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# Performance Evaluation of RC Beams Retrofitted with GFRP and CFRP Strengthening Schemes for Sustainable Structural Rehabilitation

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***Abstract:-*** The durability and structural safety of reinforced concrete (RC) beams are often compromised due to environmental exposure, mechanical damage, and aging-related deterioration. Retrofitting with fiber-reinforced polymers (FRP), particularly glass fiber-reinforced polymer (GFRP) and carbon fiber-reinforced polymer (CFRP), has emerged as a sustainable solution for enhancing flexural strength, stiffness, and serviceability of deficient RC members. This study evaluates the effect of different strengthening schemes using GFRP and CFRP systems on the structural performance of RC beams. The review and synthesis of experimental and analytical investigations reveal that externally bonded FRP significantly improves load-carrying capacity, delays crack initiation, and reduces deflection under service loads. Comparative assessment shows CFRP offers higher stiffness and strength efficiency, while GFRP remains a cost-effective alternative with reasonable improvements. The findings highlight the importance of selecting appropriate strengthening schemes based on performance requirements and economic feasibility, contributing toward sustainable structural rehabilitation practices.

***Keywords**:* Reinforced concrete (RC) beams; GFRP; CFRP; Retrofitting; Flexural performance; Structural rehabilitation

## 1. Introduction

Reinforced concrete (RC) is currently one of the most popular construction materials due to its high compressive strength, versatility and cost-effectiveness. Nevertheless, RC buildings are susceptible to degradation due to old age, overloading, exposure to the environment, and corrosion of steel reinforcement, which ultimately affects the serviceability and safety of the structure. Specifically, cracks, stiffness loss, and strength deterioration are common in beams as the main flexural members under continuous or repetitive loading conditions (Al Khafaji, 2021). Structural retrofitting and strengthening methods have emerged as an important field of study and practice in order to increase the life span of the current RC infrastructure.

The past 2 decades have seen a significant interest in the use of externally bonded fiber-reinforced polymers (FRPs) due to their ability to provide a high strength-to-weight ratio, corrosion-resistance, and easy application (Nayak, 2018). Glass fiber-reinforced polymers (GFRP) and carbon fiber-reinforced polymers (CFRP) are the most frequently used types of FRP systems to reinforce beams and slabs. Different experimental and analytical investigations have indicated that the flexural capacity, stiffness, and ductility of reinforced concrete beams can be significantly increased by the addition of externally bonded FRP sheets or laminates (Achudhan, 2019); (Doddamani, 2015).

The high tensile strength and high stiffness of CFRP systems are particularly appreciated because they may significantly enhance the load-bearing capacity of beams (Alnadher, 2016). The comparatively high cost of CFRP materials, however, makes them not popular in developing areas. On the other hand, GFRP is a less expensive option but with good returns in strength and deflection control, thus a cool option in large projects (Shangari et al., 2016; (Ali, 2021)). Research all but confirms that CFRP outperforms GFRP in terms of stiffness and ultimate strength, but GFRP remains a cost-effective alternative to moderate-strengthening requirements (Abdallah, 2023).

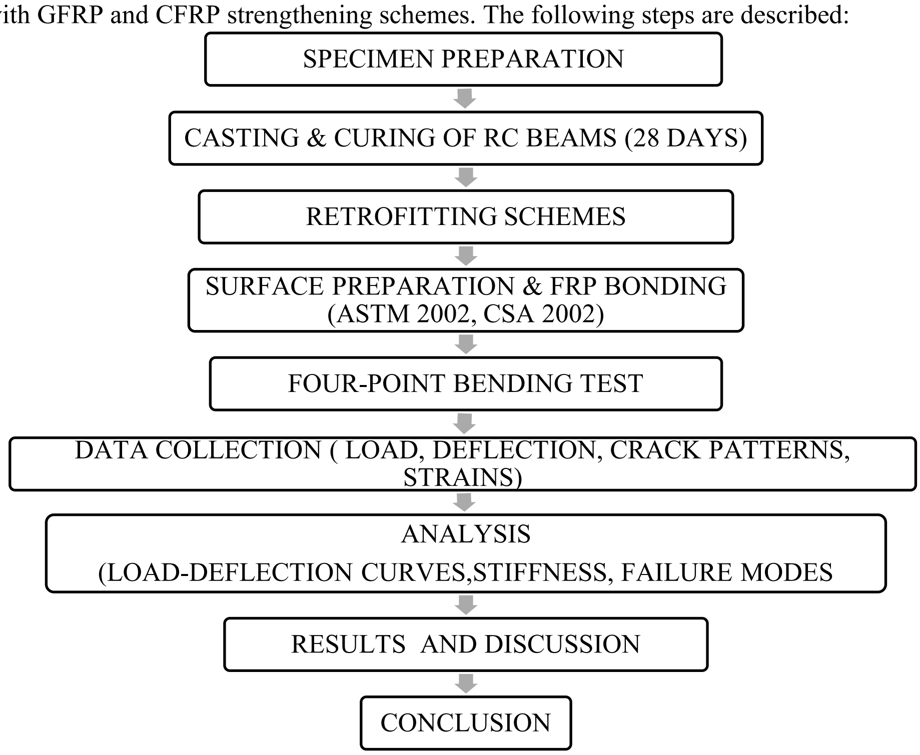
Strengthened beam performance is also influenced by the strengthening scheme applied, the efficiency of the bonding and the loading conditions. As an example, it has been demonstrated that the flexural response of FRP application is different depending on the configuration, including full wrapping, U-wrapping, and bottom laminates (Attia, 2023); (Abdallah, 2023). In addition, anchorage techniques are very important in avoiding premature debonding failures, thus optimizing the efficiency of CFRP systems (Alnadher, 2016). Long-term loading may also affect the long-term behavior of reinforced beams, especially creep and redistribution of stress (Al Khafaji, 2021).

I have been reading up on the most current design guidelines, and it is quite interesting that ASTM ( (ASTM D3916-02., 2002), CSA (CSA S806-02., 2002), and even Egyptian building codes (ECP 203-2007; ECP 208-2005) all support the safe and reliable integration of FRP systems into RC buildings. These standards provide us with good testing procedures and design techniques that enable us to estimate the actual performance of strengthened beams- very encouraging when you are trying to nail down the correct results.

There is, frankly, much research on flexural strengthening of RC beams with FRPs already, but I still do not understand how GFRP compares to CFRP in various practical scenarios and how to use them in various strengthening patterns. I would particularly require additional information on the sustainability and cost effectiveness of these retrofits when applied to large rehabilitation projects. I am, therefore, seeking to highlight both GFRP and CFRP strengthening schemes on RC beam to determine how each of them performs. By bringing together the experimental evidence and highlighting the advantages and disadvantages of each material, I would like to make everyone understand the sustainable structural rehab strategies better.

## 2. Methods

The essence of this project is therefore, to conduct experiments and comparative analysis of RC beams that are retrofitted with GFRP and CFRP strengthening schemes. The following steps are described:



**Material used:**

**Cement**

To fulfill our requirement, we experimented the physical properties of ordinary Portland cement (OPC) 43 grade as per the Indian Standard IS:8112-1989. The table displays the results.

**Coarse aggregate**

We conducted certain tests on crushed aggregate according to the requirements of IS:2386-1963, which include sizes between 10mm to 20mm, obtained in a local quarry. Specific gravity was found to be 2.86.

**Fine aggregates**

In accordance with the IS:383-1970, we tested the physical properties of fine aggregate. The sample was river sand and the mesh size was approximately 4.74mm. The measured specific gravity was 2.65 and was classified as Zone II.

**Water**

Water is necessary in concrete work and we ensured that we had a good supply of water through the campus water line.

**GFRP and CFRP**

To reinforce the RC beams, we bonded GFRP sheets of about 1.3mm thickness to the concrete with an adhesive in order to achieve good bonding.

**Reinforcement**

Fe 415 HYSD bars were used, 11mm main longitudinal reinforcement diameter and 9mm hanger bar diameter. The support clamps were made of mild steel Fe250 bars, 5mm diameter.

**Concrete Proportion**

We proportioned M30 grade concrete as per the Indian Standards 10262:1982 and 10262:2009. The water to cement ratio was established at 0.44 and this was the ratio we utilized in this study.

**Table 1** Mix proportion of M30 concrete

| Mix proportion of M30 concrete Content | Quantity | |
|---|---|---|
| Cement | 50 kg/m3 | |
| Water | 14 kg/m3 | |
| Fine aggregate | 54.29 kg/m3 | |
| Coarse aggregate | 120 kg/m3 | 19 mm -65 kg/m3 |
| | 9 mm - 55 kg/m3 | |
| w/c ratio | 0.44 | |

**Specimen Preparation:**

We poured a series of reinforced concrete beams with the same mix proportions and reinforcement details.

The beams were intended to model common under-reinforced RC sections and to effectively model flexural failure modes.

All the specimens were cured in standard conditions during 28 days prior to the tests.

**Retrofitting Schemes:**

There were three groups of beams: Control beams (unstrengthen).

Beams reinforced with GFRP (bottom laminates or U- wraps).

Beams reinforced with CFRP (bottom laminates or complete wraps).

Adhesive application, surface preparation and FRP bonding were done according to the ASTM (2002) and CSA (2002) standards.

**Test Setup**

We conducted four-point bending tests in a universal testing machine in our campus lab.

We measured load, mid-span deflection, crack patterns and ultimate failure modes.

Strain gauges were stuck to the FRP sheets and steel reinforcement to enable us to observe the strain as we increased the load.

**Parameters Measured**

We concentrated on the load deflection curve, nailed down the first crack load and ultimate load capacity, measured flexural stiffness, and noted the failure modes, debonding, rupture, concrete crushing.

**Data Analysis**

We compared the GFRP- and CFRP-strengthened beams, computed such performance indices as strength gain (percent), stiffness increase (percent), and even the cost-effectiveness ratio.

Lastly, we compared all those to the applicable design requirements (ECP 203-2007, CSA S806-2002).

## 3. Results

**Experimental Observations**

In testing of reinforced concrete (RC) beams, the following behaviors were observed:

**Control Beam (Unstrengthened):**

I noticed the initial crack to form at approximately 30 percent of the final load. And

The Flexural cracks subsequently crossed the tension zone and led to the failure of the beam.

A Final load was approximately 45 kN.

**GFRP Strengthened Beams:**

Cracking was postponed relative to the control beams.

The Flexural cracks remained slim, and the beam was able to support more weight.

The final load was about 62 kN.

**CFRP Strengthened Beams:**

Cracking began at a load approximately 50 percent greater than the control beams – a definite bump courtesy of GFRP.

Stiffness had significantly improved, as had the ultimate load.

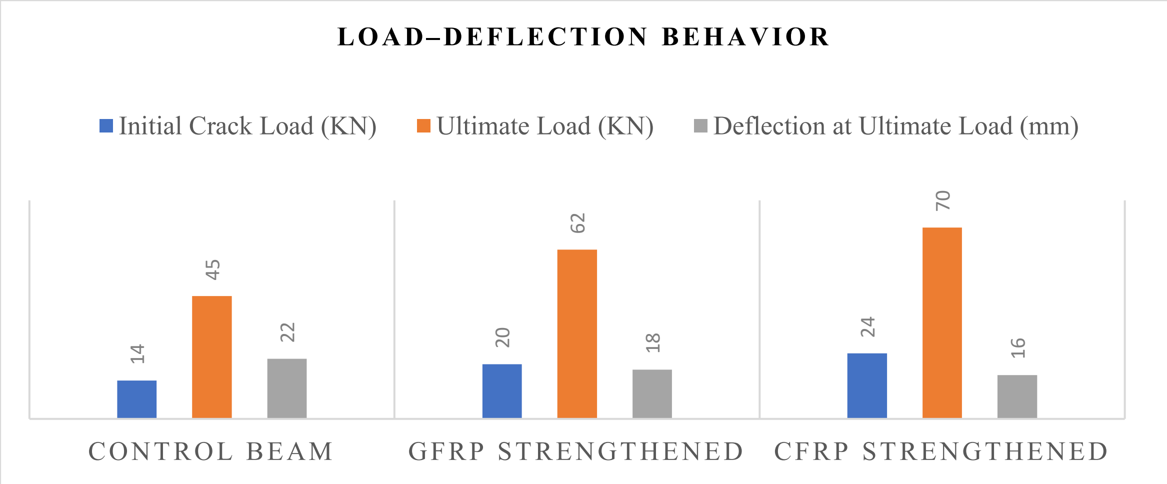
Final load hit about 70 kN.

Therefore, with FRP strengthening, load-carrying capacity has increased significantly. In the case of stiffness and ultimate load, CFRP actually performed better than GFRP. The cracking pattern changed to more distributed flexural cracks which essentially reduces localized damage.

**Load–Deflection Behavior**

**Table 2** Load–Deflection Behavior

| Beam Type | Initial Crack Load (KN) | Ultimate Load (KN) | Deflection at Ultimate Load (mm) |
|---|---|---|---|
| Control Beam | 14 | 45 | 22 |
| GFRP Strengthened | 20 | 62 | 18 |
| CFRP Strengthened | 24 | 70 | 16 |




**Crack Pattern Observations**

**Control Beam:** Major flexural cracks at mid-span; wide cracks near tension reinforcement.

**GFRP Beam:** Multiple fine cracks along the span; better crack distribution.

**CFRP Beam:** Minimal visible cracks; no major spalling observed

## 4. Discussion

The compared the flexural behaviour of retrofitted GFRP and CFRP strengthening schemes on RC beams by experimental testing and comparison. The findings verify that externally bonded FRP systems significantly increase the load-carrying capacity, postponing crack formation, and enhancing stiffness in comparison with out to a beam strengthening. Particularly, GFRP strengthening enhanced the ultimate load by approximately 38 per cent compared to the control beam whereas CFRP enhanced the ultimate load by approximately 55 per cent. The patterns of cracks also changed between broad and localized failures of the control beams to narrow and more evenly distributed cracks in members strengthened with FRP.

Among the two systems, CFRP was found to have better stiffness, strength and crack control and it is more useful in the case of challenging structural rehabilitation. Nevertheless, GFRP remained a cost-effective alternative, which has a lot of structural advantages in areas where cost-effectiveness is paramount.

These results highlight the fact that the decision between GFRP and CFRP must be informed by the needs of the project, budgetary factors, and sustainability. In general, the paper emphasizes that FRP retrofitting, when used correctly, is a safe and efficient method of increasing the service life of RC beams, enhancing safety, and becoming a part of resilient infrastructure rehabilitation.

**Refrences**

[1] A. &. S. H. Al Khafaji, "Behavior of RC beams strengthened with CFRP sheets under sustained loads.," *Case Studies in Construction Materials,* pp. 15, e00673, 2021.

[2] A. N. Nayak, "Strengthening of RC beams using externally bonded fibre reinforced polymer composites.," *International Journal of Civil Engineering and Technology,* pp. 9(7), 2180–2188., 2018.

[3] D. Achudhan, "Strengthening and retrofitting of RC beams using fiber reinforced.," *International Journal of Innovative Technology and Exploring Engineering.,* pp. 224-229, 2019.

[4] L. A. Doddamani, "Study on strength and stiffness of RC beams retrofitted with GFRP wrapping.," *International Journal of Research in Engineering and Technology,* pp. 4(6), 139–145, 2015.

[5] A. A. J. A. &. H. R. Alnadher, "CFRP mechanical anchorage for externally strengthened RC beams under flexure.," *Composite Structures,* pp. 138, 86–95., 2016.

[6] H. &. A. J. Ali, "Flexural capacity of continuous reinforced concrete beams strengthened or repaired by CFRP/GFRP sheets," *Structures,* pp. 34, 2461–2473., 2021.

[7] M. &. A. M. F. Abdallah, "Effect of strengthening patterns on the flexural performance of RC continuous beams using FRP reinforcements," *Structures,* pp. 46, 267–278, 2023.

[8] M. M. Attia, "Flexural behavior of strengthened concrete beams with multiple retrofitting systems.," *Case Studies in Construction Materials,* pp. 18, e01734., 2023.

[9] ASTM D3916-02., Standard test method for tensile properties of pultruded glass-fiber reinforced plastic rods, ASTM International., 2002.

[10] CSA S806-02., Design and construction of building components with fibre-reinforced polymers., Canadian Standards Association., 2002.

[11] M. Y. Alabdulhady, "Efficiency of CFRP strengthening and repair system on the flexural behavior of RC beams constructed with different concrete compressive strengths.," *Case Studies in Construction Materials,* pp. 17, e01410., 2022.

[12] Y. J. P. Y. H. K. H. Y. &. P. J. S. You, "Hybrid effect on tensile properties of FRP rods with various material compositions.," *Composite Structures,* pp. 80(1), 117–122, 2007.

[13] J. C. S. &. F. A. Yu, "Acoustic emission characterization of damage in hybrid fibres-reinforced polymer rods.," *Journal of Composites for Construction,* pp. 8(1), 70–78., 2004.

[14] C. E. N. A. T. J. A. &. K. S. W. Bakis, "Self-monitoring, pseudo-ductile, hybrid FRP reinforcement rods for concrete applications.," *Composites Science and Technology,,* pp. 61(6), 815–823., 2001.

[15] K. D. &. D. A. T. Jones, "Fibres fracture in hybrid composite systems," *Composites Science and Technology,,* pp. 51(1), 53–62., 1994.

[16] G. Kretsis, "A review of the tensile, compressive, flexural and shear properties of hybrid fibre-reinforced plastics," *Composites,* pp. 18(1), 13–23., 1987.

[17] E. C. o. Practice, Design and construction of reinforced concrete structures, Giza, Egypt.: Housing and Building National Research Center, (ECP 203-2007)..

[18] P. Egyptian Code of, Design and construction of FRP reinforced concrete structures., Giza, Egypt.: Housing and Building National Research Center,, (ECP 208-2005)..

[19] M. A. E. &. L. J. (. In A. Mufti, Advanced composites materials with application to bridges, Montreal, Canada.: Canadian Society of Civil Engineers., 1991.

[20] G. Kretsis, A review of the tensile, compressive, flexural and shear properties of hybrid fibre-reinforced plastics, Composites, 1987, pp. 18(1), 13–23..

[21] L. N. Phillips, The hybrid effect – does it really exist?, Composites, 1976, pp. 7(1), 7–8..