

# Review On Flexural Strengthening of RC Beam Using BFRP Laminates

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**Abstract**—In cases of structural elements, it has been analysed which may have become ineffective as time goes on due to environmental exposure, steel corrosion and increased service loads, that is Reinforced concrete (RC) beams. As a result, member strengthening has taken an essential role in today's civil engineering practice. **Introduction** Among all the various techniques available, Fiber Reinforced Polymer (FRP) systems draw lots of attention in the recent years, and Basalt Fiber Reinforced Polymer (BFRP) an emerging innovative material with good corrosion resistance, low cost, high durability has shown itself as a potential alternative for many applications. Nevertheless, the overall effectiveness of externally bonded BFRP laminates is frequently constrained by the premature debonding at the interface between laminate and concrete surface. This issue is primarily caused by stress concentration near the laminate ends. To address this limitation, anchorage systems are introduced to enhance bonding performance and delay failure. This study presents a comprehensive review of RC beams strengthened using BFRP laminates under both anchored and unanchored conditions. The findings indicate that anchorage systems significantly improve bond behaviour, enhance load transfer, delay debonding, and increase overall strength and crack resistance. As a result, the use of anchorage systems leads to a more reliable and efficient strengthening solution.

**Index Terms**—BFRP laminates, Bond behavior, Flexural strength, RC beams.

## I. INTRODUCTION

Reinforced concrete (RC) members are widely used in buildings and bridges and are primarily designed to resist bending and shear forces. However, their performance tends to decline over time due to factors

such as corrosion, environmental effects, and increased service loads.

As a result, the demand for strengthening existing structures has grown. Conventional methods, such as the use of steel plates, come with disadvantages including corrosion and additional weight. In comparison, fiber-reinforced polymer (FRP) composites provide a more efficient solution because of their high strength and durability. Among these materials, basalt fiber-reinforced polymer (BFRP) is gaining attention due to its cost-effectiveness and strong resistance to chemical attack.

The performance of BFRP strengthening largely depends on how well it bonds with the concrete surface. One of the main challenges is premature debonding, which often occurs near the ends of the laminate due to stress concentrations.

To address this issue, anchorage systems are introduced to improve the bond between BFRP and concrete. These systems help transfer loads more effectively, delay failure, and enhance the overall behaviour of strengthened beams.

In recent years, composite materials have become a preferred choice for strengthening RC structures, as they provide additional strength without significantly increasing weight. BFRP, in particular, stands out for its affordability, high tensile strength, resistance to chemicals, and environmentally friendly characteristics. However, the effectiveness of BFRP laminates still depends greatly on the quality of bonding with the concrete surface. Poor bonding can lead to early separation, which remains a critical failure mode, typically caused by stress concentrations near the laminate ends.

## II. LITERATURE REVIEW

This section reviews earlier research on the strengthening of RC beams, highlighting the different methods and materials used by various researchers. Special attention is given to studies involving BFRP laminates, both with and without anchorage systems. The review helps identify key findings from past work and also points out areas where further research is needed.

Douglas Tomlinson<sup>1</sup> and Amir Fam (2015) [1] The flexural and shear behaviour of RC beams reinforced with basalt fiber-reinforced polymer (BFRP) rebars and stirrups was investigated through four-point bending tests on nine specimens. Flexural reinforcement ratios ranged from 0.28 to 1.60 times the balanced ratio under varying shear reinforcement conditions. Ultimate and service loads increased with reinforcement ratio regardless of stirrup type. Beams without stirrups failed in shear at about 55–58% of flexural capacity, while those with BFRP stirrups failed by rupture at 90–96%, and beams with steel stirrups failed in flexure. Standard design provisions predicted flexural capacity accurately but were inconsistent for shear-critical beams, whereas the updated CF theory (compression field theory) provided rel Rami A. Hawileh, Jamal A. Abdalla a, et. al, (2016) [2] An experimental investigation was conducted on the mechanical behavior of basalt (B), carbon (C), and hybrid B–C composite laminates subjected to elevated thermal conditions (25–250 °C). A total of 140 coupon specimens were investigated to evaluate tensile strength and elastic modulus degradation. Results showed that both properties decreased with rising temperature, with carbon laminates exhibiting the most severe degradation up to 90% strength loss at 250 °C. In contrast, basalt and basalt-dominant hybrids (particularly BBC and B laminates) retained superior mechanical performance under thermal exposure. Analytical models were designed to forecast the variation of tensile strength and modulus with temperature, providing useful parameters for design. The findings highlight the superior thermal resistance of basalt-based laminates and support their application, alone or in hybrid forms, for externally strengthening RC slabs and beams.

Chen W, Pham TM, Sichembe H, Chen L, Hao H (2017) [3] Carbon FRP (CFRP) and Glass FRP (GFRP) composites have been widely researched for

strengthening reinforced concrete (RC) and masonry structures, and many studies confirm that FRP systems can significantly improve load-carrying capacity. Basalt FRP (BFRP), on the other hand, is a relatively newer material that shows great potential due to its lower cost, good mechanical properties, and excellent corrosion resistance. However, research on the use of BFRP for externally strengthening RC beams is still quite limited. This study focuses on experimentally examining how effective BFRP is in improving the flexural performance of RC beams using three-point bending tests. The structural behavior and failure patterns of both unstrengthened and BFRP strengthened beams were carefully observed. Different wrapping techniques, U-jacket anchorage, and the role of epoxy adhesives were also analyzed to understand their influence on beam capacity. Additionally, formulas developed for predicting flexural behavior in CFRP- and GFRP-strengthened beams were assessed for their suitability in BFRP applications.

Jason Duic; et al., (2018) [4] A study involving seven full-scale RC beam specimens investigated the potential of basalt fiber-reinforced polymer (BFRP) composites as a sustainable material for flexural strengthening and rehabilitation. The key parameters considered were flexural reinforcement ratio, degree of corrosion, number of BFRP layers, and the use of cross-strapping. The results demonstrated that externally bonded BFRP composites can substantially improve beam performance, provided that premature debonding is prevented through an appropriate cross-strapping scheme. The use of BFRP was effective in restoring the service, yield, and ultimate load capacities of corroded beams to levels comparable with uncorroded specimens. Strengthened beams exhibited about a 25% increase in load-carrying capacity with just three layers of BFRP, along with a notable reduction in crack widths.

Ibrahim et al., (2019) [5] conducted a numerical investigation on shear-deficient reinforced concrete (RC) beams strengthened using externally bonded BFRP composites with various wrapping configurations. The results showed that all BFRP-strengthened beams exhibited improved strength and ductility compared to control beams. Fully wrapped configurations achieved a strength increase of 37.7%, while diagonally wrapped beams showed the highest ductility improvement of 298.5%. Additionally,

strengthened beams demonstrated increased deflection at given load levels, indicating enhanced stiffness. Overall, the study confirmed that BFRP wrapping, particularly full and diagonal configurations, is effective in improving the structural performance of shear-deficient RC beams.

Surwase et al., (2019) [6] investigated the flexural behaviour of reinforced concrete (RC) T-beams strengthened using BFRP sheets through experimental analysis. The results showed that all strengthened beams exhibited improved ultimate load-carrying capacity compared to the control beam. Initial flexural cracks appeared at higher loads in strengthened beams, indicating enhanced performance. The maximum increase in load capacity was 37.5% for Beam 4 compared to the control beam, and 6.5% and 4.4% higher than Beams 2 and 5, respectively. Additionally, Beam 6, retrofitted in the web region over a 1 m length, showed minimum deflection under similar loads, demonstrating improved stiffness.

Alkhraisha et al., (2020) [7] experimentally and numerically investigated the behaviour of BFRP-reinforced concrete beams under environmental exposure, including ultraviolet radiation, humidity, and rain. The results showed that exposure had no significant impact on cracking or ultimate moment capacity, with experimental cracking and ultimate moments exceeding predicted values by 0.5–10.5% and 12–30%, respectively. The average bond-dependent coefficient ( $k_b = 0.61$ ) was lower than ACI recommendations but closer to CSA values. Increasing reinforcement ratio improved stiffness and crack distribution but did not proportionally increase moment capacity. Finite element analysis confirmed that reduced tensile strength significantly affects flexural capacity in under-reinforced beams.

Wang et al., (2020) [8] investigated the flexural strengthening of reinforced concrete (RC) beams using basalt FRP (BFRP) grids bonded with polymer cement mortar (PCM) as an alternative to epoxy-bonded systems. The results showed effective bond performance from double shear tests, with interfacial fracture energy higher than FRP sheets reported in the literature. The ultimate load of strengthened beams increased by 47.60–63.65% compared to the reference beam. The stress–strain response was compatible with flexural theory. Additionally, PCM demonstrated better bonding performance than epoxy putty, particularly with increasing fiber content, indicating

its suitability as a durable and efficient strengthening material.

Diab et al., (2020) [9] This study investigated the enhancement of shear performance in reinforced concrete (RC) T-beams using near-surface mounted (NSM) BFRP bars combined with BFRP sheets and a non-mechanical anchorage system. Beams without anchorage showed shear strength increases of 8–46%, while those with anchorage achieved significantly higher improvements of 39.6–81.6%, along with improved strain utilization. The proposed anchorage method effectively reduced premature debonding and increased strengthening efficiency. The results emphasize the importance of anchorage in improving shear behavior and durability of BFRP-strengthened RC elements.

Sara Kadhim and Mustafa Ozakça (2021) [10] In this previous experimental study, eight beams which are simply supported were tested under four-point bending using an identical concrete mix. Strengthening configurations included a single BFRP layer on the soffit, partial side wrapping with vertical extensions of 25, 75, and 105 mm, and U-strip reinforcement with or without an additional bottom layer of BFRP sheet. The results indicated that side wrapping reduced ductility compared with the reference specimen, by up to 33% for partial wrapping and 45% for full wrapping. However, toughness improved in all strengthened beams, with increases ranging from 8% to 78%. It was further observed that extending the BFRP layer along the beam sides contributed to a significant enhancement in load-carrying capacity.

Nikil et al., (2021) [11] investigated the flexural behaviour of hybrid reinforced concrete beams incorporating BFRP bars and PVA fibers to address corrosion issues. The results showed that beams with PVA fibers exhibited more ductile behaviour compared to pure FRPRC and hybrid beams without fibers. The inclusion of PVA fibers enhanced both cracking load and load-carrying capacity. The ultimate moment capacity increased by 42.99% and 211.2% at 0.125% PVA dosage compared to hybrid beams without fibers and pure BFRP beams, respectively. Additionally, ductility improved by 65% at an optimum 0.25% PVA content, highlighting the effectiveness of fiber inclusion in improving structural performance.

Panahi et al., (2021) [12] A numerical investigation using ABAQUS 6.11 was carried out to study the flexural performance of reinforced concrete (RC) beams strengthened with externally bonded (EB), near-surface mounted (NSM), and hybrid EB–NSM FRP systems. The results showed considerable increases in flexural capacity and stiffness, along with decreased mid-span deflection at failure compared to the unstrengthened beam. Both ultimate bending moment and stiffness were found to increase with higher material strength and longer embedment lengths. For equal FRP cross-sectional area, the 1Φ12 configuration achieved greater capacity than 2Φ6, while ductility reduced with increasing bar diameter. The load–deflection response exhibited a tri-linear trend, and increasing the width of FRP sheets improved load capacity but diminished ductility.

Zhu et al., (2022) [13] investigated the flexural behaviour of BFRP-reinforced concrete beams incorporating steel fibers under cyclic loading. The results showed that adding 1.5% steel fibers significantly enhanced performance, increasing service load moment by 103.3% while reducing deflection and residual deflection by 48.18% and 30.36%, respectively. Deflection increased by 11% after initial loading cycles and 8% in subsequent cycles. Higher BFRP reinforcement ratio and concrete strength improved stiffness and serviceability. Additionally, a new analytical model for deflection prediction was developed, which showed better agreement with experimental results compared to existing models.

Kadhim et al., (2022) [14] An experimental study was conducted to evaluate the flexural performance of reinforced concrete (RC) beams strengthened with basalt fibre-reinforced polymer (BFRP) under four-point bending. The results indicated that the cracking load increased by at least 50%, the yield load by at least 28%, and the ultimate strength by 37–51% compared to the reference beam. Beams with vertical BFRP extensions of 25 mm, 75 mm, and 105 mm exhibited increases in ultimate strength of 37%, 44%, and 52%, respectively. The initial stiffness remained within 90–105% of the control beam. However, ductility decreased by approximately 33% for soffit-only strengthening and by 25–29% for beams with side extensions. The use of U-shaped strips resulted in an approximate 10% increase in strength, while combined strengthening configurations achieved up to

39% improvement. Additionally, toughness was enhanced in the range of 8–78%. Mamdouh et al., (2023) [15] This research focused on enhancing the flexural capacity of reinforced concrete (RC) beams by using basalt FRP (BFRP) grids bonded with polymer cement mortar (PCM), offering an alternative to epoxy-bonded techniques. Results from double shear tests indicated strong bond performance, with interfacial fracture energy surpassing values reported for FRP sheets in existing literature. The ultimate load capacity of the strengthened beams increased by 47.60–63.65% relative to the reference beam. The observed stress–strain response was consistent with predictions from flexural theory. In addition, PCM outperformed epoxy putty in terms of bonding efficiency, particularly as fiber content increased, suggesting its effectiveness as a durable strengthening solution.

Wdowiak Postulak et al., (2023) [16] The flexural performance of glulam beams reinforced with pre-stressed BFRP bars using the near-surface mounted (NSM) method was studied under quasi-static bending. The findings showed that BFRP reinforcement increased the ultimate load capacity by up to 35.88% and improved stiffness by about 23% compared to unreinforced beams. It also reduced tensile and compressive stresses in the timber, leading to better overall performance. The numerical analysis closely matched the experimental results, confirming the effectiveness of the NSM BFRP technique. Overall, pre-stressed BFRP bars proved to be a promising and efficient method for enhancing the behavior of laminated timber structures.

Yehia et al., (2023) [17] The behavior of reinforced concrete beams with openings was examined under hybrid strengthening using internal steel/BFRP bars and external BFRP sheets. Unstrengthened beams exhibited a 75% reduction in load capacity compared to solid beams. Internal strengthening using steel and BFRP bars increased capacity by 62% and 60%, respectively, whereas external BFRP sheets provided a 76% improvement. The combined strengthening method significantly enhanced performance, achieving increases of 137% in load capacity and 191% in energy absorption. Crack development was well controlled, and numerical results closely matched experimental data, validating the efficiency of hybrid BFRP strengthening strategies.

Manibalan et al., (2023) [18] investigated the response of BFRP-strengthened beams, retrofitted through external bonding, was analyzed by subjecting them to repeated loading cycles. Test results indicated that the retrofitted specimens carried higher ultimate loads, showing improvements of 24.32%, 21.05%, and 15% over the control beams. Additionally, reductions in mid-span deflection of 17.63%, 14%, and 6.13% were recorded, respectively. The strengthened beams also demonstrated improved ductility, achieving a maximum ductility factor of 3.583, along with enhanced stiffness during both the cracking phase and post-yield behavior. Numerical analyses carried out using ANSYS showed strong agreement with the experimental observations, thereby validating the results. Overall, the study demonstrates that BFRP laminates in RC components leads to better performance under cyclic loading and supports a longer structural lifespan.

Liu et al., (2023) [19] investigated the anchoring performance of prestressed basalt fibre-reinforced polymer (BFRP) laminates using wedge anchorages through 15 FRP laminate–anchorage assemblies. The results showed that the anchorage efficiency of CFRP laminate–anchorage assembly is higher than that of BFRP, and traditional CFRP anchorages easily damage BFRP laminates due to their lower elastic modulus and transverse shear strength. Anchorage with a retracted stressing end wedge achieved higher normal stress and anchoring capacity. The sandpaper mat improved friction and reduced stress concentration. Increased presetting load improved ultimate load and stiffness but intensified stress concentration at the anchorage end.

Asadi et al., (2023) [20] investigated reinforced concrete (RC) beams strengthened with basalt fibre-reinforced polymer (BFRP) fabrics under two-point loading. The results showed that the flexural capacity of the wrapped RC beams increased in percentage varied from 9.4 to 56%, with a maximum increase of 46.6%. The ductility increased by 84%, while a percentage decline in ductility varied from 5 to 89% compared to unstrengthened beams. Failure modes included FRP rupture, concrete crushing, debonding, and delamination. Over-reinforced beams showed sudden compressive failure, while improved crack distribution with reduced crack width and length was observed due to better stress redistribution.

Deven et al., (2023) [21] The study evaluated the effectiveness of externally bonded FRP composites, with particular emphasis on basalt fiber fabrics, for the strengthening and retrofitting of reinforced concrete (RC) beams. The results indicated that FRP strengthening techniques can restore or improve load-carrying capacity without increasing the cross-sectional dimensions of the member. A comparative assessment of various FRP materials revealed that basalt fiber provides performance comparable to carbon fiber, while being more economical and easier to manufacture. Although carbon fiber exhibits slightly higher tensile strength, basalt fiber offers superior resistance to chemical attack, fire, and environmental weathering. These findings suggest that basalt fiber is a cost-effective and durable alternative for structural strengthening and retrofitting applications.

Hawileh et al., (2023) [22] evaluated the impact of different quantities of FRP spike anchors related to bending performance of FRP-strengthened RC beams under four-point bending conditions. The results revealed a substantial improvement in strain utilization of the FRP laminates, increasing from 27% in beams without anchorage to 61% and 99% in beams provided with two and four anchors, respectively. The inclusion of anchors significantly postponed premature debonding and improved the overall flexural behavior, leading to increased load-bearing capacity and enhanced ductility. The study determined that the use of at least two spike anchors offers an effective approach to enhance bond characteristics and strengthening efficiency. Overall, the findings highlight the critical role of anchorage systems in controlling premature laminate separation and improving structural performance.

Saribiyik et al., (2023) [23] presented both experimental and finite element analyses to assess the bond behaviour of basalt fibre-reinforced polymer (BFRP), strips externally attached to notched reinforced concrete (RC) beams. Premature debonding was identified as a major constraint in FRP-strengthened systems, and the study considered several influencing aspects, including bond length, surface condition, anchorage layout, and thickness of the strips. The findings showed that proper surface preparation improved the load-carrying capacity by about 17%, while increasing the bond length beyond 100 mm had little effect on strength.

It was also observed that providing anchorage systems contributed to better structural response. Steel anchorage systems exhibited the highest effectiveness, delivering an enhancement of approximately 24–26% over other anchorage types and as much as 43% relative to unanchored specimens. These systems delayed debonding and enabled more uniform stress distribution. Unanchored beams mainly failed due to debonding, whereas anchored beams exhibited rupture of the BFRP strip, indicating better utilization of the material capacity. The numerical analysis closely matched the experimental observations and revealed that concrete layer thickness had a greater influence than adhesive length.

Changchun et al., (2024) [24] investigated the flexural behavior of reinforced concrete (RC) beams strengthened with BFRP sheets using MWCNT-modified epoxy under four-point bending. The results showed that yielding load, ultimate load, and ultimate deflection increased by 7.4%, 8.3%, and 18.2%, respectively, compared to pure epoxy. Post-yield stiffness, energy absorption, and ductility improved by 22.6%, 29.1%, and 14.3%. The modified epoxy effectively delayed debonding, constrained crack development, and enhanced interfacial bonding.

Kariyawasam Don et al. (2024) [25] investigated the mechanical and fracture characteristics of Basalt Fibre-Reinforced Polymer (BFRP) laminates produced using environmentally friendly bio-based resins. Two types of bio-resins, AMPRO™ BIO (40% bio-content) and Change Climate (77% bio-content), were evaluated and compared with a conventional epoxy system, WEST SYSTEM®. The experimental program included tests to determine tensile strength, shear behaviour, and fracture properties of the laminates.

The results indicated that tensile strength improved by 6% and 17% for AMPRO™ BIO and Change Climate resins, respectively, while only minor changes were observed in tensile modulus. In terms of shear performance, Change Climate showed a slight reduction in strength but an increase in modulus, whereas AMPRO™ BIO exhibited notable decreases in both parameters. For fracture behaviour, Mode I results showed reductions for both resins, more significant in AMPRO™ BIO, while Mode II results revealed improvement for AMPRO™ BIO and a decrease for Change Climate. Overall, the study suggests that bio-based resins, particularly Change

Climate, have strong potential as sustainable alternatives to traditional epoxy, although further investigation is needed regarding curing conditions and combined fracture modes.

Ashika et al., (2024) [26] investigated the retrofitting of reinforced concrete (RC) beams using basalt fibre-reinforced polymer (BFRP) sheets in a U-wrap configuration. The results showed that compressive strength increased by 11.41% and tensile strength by 14.39%. The load-carrying capacity of BFRP-wrapped beams increased by 7.36%, while deflection decreased by 18.2% compared to the control specimen. Additionally, crack width was reduced, and durability improved, with a 43.86% reduction in charge passed in RCPT tests. These findings demonstrate that BFRP sheets significantly enhance strength, stiffness, and durability, making them effective for retrofitting damaged RC beams.

Jaber et al., (2025) [27] The study explored the flexural performance of continuous reinforced concrete (RC) beams strengthened and rehabilitated using near-surface mounted (NSM) BFRP ropes. The findings indicated that flexural strength increased by 18% to 44%, while ductility improved by 9–11% in strengthened beams and 13–20% in rehabilitated beams. Optimized arrangements resulted in load capacity gains ranging from 31% to 65% and 21% to 58%. The experimental outcomes were in close agreement with finite element analysis, with discrepancies between 0.125% and 7.3%, and the ACI 440.2R-08 guidelines were observed to be conservative. Overall, NSM-BFRP ropes significantly improved load capacity, ductility, and overall structural behavior without any debonding problems.

Aswad et al., (2025) [28] investigated the flexural behaviour of steel and BFRP reinforced concrete (RC) beams exposed to elevated temperatures ranging from 200°C to 700°C. The results showed that load-carrying capacity decreased for all beams, with reductions of up to 35.5% for steel RC beams at 400°C and 66.1% for BFRP RC beams at 700°C compared to room temperature conditions. Steel RC beams exhibited 5.7% to 60.5% higher load capacity than BFRP beams. Failure modes differed, with steel beams showing flexural-shear failure and BFRP beams failing by concrete crushing, indicating better high-temperature performance of steel reinforcement.

Abdel et al., (2025) [29] investigated the effectiveness of BFRP sheets and ropes in strengthening and retrofitting two-span reinforced concrete (RC) beams. The results showed that externally strengthened beams achieved shear capacity increases of 17% to 37.4%, while retrofitted (preloaded) beams showed improvements of 5.7% to 19.4%. Strengthening without prior damage yielded better performance due to improved bonding conditions. All specimens failed in brittle shear near critical regions, with no debonding observed. The study also confirmed strong agreement between experimental, finite element, and ACI 440.2R-08 predictions, with deviations limited to 0.21%–5.6%, demonstrating the reliability of analytical models for BFRP-strengthened beams.

Kumari et al., (2026) [30] An analytical study was carried out to evaluate the use of BFRP composites for improving the shear capacity of reinforced concrete (RC) beams through different wrapping techniques. The findings showed a noticeable increase in shear strength, with gains of 29.28%, 46.4%, 52.88%, 53.59%, and 39.91% for various configurations compared to the control beams. Among the methods considered, side wrapping and U-strip wrapping proved to be the most effective. In addition to enhancing shear capacity, BFRP strengthening also improved flexural stiffness and reduced beam displacement. The analytical results were in close agreement with experimental observations, indicating the reliability of the model. Furthermore, machine learning approaches especially the random forest model achieved high prediction accuracy, emphasizing the influence of factors such as wrapping configuration, thickness, and material strength on shear performance.

#### A. Summary of Literature Review

Applying Basalt Fiber Reinforced Polymer to RC beams leads to better performance in both flexural and shear. Its use can increase load-carrying capacity by nearly 40-45% and improve stiffness by about 20-25%. Moreover, beams strengthened with BFRP exhibit better fatigue resistance, higher ductility, and increased energy absorption capability. In general, earlier studies indicate that integrating BFRP strengthening with appropriate anchorage methods and proper installation methods leads to significant improvements in strength, stiffness, ductility, and fatigue behaviour of structural members.

#### B. Research Gap

From the literature review, the following observations were made:

1. Most existing studies on BFRP laminate-strengthened RC beams primarily emphasize flexural strength enhancement, while the specific influence of anchorage systems on improving laminate efficiency has not been systematically addressed.
2. Premature debonding is widely identified as the dominant failure mode in BFRP-retrofitted beams; however, detailed experimental investigations on the effectiveness of anchorage systems in mitigating this issue are still limited.
3. In many studies, anchored and unanchored BFRP systems are evaluated separately, with very few direct comparative investigations conducted under identical geometric configurations, material properties, and loading conditions.

### III. CONCLUSION

The review indicates that Basalt Fiber Reinforced Polymer (BFRP) is a promising material for strengthening reinforced concrete (RC) beams, as it improves bending performance and load-carrying ability. However, the effectiveness of externally bonded BFRP laminates is often reduced due to early debonding, which prevents full use of their tensile strength. Studies reviewed in this work show that adding anchorage systems improves bonding, ensures better stress transfer, and increases the ultimate capacity of beams. These systems also help delay debonding, leading to higher ductility and more stable modes of failure, whereas beams without anchorage tend to fail prematurely due to early separation.

In addition, beams strengthened with BFRP demonstrate better stiffness, resistance to repeated loading, and energy absorption capacity, making them suitable for structures under cyclic or dynamic loads. The overall performance depends on several factors, including surface condition, laminate arrangement, type of anchorage, and quality of installation. Well-designed anchorage systems allow improved strain utilization and help distribute stresses more evenly along the bonded surface. Both experimental and analytical studies suggest that proper anchorage design can change the failure pattern from brittle debonding to a more ductile and desirable response.

Overall, the combined use of BFRP laminates with effective anchorage systems and proper application techniques is essential to achieve reliable performance, improved durability, and extended service life of RC beams.

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