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Experimental Study on the Behavior of Reinforced Concrete Beams Reinforced with BFRP Bars

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Abstract: This research investigates the structural performance of reinforced concrete (RC) beams reinforced with Basalt Fiber Reinforced Polymer (BFRP) bars. The study aims to determine the tensile, flexural, and torsional performance of BFRP-reinforced beams as an alternative to traditional steel reinforcement. Experimental tests including tensile strength tests, flexural strength tests, and torsional strength tests were conducted on both BFRP and steel reinforced beams. Results demonstrate that while BFRP bars provide corrosion resistance and lower density, they exhibit lower stiffness and a linear elastic behavior until failure. The findings support the viability of BFRP bars in non-prestressed structural applications, particularly in corrosive environments.
Keywords: BFRP, reinforced concrete, flexural strength, tensile strength, torsional strength, corrosion resistance.

I. LITERATURE REVIEW

1) Alsayed et al. (2000)

This research explored modifications to existing ACI models for predicting the behaviour of concrete beams reinforced with Glass Fiber Reinforced Polymer (GFRP) bars. Two experimental test series were conducted: the first validated adjustments for flexural strength and deflection models, while the second focused on determining minimum reinforcement requirements. Findings showed that GFRP-reinforced beams could be accurately assessed using adapted ultimate strength theories. The deflection predictions of the original ACI model underestimated actual behaviour, whereas the revised models provided more accurate estimations, especially at service loads.

2) Wu et al.

Wu and colleagues provided a comprehensive overview of the application of Basalt Fiber Reinforced Polymer (BFRP) in construction. Their work emphasized the material's strength, durability, and compatibility with hybrid reinforcement strategies, including combinations with Carbon FRP and steel. The paper noted that while BFRP structures exhibit commendable mechanical properties, further research is needed to evaluate long-term performance and suitability across varied construction scenarios.

3) Urbanski et al.

This study experimentally assessed concrete beams using BFRP rebars to understand their performance relative to conventional steel-reinforced structures. The authors investigated critical parameters such as ductility, stress distribution, cracking, and deformation. One notable aspect was the consideration of bond slip between BFRP and concrete. Results indicated that although BFRP offers notable strength advantages, its brittle failure and interface behavior need careful attention in structural design.

4) Inman et al. (2016)

In their comparative analysis, Inman and co-authors assessed both the mechanical and environmental aspects of using BFRP rebar instead of traditional steel. Through material testing and life cycle analysis, the study found BFRP to be lighter, corrosion-resistant, and environmentally friendlier, with reduced embodied emissions. However, due to its lower elastic modulus, BFRP exhibited higher deflections at service loads compared to steel, which could affect design decisions.

5) Hadi and Yuan (2017)

Hadi and Yuan investigated the flexural behavior of composite concrete beams reinforced with both steel and GFRP bars. Their experimental results showed that the inclusion of steel provided greater ductility, whereas beams reinforced solely with GFRP experienced brittle failure and reduced stiffness.

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The study also explored the positioning of GFRP I-beams within the concrete, noting minor influence on performance. The overall conclusion was that a hybrid reinforcement strategy offers enhanced strength and ductility.

6) Hollaway and Teng (2008)

Hollaway and Teng reviewed the development and application of FRP composites in civil infrastructure. The paper detailed the properties, advantages, and common limitations of these materials, particularly in reinforcement and retrofitting of structures. The study emphasized that although FRP offers lightweight and corrosion resistance, factors such as bond behavior, long-term durability, and fire resistance must be addressed for broader implementation.

7) Bank (2006)

Bank presented a detailed examination of FRP composites in civil engineering, focusing on their mechanical properties and performance in various structural applications. The author discussed the benefits of BFRP and GFRP in reinforcement, highlighting their high strength-to-weight ratio and non-corrosive nature. However, the study also acknowledged issues related to cost, brittleness, and lack of standardized design codes.

8) Nanni and Dolan (1993)

This early investigation into FRP use in concrete structures analyzed the performance of GFRP and CFRP bars under different loading conditions. The results revealed that FRP bars provided effective reinforcement with adequate bond characteristics and strength. The authors called for the development of design guidelines and emphasized the need for further testing to validate FRP use in real-world structural applications.

II. INTRODUCTION

BFRP bars present an innovative alternative to steel reinforcement in RC structures, especially in corrosive environments. Their advantages include high tensile strength, corrosion resistance, and low weight. However, they show lower modulus of elasticity and lack ductility.

III. OBJECTIVES

1) To assess the flexural behavior of RC beams reinforced with BFRP.
2) To compare the tensile performance of BFRP bars and conventional steel rebar.
3) To evaluate the suitability of BFRP as a replacement for steel in RC beams.

IV. METHODOLOGY

1) M30 grade concrete mix designed as per IS 10262.
2) Material testing: cement, aggregates, BFRP and steel rebars.
3) Beam specimens cast with both BFRP and steel reinforcement.
4) Curing for 7 and 28 days followed by flexural, tensile, and torsional testing.

V. RESULTS AND DISCUSSION

A. Tensile Test

BFRP bars exhibited an average ultimate tensile strength of 780 MPa, which is significantly higher than the 410 MPa observed in conventional steel bars. The failure in BFRP occurred in a brittle manner, without yielding, whereas steel bars showed yielding followed by necking.

B. Tensile Test Observations

Parameter	BFRP Bar	Steel Bar
Ultimate Tensile Strength (MPa)	780	410
Modulus of Elasticity (GPa)	45	200
Failure Mode	Brittle Fracture	Yield + Necking
Ductility	Low	High

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C. Tensile Test Setup

Figure 1: Tensile Testing of BFRP Bar

Figure 2: Tensile Failure of Steel Bar

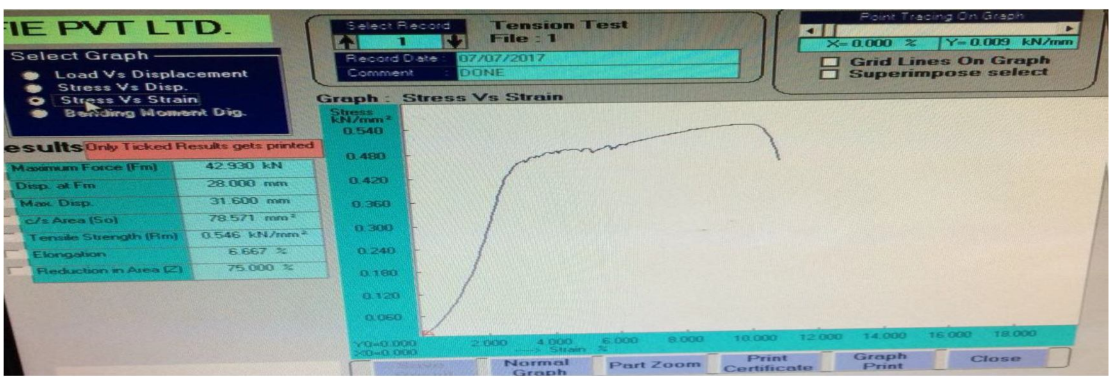

Figure 3: Stress-Strain Curve of Steel Rebar

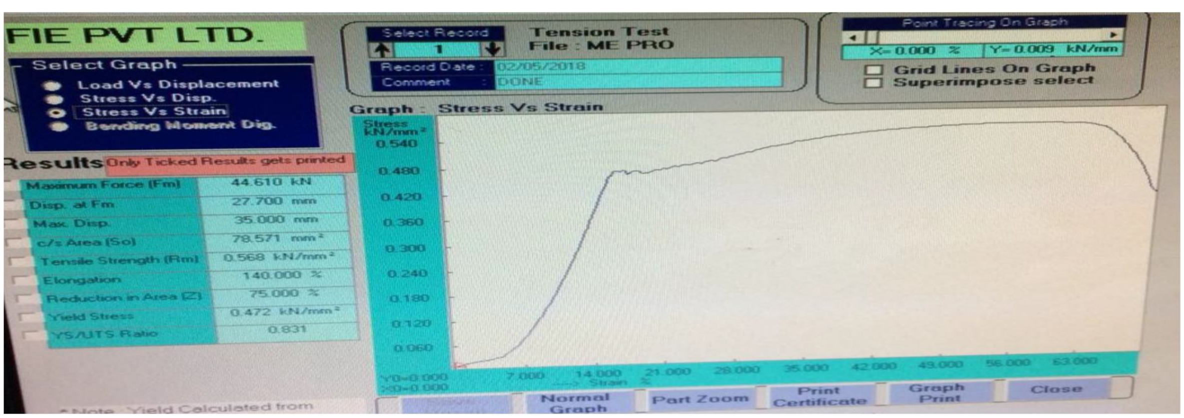

Figure 4: Stress-Strain Curve of BFRP Rebar

1) Flexural Test: BFRP reinforced beams showed reduced deflection compared to steel but with less ductility.
2) Torsional Test: Steel reinforced beams exhibited higher energy absorption under torsion.
3) Load-Deflection Behavior: BFRP beams maintained linear elastic behavior up to failure.

D. *Tabulated Results*

Test Type	Reinforcement Type	7-Day Strength (Ultimate load)	28-Day Strength (Ultimate load)	Mode of Failure
Flexural Strength	Steel Bars	74.5 kN	105.65 kN	Yielding + cracking
Flexural Strength	BFRP Bars	66.56 kN	94.48 kN	Brittle fracture
Torsional Strength	Steel Bars	35.45 kN	56.60 kN	Ductile torsion
Torsional Strength	BFRP Bars	39.84 kN	56.24 kN	Brittle diagonal crack
Tensile Test	Steel Bar	—	410 MPa	Yield + necking
Tensile Test	BFRP Bar	—	780 MPa	Sudden fracture

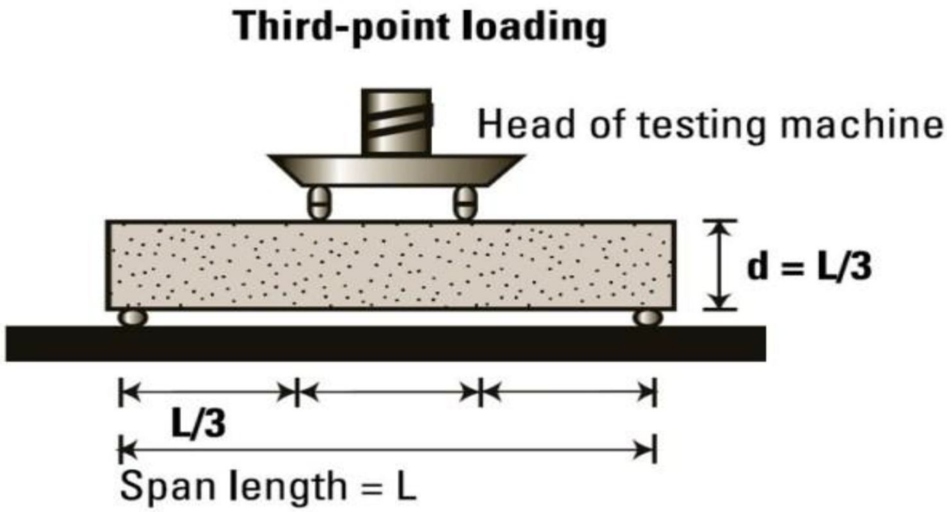

Figure 5: Flexural Test Setup

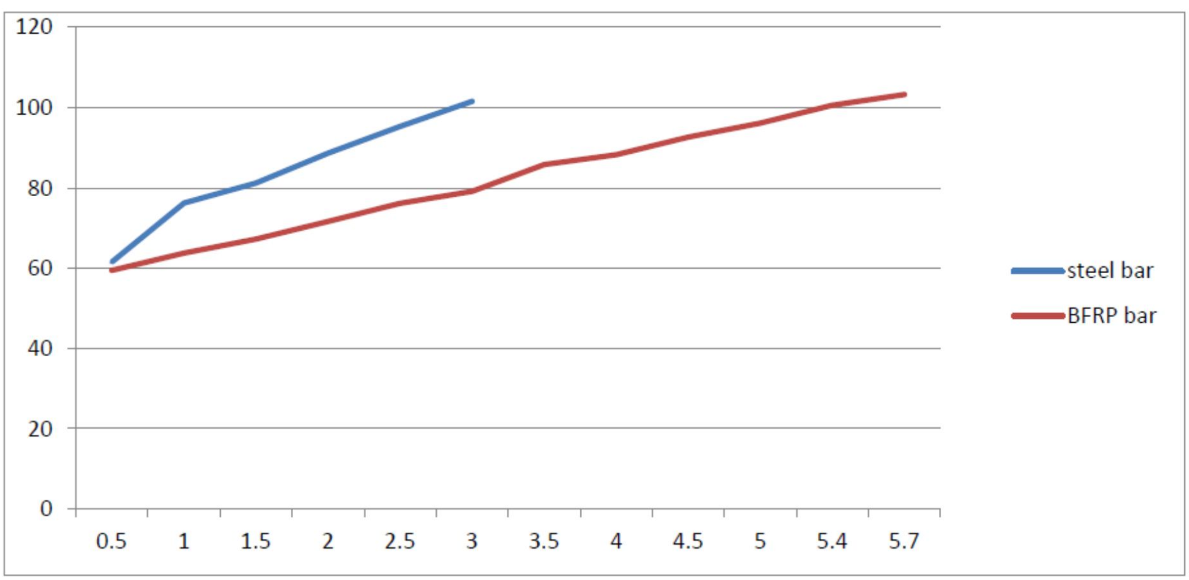

Figure 6: Load vs. Deflection Curve for BFRP and Steel RC Beams

VI. CONCLUSION

BFRP bars offer a corrosion-resistant alternative for reinforcing RC beams in aggressive environments. Despite their limitations in ductility and modulus of elasticity, they are suitable for structures requiring high durability and low maintenance. Further studies are suggested for long-term performance evaluation and hybrid reinforcement strategies.

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[1] Alsayed, S.H., et al. (ACI Model Modifications for GFRP Reinforcement)
[2] Wu, Z., et al. (BFRP in Infrastructure Applications)
[3] Urbanski, M., et al. (Comparative Study on BFRP and Steel Reinforced Concrete)
[4] Inman, M., et al. (Environmental and Mechanical Performance of BFRP)
[5] Hadi, M.N.S., et al. (Flexural Behavior of Composite Beams with GFRP)

APPENDICES

1) Mix design details
2) Detailed testing procedures and results
3) Figures and tables of stress-strain and load-deflection curves