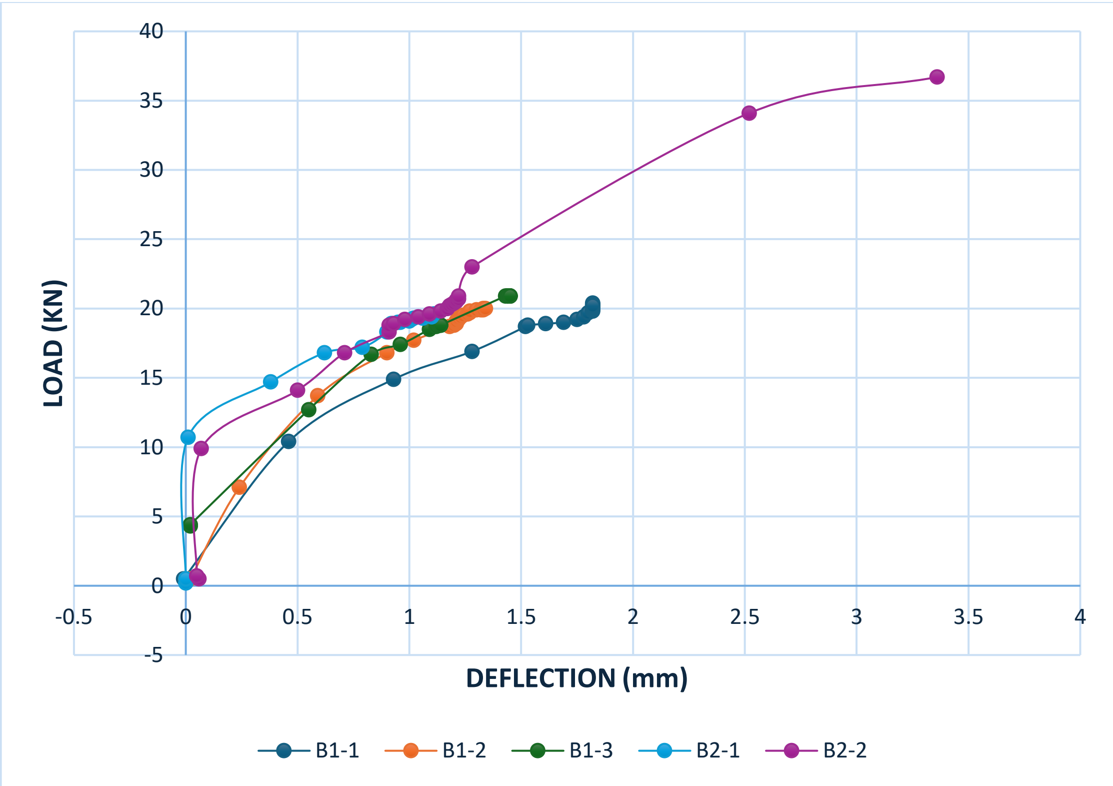
Beam Identity	Beam Size (mm)	Strengthening technique	First Crack Load (KN)	Ultimate Load (KN)	% increase in Load Carrying Capacity	Deflection (mm)	% increase in Deflection	Mode of Failure
B1	1500x100x150	Conventional beam	20.43	44.9	-	1.53	-	Flexure
B2	1500x100x150	Steel reinforcement +polypropylene fiber.	28.15	44.65	-	2.33	52.28	Flexure
B3	1500x100x150	GFRP bars reinforced beam +polypropylene fiber	18.05	42.15	-	4.94	222.87	Flexure
B4	1500x100x150	2GFRP bars (in tension) +2steel bars +polypropylene fiber	18.9	44.95	0.11	3.45	125.49	Flexure
B5	1500x100x150	2GFRP bars (in compression zone) +2steel bars +polypropylene fiber	20.85	46	2.44	1.8	17.6	Flexure

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 07, July-2024

5.5.2: Comparison of first crack load v/s deflection for all set of beams

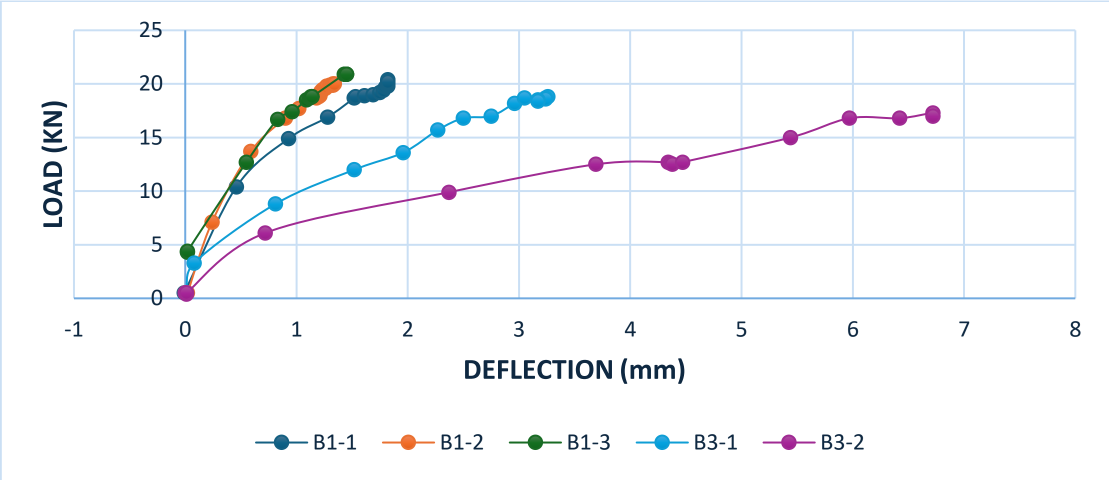


5.5.3: Load v/s deflection curves for Conventional RC Beams v/s PFRC Beams with Steel bars.

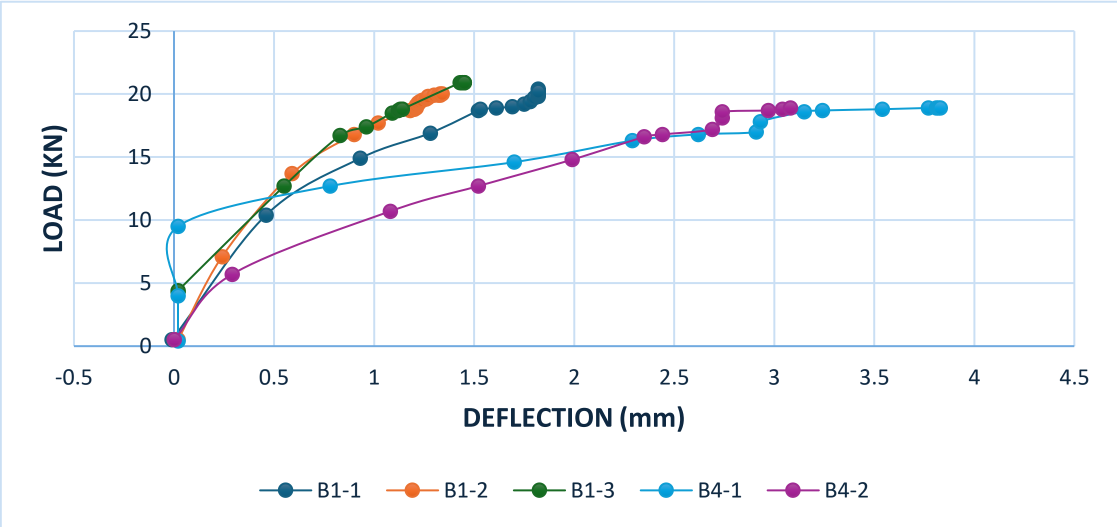


International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 07, July-2024

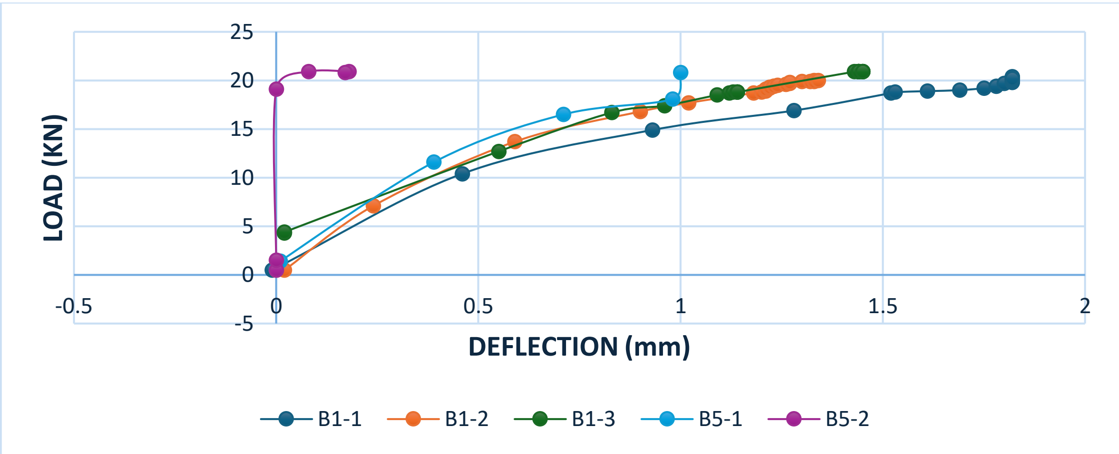
5.5.4: Load v/s deflection curves for Conventional RC Beams v/s PFRC Beams with GFRP bars.



5.5.5: Load v/s deflection curves for Conventional RC Beams v/s PFRC Beams with GFRP bars in Tension zone



5.5.6: Load v/s deflection curves for Conventional RC Beams v/s PFRC Beams With GFRP bars in Compression zone



VI. CONCLUSIONS

From the experimental results the following conclusions are drawn,

1. The behaviour of the beam in flexure can be enhanced using steel rebar in combination with GFRP reinforcement in terms of increased capacity for carrying the load, higher deflection compared to GFRP-reinforced beam. In the post-cracking stage, GFRP bar, along with the steel bar, is taking more load, and the beam fails in shear. Therefore, shear reinforcement needs to be taken care of by decreasing the spacing of shear reinforcement.
2. The critical load-carrying capability of hybrid-reinforced concrete beams is more compared to beam reinforced using only GFRP and steel, respectively.
3. The first crack load and ultimate load carrying capacity of PFRC beams with steel is Increased by 37.78% and decreased by 0.55% Respectively and deflection increased by 52.28% as compared to conventional beam.
4. The first crack load and ultimate load carrying capacity of PFRC beams with GFRP bars is decreased by 11.6% and 6.12% Respectively as compared to conventional beam and deflection at first crack is increased by 222.87%.
5. Compared to conventional beam the first crack load and ultimate load carrying capacity of PFRC with GFRP at compression zone is decreased by 7.5% and increased by 0.11% respectively and deflection at first crack load is increased by 125.5%
6. Compared to conventional beam the first crack load and ultimate load carrying capacity of PFRC beams with GFRP at tension zone is increased by 2.05% and 2.45% respectively and deflection at first crack load is increased by 17.6%.
7. The deflection at mid span at first crack is maximum in PFRC beam with GFRP and minimum in PFRC beam with GFRP bars in tension zone
8. As compared to set of all beams the PFRC beams with steel reinforcement gives the maximum load carrying capacity at first crack.
9. Comparing first crack load and ultimate load of all set of beams, The PFRC beams with GFRP bars at Compression zone showed better results than other set of beams.
10. By using polypropylene fiber reinforced concrete, the average crack width is decreased in all set of beams as compared to conventional beams.

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