Experimental Investigation of Reinforced Concrete Beam with Glass Fibre Reinforced Polymer Bars

Prof. R. H Mohankar[1], Mr. Adarsh Patle[2], Mr. Aditya Parate[3], Mr. Chanchal Wagh[4], Mr. Chirag Wagh[5], Ms. Shreya Dahagane[6], Ms. Tanu Wavre[7]

[1]*Professor, Department of Civil Eng, Priyadarshini Bhagwati College of Engineering, Nagpur*

[2,3,4,5,6,7]*Students, Department of Civil Eng., Priyadarshini Bhagwati College of Engineering, Nagpur*

***Abstract*—Corrosion of steel reinforcement from chloride exposure can compromise the strength of reinforced concrete structures. Rust formation expands, applying pressure on concrete, resulting in cracks and spalling. Prompt repair is crucial for severe cases of spalling. This research assessed the efficacy of repair strategies for reinforced concrete beams post-spalling, including grouting and different techniques involving Glass Fiber Reinforced Polymer (GFRP) reinforcement. Fiber reinforced Polymer (FRP) composites are currently employed in the civil engineering industry as externally bonded reinforcement (EBR) of existing reinforced concrete (RC) and masonry structures and as internal reinforcement of concrete elements as an alternative to steel reinforcing bars. Carbon FRP (CFRP) composites are mainly used for EBR applications whereas glass.**

***Index Terms*—Punching Shear, Steel Fibers, Flat Plates Fire, Glass fibers, Mechanical properties, GFRP bars.**

I. INTRODUCTION

In addition, they simplify and speed up site operation, allow easy and flexible partitioning of space and reduce the overall height of building [2]. One of the main problems in these slabs is the punching shear failure occurred at the connection between column and slab. Punching shear failure takes place when a plug of concrete is pushed out from the slab immediately above the column [3]. At elevated temperatures, concrete and steel undergo a reduction in their properties such as the strength, stiffness and physical properties [4, 5]. Some of these properties cannot recoverable after cooling, therefore, the punching strength of flat slabs subjected to fire is expected to be significantly affected GFRP bars are sensitive to some environmental conditions.

In particular, alkaline environment, moisture, and extreme temperatures degrade their mechanical properties (e.g., tensile strength, ultimate strain, and modulus of elasticity) [17–21]. GFRP reinforcing Received 13 October 2017; Received in revised form 18 December 2017; Accepted 18 December 2017Available online 21 December 2017 Corresponding author. bars are usually comprised of E-Glass fiber reinforcement, which is known to be degraded by marked alkaline environment.

The elastic modulus and strength of GFRP bars decrease with increasing temperature. This behavior is mainly caused by the marked change of mechanical properties of the organic matrix when temperature attains values close or above the glass transition temperature of the matrix, whereas the glass fibres do not significantly change their properties

Currently, the long-term behavior of RC beams strengthened with FRP received great attention of researchers. Pelvris and Triantafillou studied the time-dependent behavior of RC beams strengthened with FRP laminates and proposed an analytical model to predict the long-term deflections. They reported that increasing the CFRP area decreased both the immediate and the creep deflections. Similarly, experimental results by Chami et al., El-Sayed et al., Hong, Sobuz et al. proved that the presence of externally bonded.

The present paper studied the structural performance of the Geopolymer concrete columns reinforced by GFRP bars subjected to eccentric load. Results are compared with columns made of ordinary concrete reinforced by steel bars. The properties of geopolymer concrete, normal strength concrete, GFRP bar and steel bar were studied. Additionally, the effects of the longitudinal bar types, the load eccentricity and the concrete types (normal strength concrete and Geopolymer concrete) were investigated on the load-lateral deflection curves, first cracking loads, ultimate load, failure modes, crack patterns and concrete strain variation of specimens.

II. LITERATURE REVIEW

Kamal et al. [9] investigated the effects of different fibres (steel and polypropylene fibers) on the mechanical properties of self-compacting concrete. A total of (90) cubes 100×100×100 mm was tested to determine the compressive strength. The results showed that the optimum percentage of steel and polypropylene fibre was 0.75 and 1.0% of the cement content, respectively resulted in an increase in the compressive strength of concrete by about 37 to 13%, respectively. Minh et al. [10] studied the behavior of steel fibre reinforced concrete flat slabs in case of punching shear. Results showed that steel fibre improved the punching shear capacity of the tested slabs between 9 to 39.8% as a result to adding 30 to 60 kg/m3 of steel fibre where this increase was proportional to the fibre volume fraction. Also, the average crack width in the slabs was reduced by about 70.8%. An experimental study about the effect of fire on some mechanical properties of concrete was carried out by Umran [11]. The compressive strength of concrete was measured by cubes of 150 mm whereas the flexural strength of concrete was measured by prisms of 100×100×400 mm dimensions. The specimens were fired at three burning temperatures 400, 500, and 700 °C with duration of 0.5, 1.0, 1.5, and 2.0 hours. Results showed that the reduction in the compressive strength was between 15-30% at 400 °C, 22 41% at 500 °C and 38-57% at 700 °C. While, the reduction in the flexural strength was between 22-33% at 400 °C, 33-60% at 500 °C and 55-80% at 700 °C.

Venkatesh, [12] indicated different levels of decease in the compressive strength of the concrete subjected to fire. The compressive strength of the concrete decreased slightly up to 400 oC and decreased rapidly at about 600 oC. This decrease began to diminish continuously as the temperature increased and approximately disappeared at 1000oC. Rawaa et al. [13] investigated the effect of fire on the compressive strength of reactive powder concrete. Different burning temperatures 300, 400 and 500ºC with three steel fibre volume fraction 0, 1 and 1.5% were investigated in this study. Two cooling methods were adopted, sudden and gradual. Results showed that steel fibres ratio 1% presented the optimum response. Moreover, the sudden cooling method was improved to be the critical cooling method. Moss et al. [14] studied experimentally the behaviour of two way reinforced concrete slab affected by fire. Moss noticed that the concrete and steel reinforcement in the lower face of the slab were heated well prior those in the upper face of the slab. When the temperature reached to 300℃ in the steel reinforcement, the steel yield strength began to decrease causing a decrease in the bending moment and membrane strength. Hamed et al. [15] investigated experimentally the effect of fire on punching strength of flat slabs. Fourteen specimens were fired on their tension and then cooled gradually or suddenly by spraying water. Results showed that there was a reduction in the initial crack loads and ultimate punching loads by about 18.3 and 43%, respectively resulted from exposure of slabs to fire. Sudden cooling was found to reduce punching strength by 25% compared to specimens gradually cooled.

III. MATERIAL & METHODS

3.1. Materials Properties

3.1.1 Cement:

Portland Pozzolana Cement (PPC 53 Grade) was used as the binding material. It consists of clinker, gypsum, and 15–35% pozzolanic material, which enhances durability, reduces permeability, and improves resistance to chemical and marine attack. PPC contributes to the formation of dense and durable concrete.

Cement quality also directly influences the long-term durability of GFRP-reinforced beams, especially in aggressive environments where resistance to chemical attack, carbonation, and chloride penetration is essential. Thus, the choice of cement type, mix proportioning, and curing regime significantly affect the mechanical performance and service life of beams reinforced with GFRP bars, making cement not just a binder but a decisive factor in the success of such experimental investigations.

3.1.2 Fine Aggregate:

River sand was used as fine aggregate, conforming to standard grading requirements with a fineness modulus in the range of 2.6–3.2. Fine aggregates improve the workability and compactness of concrete and play a vital role in achieving a uniform mix.

Fine aggregate, usually natural river sand or manufactured sand (M-sand), is used to fill the voids between coarse particles and ensure a dense, workable mix. Its grading, cleanliness, and particle size distribution directly influence the workability, strength, and bond characteristics of the concrete. Well-graded fine aggregate helps achieve proper compaction and reduces segregation, which is essential for maintaining uniform stress transfer between the cement paste and the GFRP bars.

3.1.3 Coarse Aggregate:

Coarse aggregates of size 20–40 mm was used to provide strength and stability to the concrete matrix. These aggregates form a rigid framework, enhancing load-bearing capacity and overall durability of the concrete.

Glass Fiber Reinforced Polymer (GFRP) bars, coarse aggregate is a crucial component of the concrete mix, providing bulk, strength, and stability to the matrix. Typically, crushed stone or gravel of suitable size (often 10–20 mm) is used as coarse aggregate, and its angular shape helps improve interlocking within the cement paste, thereby enhancing the compressive strength of the beam.

3.1.4 Steel Reinforcement

In this study, two types of steel reinforcing rebars were utilized: first, deformed steel rebars of nominal diameter Ø4 mm as transverse ties and second, deformed steel rebar of nominal diameter Ø12 mm as longitudinal and corbel reinforcement (Ukrainian production). Based on ASTM A496-02 [39] requirements, tensile testing was performed on three samples, provided from each kind of steel reinforcing rebars. The machine was able to draw the load displacement curve using a computer program up to the failure of the sample.

Conventional reinforced concrete relies on steel bars because of their high tensile strength, ductility, and excellent bond with cementitious matrices. Steel reinforcement provides the tensile resistance that complements concrete's compressive strength, ensuring structural stability under bending and shear loads. In contrast, GFRP bars are introduced to overcome steel's susceptibility to corrosion, especially in aggressive environments. When steel is used in such experiments, its mechanical properties such as yield strength, modulus of elasticity, and stress–strain behaviour are carefully studied alongside the concrete matrix to establish baseline performance.

3.1.5 GFRP Reinforcement

Glass Fiber Reinforced Polymer (GFRP) bars were prepared using continuous glass fibres embedded in an unsaturated polyester resin matrix with 1% hardener. The fibres, aligned longitudinally, provide strength and stiffness, while the resin ensures proper bonding and stress transfer. The resulting bars of 8 mm diameter consist of approximately 80% fibre and 20% resin. GFRP bars are lightweight, non-corrosive, and exhibit high tensile strength, making them a promising alternative to steel reinforcement. Their anisotropic nature and fibre composition significantly influence their mechanical properties, including stiffness, strength, and failure characteristics.

Fig. 2. GFRP Reinforcement Bar

IV. METHODOLOGY

- ❖The study commenced with a review of existing literature to understand the behaviour of steel and GFRP reinforced concrete beams. Materials were selected and tested for their fundamental properties before specimen preparation.
- ❖Concrete beam specimens of uniform dimensions (150 mm × 150 mm × 700 mm) were cast with both steel and GFRP reinforcement while maintaining consistent reinforcement ratios. Proper mixing, compaction, and curing were carried out to ensure quality and uniformity.
- ❖After curing, the specimens were tested under controlled loading conditions using a Universal

Testing Machine (UTM). Parameters such as load, deflection, crack pattern, and ultimate strength were recorded.

- ❖The experimental data were analyzed through a comparative study to evaluate the structural performance of steel and GFRP reinforced beams in terms of strength, stiffness, and failure behaviour.

4.1 Compressive strength:

Compressive strength or compression strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to Tensile strength, which withstands loads tending to elongate. Compressive strength is a widely accepted measure to assess the performance of a given concrete mixture. Cubical moulds of size 150mm × 150mm x 150mm are commonly used. This concrete is poured into the mould and appropriately tempered to prevent voids. After 24 hours, moulds are removed, and test specimens are put in water for curing. The top surface of these specimens should be made even and smooth. This is achieved by placing cement paste and spreading it smoothly over the entire specimen surface. These specimens are tested using a compression testing machine at 7, 14, and 28 days of curing. Load should be applied gradually at the rate of 140 kg/cm2 per minute till the specimens fail in the compression testing machine or universal testing machine

4.2 Flexural strength:

Flexural strength is the ability of a beam or slab to resist failure in bending. The flexural strength is expressed as "Modulus of Rupture" in MPa. Tensile stress is likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature variation etc. beam test are found to be dependable to measure flexural strength property of concrete. The specimen of size 150mm × 150mm × 700mm. The test should be conducted on the specimen immediately after taken out of the curing condition to prevent surface drying which decline flexural strength. Prepare the test specimen by filling the concrete into the mould in 3 layers of approximately equal thickness. Tamp each layer 35 times using the tamping rod. Clean the bearing surfaces of the supporting and loading rollers and remove any loose sand or other material from the surface of the specimen where they are to contact the rollers. The load shall be applied at a rate of loading of 400 kg/min for the 150mm specimens.

4.3 DIAMETER OF REINFORCEMENT BAR

- A reinforcement bar of 8 mm and 10 mm diameter was selected for the experimental investigation.
- The 8 mm diameter rebar is commonly used in practical reinforced concrete construction, particularly in beams, slabs, etc.
- It allows direct comparison between steel and GFRP reinforcement under identical loading conditions.
- Smaller diameters ensure better bond characteristics and uniform stress distribution within the concrete section.
- Handling, placement, and testing of specimens become easier and more controlled.
- Both steel and GFRP rebars were maintained at the same diameter and length, ensuring consistency throughout the experimental work.

4.4 LABORATORY TESTING ON MATERIALS:

A) Tests on Materials:

1) Steel Reinforcement:

Steel bars were tested to determine their mechanical properties such as ultimate tensile strength, and elongation. Tensile testing was performed using a Universal Testing Machine (UTM) as per standard procedures. These properties are essential for understanding the load-carrying capacity and ductility of reinforced concrete.

2) GFRP Bars (Glass Fiber Reinforced Polymer):

GFRP bars were tested primarily for tensile strength. Unlike steel, GFRP exhibits linear elastic behaviour until failure without yielding. The test helps in assessing its suitability as a corrosion-resistant alternative to steel reinforcement.

3) Cement: Tests on cement included:

Consistency test (to determine water requirement), Initial and final setting time, Compressive strength test. These tests ensure the quality, strength development, and proper hydration characteristics of cement.

4) Sand (Fine Aggregate):

Sand was tested for: Specific gravity, Water absorption. These properties influence workability, strength, and durability of concrete.

5) Coarse Aggregates:
Tests conducted include Sieve analysis, Specific gravity and water absorption These tests evaluate the strength, toughness, and suitability of aggregates in concrete

B) Tests on Hardened Concrete:
1) Compressive Strength Test:
Compressive strength is the most important property of concrete. Cube specimens were tested in a compression testing machine at specified curing periods (e.g., 14 and 28 days). This test determines the load-bearing capacity of concrete.

2) Flexural Strength Test:
Flexural strength (modulus of rupture) was determined using beam specimens under two-point loading condition. This test evaluates the tensile strength of concrete in bending and is especially important for structural elements like beams.

V. RESULTS AND DISCUSSION

The tensile strength of GFRP bars was found to be higher than that of steel bars. Flexural strength results indicated that GFRP beams exhibited approximately 15–20% higher strength than steel beams. Steel-reinforced beams showed ductile failure with gradual crack formation, whereas GFRP beams exhibited sudden brittle failure. The brittle nature of GFRP requires careful design considerations for structural applications.

COMPARISON OF TENSILE STRENGTH OF GFRP BAR AND STEEL BAR (DIAMETER OF BAR 8MM) (laboratory v/s company)

Specimen	JSW Steel	Lab Steel	%Change in strength of bar
	719.69 N/mm^2	813.68 N/mm^2	11.56 %
	697.24 N/mm^2	851.48 N/mm^2	18.12 %
	717.66N/mm^2	765.93N/mm^2	6.31 %

Specimen	Lab GFRP	Vagnar GFRP	% Change in strength of bar
	680.39 N/mm^2	1150 N/mm^2	40.84 %
	730.12 N/mm^2	1110 N/mm^2	34.2 %
	704.66 N/mm^2	1130 N/mm^2	37.65 %

COMPARISON OF TENSILE STRENGTH OF GFRP BAR STEEL (DIAMETER BAR 10MM) (laboratory v/s company)

Specimen	Steel Company	Steel	%Change in Strength of bar
	630.3 N/mm^2	700.63N/mm^2	10.04 %
	651.9N/mm^2	640.92N/mm^2	1.69 %
	646.8N/mm^2	680.73N/mm^2	4.99 %

Specimen	GFRP Company	GFRP	%Change in Strength of bar
	1150 N/mm^2	497.61N/mm^2	56.8 %
	1149 N/mm^2	541.40N/mm^2	52.81 %
	1152N/mm^2	571.25N/mm^2	50.42 %

VI. CONCLUSION

The behaviour of GFRP-reinforced structural members in flexure and discusses load–defection characteristics, bond strength, and crack patterns for such members. This aims to critically review the application of GFRP as reinforcing bars in concrete structures, especially in beams. The findings of the literature study are summarized as follows.
Generally, FRP-reinforced concrete elements are designed based on increased values of safety factors. The design guidelines given by ACI and CSA code will be applied to designing GFRP- reinforced concrete structures. However, no specific design

codes, especially in the Indian context, are available for such members.

The lower value of the elasticity modulus and the higher rupture strain in GFRP are the main factors responsible for the higher ultimate strength, lower stiffness, and higher defection of GFRP-strengthened beams than the steel-reinforced beams. GFRP-reinforced members in flexure outperformed steel-reinforced beams.

REFERENCES

[1] S. F. Husain, M. Shariq, and A. Masood, "GFRP bars for RC structures – A review," in *Proc. International Conference on Advances in Construction Materials and Structures (ACMS 2018)*, IIT Roorkee, India, Mar. 7–8, 2018, pp. 1–10.

[2] K. Khorramian and P. Sadeghian, "Material characterization of GFRP bars in compression using a new test method," *Journal of Testing and Evaluation*, vol. 49, no. 2, 2021.

[3] T. A. Kinjawadekar, S. Patil, and G. Nayak, "A critical review on glass fiber-reinforced polymer bars as reinforcement in flexural members," *Journal of the Institution of Engineers (India) Series A*, vol. 104, no. 2, pp. 501–516, 2023.

[4] M. N. Sheikh and Z. Kharal, "Replacement of steel with GFRP for sustainable reinforced concrete," *Construction and Building Materials*, vol. 210, pp. 353–365, 2019.

[5] R. Murugan and G. Kumaran, "Experiment on RC beams reinforced with glass fibre reinforced polymer reinforcements," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 6S4, pp. 35–41, 2019.

[6] M. N. Telavane *et al.*, "Effect of GFRP rebar on the flexural strength of high-performance concrete beams," *JETIR*, vol. 11, no. 7, pp. 123–128, 2024.

[7] M. H. Mohammed, "A review of bond behaviour of GFRP bars with concrete," *Journal of Engineering and Sustainable Development*, vol. 23, no. 3, pp. 142–157, 2019.

[8] V. Deshmukh and N. P. Phadatare, "Experimental study of replacement of steel bars with FRP bars," *IRJET*, vol. 7, no. 8, pp. 4190–4196, 2020.

[9] J. Rovira *et al.*, "Development and applications of glass fibre bars as reinforcement in concrete structures," in *ICCM-18*, Valencia, Spain, 2011.

[10] D. H. Tavares, J. S. Giongo, and P. Paultre, "Behaviour of RC beams reinforced with GFRP bars," *IBRACON Structures and Materials Journal*, vol. 1, no. 3, pp. 285–295, 2008.

[11] S. Alkjk, R. Jabra, and S. Alkhater, "Preparation and characterization of GFRP reinforced concrete," *SSP – Journal of Civil Engineering*, vol. 11, no. 1, pp. 15–22, 2016.

[12] J. D. Chaitanya Kumar *et al.*, "Experimental studies on glass fibre concrete," *American Journal of Engineering Research*, vol. 5, no. 5, pp. 100–104, 2016.

[13] M. Mukaram *et al.*, "Experimental investigation on glass fibre reinforced concrete," *IRJET*, vol. 8, no. 4, pp. 1390–1393, 2021.

[14] P. M. Bhagatkar *et al.*, "Experimental investigation on glass fibre reinforced concrete," *JETIR*, vol. 8, no. 6, 2021.

[15] M. İskender and B. Karasu, "Glass Fibre Reinforced Concrete (GFRC)," *ElCezerî Journal of Science and Engineering*, vol. 5, no. 1, pp. 136–162, 2018.

[16] B. Ali *et al.*, "Influence of glass fibres on mechanical properties of concrete," *Civil Engineering Journal*, vol. 5, no. 5, pp. 1007–1019, 2019.

[17] A. A. Pol and S. M. Rangari, "Structural behaviour of RC multistorey building with GFRP reinforcement," *TOJQI*, vol. 12, no. 6, pp. 414–426, 2021.

[18] Naganna *et al.*, "Experimental investigation on steel and GFRP RC beams," *IJERT*, vol. 13, no. 7, pp. 1–8, 2024.