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Study of FRP on Preloaded Beam as A Method of Retrofitting - A Review

Prajwal L[1], Guruprasad M Balagi[2], Dr.Chethan Kumar.S[3]
[1]PG in Structural Engineering, Dr Ambedkar Institute of Technology, Bengaluru, Karnataka - 560056, India.
[2]PG in Structural Engineering, Dr Ambedkar Institute of Technology, Bengaluru, Karnataka - 560056, India.
[3]Assistant Professor, Department of Civil Engineering, Dr Ambedkar Institute of Technology, Bengaluru, Karnataka - 560056, India.
Emails: *prajwalprajju3039@gmail.com[1], prasadguru1112@gmail.com[2], chethans0504@gmail.com[3]*

Abstract
Over the past two decades, fiber-reinforced polymers have gained prominence in structural engineering due to their unique properties, offering an alternative to traditional materials like steel and concrete. FRPs consist of high-strength fibers embedded in a polymer matrix, resulting in superior strength-to-weight ratios, excellent corrosion resistance, and fatigue durability. These materials are widely used in aerospace, automotive, and infrastructure applications. Key types of FRPs include carbon fiber reinforced polymer, glass fiber reinforced polymer, aramid fiber reinforced polymer, and basalt fiber reinforced polymer, each offering specific advantages. CFRP is recognized for its high tensile strength, while GFRP is widely chosen for its affordability and adequate performance in less demanding structural applications. This review paper focuses on retrofitting predamaged reinforced concrete beams using carbon fiber-reinforced polymer and glass fiber-reinforced polymer sheets. It examines how preloading, fiber material, and fiber arrangement affect the structural performance of these beams, particularly in terms of flexural strength, ductility, stiffness, and failure mechanisms. Going through several papers the studies showed that CFRP and GFRP significantly enhance load-bearing capacity, energy absorption, and delay failure due to deboning. Key factors such as preload levels and fiber configuration were compared by go thronging several paper. The paper highlights real-world applications, where CFRP is commonly used in bridge rehabilitation and GFRP is favored for less demanding tasks, such as retrofitting low-rise building beams, both playing a critical role in extending the service life of structures while reducing costs.

Keywords: *Fiber Reinforced Polymer, CFRP, GFRP, Preload, Fiber Orientation, Retrofitting, Rehabilitation.*

1. Introduction

Many reinforced concrete (RC) structures are experiencing various forms of damage, such as excessive deflections, concrete spalling, poor concrete quality, freeze-thaw cycles, and steel corrosion caused by large cracks and exposure to harsh environments, as well as inadequate initial design. Additionally, the load-bearing capacity of civil structures may deteriorate due to aging and damage accumulated during their service life. As a result, repairing and strengthening both damaged and undamaged structural elements using externally bonded fiber-reinforced polymer (FRP) sheets or laminates has emerged as a significant challenge for civil engineers and researchers.[1] Steel has traditionally been used to reinforce concrete structures. However, its susceptibility to corrosion and challenges related to its heavy weight and large size have prompted engineers to explore alternatives. Fiber Reinforced Plastics (FRP) have emerged as a popular option due to their lightweight nature, high strength, and excellent resistance to fatigue and corrosion. Although FRP's application in reinforcing concrete structures began in the 1990s, the technology has since gained widespread use. Numerous studies have examined the use of Glass or Carbon FRP sheets for enhancing the flexural strength of concrete beams, investigating aspects such as load-deflection, load-strain, failure patterns, and ductility. These studies revealed a significant increase in ultimate load capacity (ranging from 40 to 200%) and strong energy absorption capabilities. To fully understand the flexural performance of FRP-

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reinforced concrete members, it is important to evaluate their strength at various stages, including pre-cracking, post-cracking, and post-yielding. One major issue observed is the debonding of FRP, which negatively impacts flexural strength. This has led to the need for specific FRP arrangements on beams to delay debonding and achieve the expected failure behavior. Currently, no codes or standards adequately address the impact of preload levels or the effective arrangement of FRP, as there is a lack of experimental data on how preload affects flexural performance.[2]

1.1 Carbon Fiber Reinforced Polymer

Carbon Fiber Reinforced Polymer is a composite material made of carbon fibers embedded in a polymer matrix, typically epoxy resin [3]. The carbon fibers provide the material with exceptional strength and stiffness, while the polymer matrix ensures that the fibers are held together and protected. CFRP is widely used for structural strengthening, especially in the construction and aerospace industries, due to its superior mechanical properties, including high tensile strength, lightweight, and resistance to corrosion.

1.2 Glass Fiber Reinforced Polymer

Glass Fiber Reinforced Polymer is a composite material made of glass fibers embedded in a polymer matrix, commonly epoxy, vinyl ester, or polyester resin. It is widely used in construction for reinforcing concrete structures due to its high tensile strength, corrosion resistance, and lightweight properties. Unlike traditional steel reinforcement, GFRP does not rust, making it particularly beneficial in environments prone to corrosion, such as coastal areas or structures exposed to chemicals.

2. Properties of FRP

The study conducted by Mostefa Hamrat et al. focused on analyzing the mechanical properties of Fiber Reinforced Polymers (FRPs), specifically Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP). The research highlighted the differences in tensile strength and elasticity between CFRP sheets, CFRP laminates, and GFRP sheets. These materials were bonded to reinforced concrete beams using epoxy resins, which displayed varying mechanical properties depending on the type of FRP applied. The properties are given below Table 1.

Table 1 Properties of FRP

Material	Elastic Modulus (GPa)	Poisson's Ratio	Tensile strength (MPa)	Layer Thickness (mm)	Fiber Orientation (°)
CFRP Sheet	234	0.3	4300	0.13	0
GFRP Sheet	74	0.25	2500	0.27	0

3. Pre Loading of Beams

Preloading process is crucial because it simulates damage under service conditions, making the experiment more reflective of real-world scenarios (Table 2).

Table 2 Preload % on beam

Author	Preload %	FRP used
Mostefa Hamrat a et al	60	CFRP
Zhang Ai-huiet al	30,60,80	CFRP
Xiong and Xu	0,50,70	CFRP
Benjeddou et al.	0,80,90,100	CFRP
Cao et al	50	CFRP
Kaushal Parikh, C.D.Modher	0,40,90	GFRP
Sagar and Shivaraj Mangalgi	30,45,60	CFRP and GFRP

4. Flexural Strengthening of Beams

Flexural strengthening of beams using fiber-reinforced polymer materials is a widely adopted technique to enhance the structural performance of reinforced concrete elements. FRP systems, such as carbon fiber reinforced polymer and glass fiber reinforced polymer, offer high strength-to-weight ratios, corrosion resistance, and ease of application. The flexural behavior of CFRP-strengthened RC beams shows significant improvement. When CFRP composites are applied to the tension face of beams

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with preloads below 80% of their original yielding strength, the ultimate flexural load-carrying capacities remain nearly identical, regardless of the preload or damage levels. This indicates that for preloads up to 80%, the impact on flexural performance is minimal, allowing designers to disregard these factors. However, beams with preloads exceeding 90% of their yielding strength experience a noticeable reduction in flexural capacity, highlighting a critical threshold where performance deteriorates. Further investigation is needed to understand the behavior of beams strengthened under such high preload conditions. [4] The beams strengthened with GFRP and preloaded to 70% of their ultimate load exhibited enhanced deflection behavior and a 14% increase in load-carrying capacity. Additionally, cracks in the control beams appeared at lower loads (15-20 kN), whereas the strengthened beams delayed crack initiation (20-25 kN) and displayed more uniform crack distribution (Table 3). These findings confirm the effectiveness of GFRP in improving load capacity and shifting failure modes from flexural to composite action. [5-7]

Table 3 Flexural capacity

Beam type	Preload Level (%)	Flexural Capacity (%)	Deflection Behavior
CFRP-Strengthened	< 80	Nearly identical to undamaged beams	Similar to undamaged beams
CFRP-Strengthened	< 90	Reduced	Needs further investigation
GFRP-Strengthened	70	+14%	Enhanced

5. Effect of CFRP and GFRP on Flexural Strengthening of Preloaded Beams

Preloading significantly influences the effectiveness of strengthening reinforced concrete beams, particularly when using CFRP and GFRP as reinforcement materials. Studies show that for beams preloaded up to 30%, both CFRP and GFRP enhance flexural capacity, though GFRP's effectiveness diminishes as preloading levels increase. This reduction in performance at higher loads is likely due to GFRP's lower stiffness and strength, which make it less capable of handling stress concentrations compared to CFRP [8]. On the other hand, CFRP remains highly effective even at higher preloads, providing superior tensile strength and stiffness. A key advantage of CFRP is its ability to improve ductility, allowing beams to undergo greater deflection and energy absorption before failure, which is particularly beneficial in structures subjected to dynamic or seismic forces. GFRP, while less effective at high preloads, still offers important benefits, such as delaying the onset of cracks and enhancing long-term durability by distributing stresses more evenly across the beam surface. This crack prevention capability is crucial in maintaining structural integrity and preventing premature failure, especially in corrosive environments. Additionally, both materials significantly improve the flexural performance of beams, though CFRP typically offers superior results due to its higher strength. Despite its reduced effectiveness at higher preloads, GFRP remains valuable in applications where moderate preloading and crack control are key concerns [9]. Overall, CFRP provides stronger performance in high-stress scenarios, while GFRP excels in enhancing durability and preventing crack formation in preloaded beams.

6. Debonding

Debonding is a critical issue in the strengthening of reinforced concrete beams using FRP (Fiber Reinforced Polymer) sheets, as it involves the separation of the FRP sheet from the concrete surface. This separation can be triggered by several factors, such as improper surface preparation, the presence of air gaps during the application of the sheets, or bond failure caused by stress concentrations [10]. When debonding occurs, it significantly reduces the effectiveness of the strengthening technique, as the load transfer between the concrete and the FRP is compromised. In particular, using multiple layers of FRP can increase interfacial stresses, leading to earlier debonding due to the accumulation of higher stresses at the interface. Similarly, thicker FRP sheets or laminates are prone

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to debonding more quickly because they experience greater stress concentrations, especially under load. In many cases, debonding is observed as the primary mode of failure, particularly in beams strengthened with CFRP sheets. In such instances, the concrete substrate beneath the CFRP becomes the weakest point, leading to the separation of the sheet from the concrete surface during failure [11]. This debonding failure mode not only limits the efficiency of the strengthening system but also highlights the importance of proper installation techniques and material selection [12]. The issue is particularly prevalent in the strengthening of beams with GFRP sheets, where debonding can significantly hinder the material's ability to enhance the structural performance of the beam. To address this issue, researchers have explored alternative arrangements to delay debonding. One such approach is the "N arrangement" for GFRP sheets, which has been shown to be more effective than the traditional "T arrangement" in reducing debonding and improving the overall flexural strength of the beams. By modifying the configuration of the GFRP sheets, the N arrangement redistributes stresses more efficiently, delaying the onset of debonding and allowing the beams to achieve higher load capacities. This highlights the potential for innovative design strategies to mitigate the challenges of debonding and improve the long-term effectiveness of FRP-based strengthening systems.

7. Fiber Orientation

Fiber orientation in Fiber Reinforced Polymers (FRPs) is a crucial factor influencing their performance in structural applications, particularly in the confinement of concrete elements. Alireza Bahadori and colleagues emphasize that optimal fiber alignment, such as in the hoop direction for concrete columns under compressive loads, maximizes the material's mechanical properties, including compressive strength, ductility, and energy absorption. Small deviations from the intended fiber orientation, even by 5°, can lead to significant reductions in these properties, with compressive strength diminishing by up to 4.5%. These deviations introduce stress concentrations that reduce the material's overall efficiency in strengthening applications. The study highlights that careful control of fiber alignment is essential for maximizing the structural benefits of FRP reinforcement. Misalignment increases the likelihood of premature failure, as fibers that are not aligned with the primary direction of stress do not provide optimal load transfer. For example, in the case of uniaxial compressive loading, fibers should ideally be oriented circumferential to prevent the dilation of the concrete core. Inadequate alignment, whether intentional or due to installation errors, can result in reduced structural integrity, early debonding, or failure, emphasizing the need for meticulous application.

Conclusion

- The study by Mostefa Hamrat et al. compared the mechanical properties of CFRP and GFRP sheets used in reinforced concrete beams. CFRP sheets exhibited higher stiffness and tensile strength, while GFRP sheets were more cost-effective. The choice of material depends on the specific application requirements.
- Preloading beams to various percentages of their load capacity effectively simulates real-world damage, providing critical insight into the flexural performance and strengthening potential of CFRP retrofitted beams under realistic service conditions.
- The flexural behavior of CFRP-strengthened RC beams shows significant improvement, especially for preloads below 80% of the original yielding strength. However, preloads exceeding 90% lead to reduced flexural capacity, indicating a critical threshold. GFRP-strengthened beams with 70% preloads demonstrate enhanced deflection behavior and increased load-carrying capacity.
- Both CFRP and GFRP improve flexural capacity in preloaded beams, but CFRP provides better ductility and performance at higher preload levels, while GFRP is less effective as preloading increases, although it still helps delay crack formation and enhances structural integrity.
- Debonding, a critical issue in FRP strengthening, reduces effectiveness by causing

separation from the concrete surface; it is influenced by factors such as surface preparation, sheet thickness, and interfacial stresses, but innovative arrangements like the "N arrangement" for GFRP can help delay debonding and improve beam performance.

References

[1]. Mostefa Hamrat, Farid Bouziadi, Bensaid Boulekbache, Tahar Hassaine Daouadji, Selma Chergui, Abderahim Labed, Sofiane Amziane, "Experimental and numerical investigation on the deflection behavior of pre-cracked and repaired reinforced concrete beams with fiber-reinforced polymer," Elsevier,https://doi.org/10.1016/j.conbuildm at, 2020.

[2]. Amira Adel Abdel Hamed, Khaled Farouk Omar El-kashif, Hamed Mohamed Salem, "Flexural strengthening of preloaded reinforced concrete continuous beams: An experimental investigation," Elsevier, https://doi.org/10.1016/j.aej.2018.11.011, 2018.

[3]. Kaushal Parikh, C.D.Modhera, "Application of GFRP on preloaded retrofitted beam for enhancement in flexural strength ," International Journal of Civil and Structural Engineering ,Volume 2, No 4, 2012.

[4]. T.P. Meikandaan and Dr. A. Ramachandra Murthy, "Flexural Behaviour of RC Beam Wrapped with GFRP Sheets," International Journal of Civil Engineering and Technology (IJCIET),Volume 8, Issue 2, 2017.

[5]. Sagar and Shivaraj Mangalgi, "Strengthening of preloaded rc beams containing circular opening at shear by using cfrp and gfrp sheets," International Journal of Structural and Civil Engineering Research,Vol. 4, No. 1, 2015.

[6]. Zhang Ai-Huir, Jin Wei-Liang And Li Gui-Bing, "Behavior of preloaded RC beams strengthened with CFRP laminates," Journal of Zhejiang University Science A,Project (No. 03HK03), 2005.

[7]. Guibing Li, Aihui Zhang and Yugang Guo, "Effect of Preload Level on Flexural Load-carrying Capacity of RC Beams Strengthened by Externally Bonded FRP Sheets," The Open Civil Engineering Journal,426-434, 2015.

[8]. PengGao , XianglinGu , Ayman S. Mosallam, "Flexural Behavior Of Preloaded reinforced concrete Beams Strengthened By Prestressed cfrp laminates," Composite Structures, http://dx.doi.org/10.1016/j.compstruct.2016.08.013, 2016.

[9]. Marco Arduini and Antonio Nanni, "Behavior Of Precracked RC Beams Strengthened With Carbon Frp Sheets," Journal Of Composites For Construction, 1090-0268/97/0002-0063-0070, 1997.

[10]. Nabil F. Grace and S. B. Sing, "Durability Evaluation of Carbon Fiber-Reinforced Polymer Strengthened Concrete Beams: Experimental Study and Design," ACI Structural Journal, Title no. 102-S05, 2005.

[11]. Tom Norris, Hamid Saadatmanesh and Mohammad R. Ehsani, "Shear And Flexural Strengthening Of Ric Beams With Carbon Fiber Sheets," Journal Of Structural Engineering, 0733-9445/97/0007-0903-0911, 1997.

[12]. Tan, C.L , Azmi, A.I. and Mohamad N, "Performance Evaluations of Carbon/Glass Hybrid Polymer Composites," Advanced Materials Research Vol. 980 (2014) pp 8-12, 2015.