Review On Flexural Performance of Retrofitted RC Beams with Hybrid Natural Fiber Reinforced Polymer

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Abstract—**Natural and hybrid fiber reinforced polymer (FRP) composites are emerging as viable alternatives to conventional synthetic FRPs for strengthening and retrofitting reinforced concrete (RC) structures. This paper presents a comprehensive review of experimental and analytical studies on the use of natural fibers such as sisal, jute, flax, and hemp, as well as hybrid systems combining natural and synthetic fibers. The results indicate significant enhancement in structural performance, including increased flexural and shear strength, improved load-carrying capacity, enhanced ductility, and effective crack control. Key influencing parameters include fibre surface treatment, fibre volume fraction, number of layers, and strengthening configurations such as U-wrap and full wrap. Hybrid composites demonstrate improved interfacial bonding and mechanical efficiency, achieving performance comparable to CFRP and GFRP systems. However, issues related to long-term durability, environmental degradation, and absence of standardized design guidelines limit practical implementation. Further research is required to optimize material properties and establish design frameworks for large-scale applications.**

Index Terms—**Natural fiber composites, Sisal fiber, Alkali treatment, Mechanical properties, Structural strengthening.**

I. INTRODUCTION

Reinforcement corrosion and structural deterioration in reinforced concrete (RC) structures are common and prompted many researchers to seek alternative materials and rehabilitation techniques. While many solutions have been investigated over the past decades, there is always a demand to search for use of new technologies and materials to upgrade the deficient structures. In this context, strengthening with Fiber Reinforced Polymers (FRP) composite materials in the form of external reinforcement is of great interest to the Civil engineering community. The conventional strengthening methods of reinforced concrete structures attempt to compensate the lost strength by adding more material around the existing sections. Thus, retrofitting and rehabilitation of structures can be concluded to be the best alternative.

The use of fibre reinforced polymer (FRP) laminates for strengthening and retrofitting reinforced concrete (RC) members has significantly increased in the last few decades. There have been many experimental and analytical investigations on the behaviour of RC members strengthened with FRP laminates. FRP laminates are commonly used for flexural strengthening, and their application has demonstrated a considerable enhancement in the performance of RC members. The most commonly used kinds of FRP laminates are carbon (CFRP) laminate, glass (GFRP) laminate, and aramid (AFRP) laminate. However, these laminates are typically unidirectional and exhibit high tensile strength in only one direction, which can result in bulging out of the concrete and wrinkles in the FRP laminates during failure. To prevent these failures, a relatively new technique of strengthening and retrofitting has been investigated using sprayed fibre reinforced polymer (Sprayed-FRP) composite.

However, natural fibres possess certain limitations such as high moisture absorption, variability in properties, and relatively lower strength compared to synthetic fibres. To overcome these drawbacks, various physical and chemical treatment methods have been explored. Among them, alkali treatment using sodium hydroxide (NaOH) has been found to be effective in improving fibre–matrix bonding by removing impurities such as lignin and hemicellulose, thereby enhancing the mechanical performance of the composites. Additionally, the fabrication method plays a crucial role, with techniques like hand lay-up being widely used due to their simplicity and cost-effectiveness.

II. LITERATURE REVIEW

This section discusses previous studies on the strengthening of RC beams. Different approaches and materials explored by various researchers are briefly considered. The collected information helps in recognizing major observations and also indicates where additional work is still required.

Md Ashraful Alamet al., (2015) [1] investigates the development of natural fibre-based composite plates for retrofitting reinforced concrete structures using the hand lay-up technique with epoxy resin. The fibres were treated with 6% NaOH solution to enhance interfacial bonding and mechanical performance. Experimental results showed that jute and kenaf fibre composites exhibited higher tensile strength (~137 MPa and ~136 MPa) compared to jute rope, while treated fibres performed slightly better than untreated ones in terms of strength and stiffness. The composites demonstrated linear elastic and brittle behavior, and their low density makes them a lightweight alternative to conventional materials. Additionally, alkali treatment significantly reduced moisture content and water absorption, improving durability. Overall, the study concludes that natural fibre composites, especially jute and kenaf-based plates, are promising, sustainable, and cost-effective materials for structural retrofitting applications.

G. Yuvaraj B et al., (2016) [2] This study investigates the mechanical behavior of sisal–glass fibre reinforced epoxy hybrid composites fabricated using the hand lay-up method with different fibre ratios. The composite structure consisted of glass fibre layers on the outer surfaces and sisal–glass mixtures in the core, with fibres chemically treated to improve bonding. Experimental tests, including double shear, inter-lamination, and hardness tests, showed that mechanical properties significantly depend on fibre composition. The results indicated that the 50:50 ratio of glass and sisal fibres exhibited the best performance, achieving the highest breaking load (1.43 kN), improved delamination resistance (8.52 kN), and higher hardness values compared to other ratios. As observed from the tables and graphs on page 5, increasing glass fibre content enhanced strength and reduced displacement. Overall, the study concludes that hybridization of natural sisal with glass fibre improves strength, durability, and structural performance, making such composites suitable for applications like automotive components, railway partitions, and marine structures.

Tara Sen et al., (2019) [3] This study investigates the use of natural sisal fibre reinforced polymer (FRP) as a sustainable alternative to conventional carbon and glass FRP for retrofitting reinforced concrete (RC) beams to enhance shear strength. Experimental results showed that both full wrapping and strip wrapping techniques significantly improved the load-carrying capacity, with full wrapping providing the highest strength increase. Notably, sisal FRP demonstrated ductile failure behavior with large deflections and warning before failure, unlike carbon FRP (sudden rupture) and glass FRP (debonding), which showed brittle failure. The study concludes that sisal FRP is an effective, eco-friendly, and sustainable material for structural retrofitting, offering comparable performance to synthetic FRPs while reducing environmental impact.

Shulanki Palet al., (2019) [4] This review paper discusses the use of natural fibres such as sisal, bamboo, coir, jute, and kenaf in construction and structural strengthening applications, highlighting their potential as sustainable alternatives to synthetic materials like glass and carbon fibres. The study explains that natural fibre-reinforced composites offer advantages such as low cost, light weight, corrosion resistance, renewability, and eco-friendliness, while also improving properties like tensile strength, ductility, crack resistance, and impact strength. Overall, it concludes that natural fibres are promising materials for retrofitting, rehabilitation, and general construction, supporting sustainable and cost-effective engineering solutions.

Athiappan. K et al., (2014) [5] The study evaluates the flexural behavior of reinforced concrete beams incorporating sisal fibre as a natural reinforcement material to improve tensile performance. Concrete of M40 grade was tested with varying fibre contents (0.1%–0.5%), and the optimum dosage was found to be 0.3%, which showed the best improvement in mechanical properties. As observed from the load–deflection graph, beams with 0.3% sisal fibre exhibited a higher ultimate load (170 kN vs 150 kN), increased initial crack load, greater stiffness, and improved energy absorption compared to conventional beams. The addition of sisal fibre also reduced crack formation and enhanced ductility, although workability decreased with higher fibre content. Overall, the study concludes that sisal fibre significantly improves flexural strength, stiffness, and durability of RC beams, making it a cost-effective and sustainable alternative for structural applications.

Yogesh Ravindra Suryawanshiet al., (2013) [6] the review paper examines the use of sisal fibre as a reinforcement material in cement-based composites, highlighting its potential to improve mechanical performance and sustainability in construction. The paper highlights durability challenges, particularly fibre degradation in alkaline cement environments, and suggests solutions such as low calcium hydroxide matrices to improve long-term performance. The sisal fibre composites exhibit good ductility, energy absorption, and fatigue resistance, making them suitable for applications like roofing elements, structural components, and strengthening systems. Overall, the study concludes that sisal fibre reinforced composites are a promising, low-cost, and eco-friendly alternative for construction, though further research is needed to improve durability and structural applications.

D.P. Archana et al., (2022) [7] This study investigates the mechanical and durability properties of sisal and jute fibre-reinforced biocomposites, focusing on the effect of 4% NaOH (alkali) treatment using the hand lay-up technique. Experimental results showed that treated fibre composites exhibited significantly improved tensile, flexural, and impact strength compared to untreated ones due to better fibre–matrix bonding. The results showed that tensile strength increased from 76.14 MPa to 97.88 MPa for sisal composites, while flexural and impact strengths also showed noticeable improvement. Additionally, water absorption decreased in treated composites, indicating enhanced durability. The graphs further confirm consistent improvement across all mechanical properties after treatment. Overall, the study concludes that alkali-treated natural fibre composites offer improved strength, durability, and suitability for structural strengthening and retrofitting applications, making them a viable sustainable alternative to synthetic composites.

Arslan Qayyum Khan et al., (2023) [8] This paper investigates the flexural strengthening of reinforced concrete (RC) beams using sisal fibre reinforced polymer (SFRP) composites as a sustainable alternative to synthetic FRPs. The results showed that SFRP significantly enhanced load-carrying capacity, ductility, and crack distribution, with improvements up to 87% for low-reinforced beams. Among the anchorage systems, the SEM system proved most effective in preventing debonding, while U-shaped configuration (configuration B) provided superior bonding and performance. Additionally, increasing the number of SFRP layers improved strength, particularly in beams with lower reinforcement ratios. Finite element analysis closely matched experimental results, validating the findings.

Kuruvilla Joseph et al., (1999) [9] This paper discusses the structure, composition, and mechanical properties of sisal fibers, highlighting their moderate tensile and flexural strength along with high impact resistance. The review covers various processing techniques and examines the performance of sisal fibers in thermoset, thermoplastic, and rubber matrices, emphasizing the role of fiber content, orientation, length, and surface treatments in improving interfacial bonding and overall composite properties. Findings indicate that chemical modifications significantly enhance strength, durability, and moisture resistance of the composites.

Diallo Souleymane M'Bara et al., (2019) [10] This study looks at the shear performance of failed reinforced concrete (RC) beams that were retrofitted with sisal mat polymer composites applied as strips in key areas. Experimental tests on four beams, including two control and two retrofitted, under three-point bending showed that the sisal mat composite greatly improved load-carrying capacity, ductility, and crack control. There were increases of about 21.1% and 4.87% in ultimate load for different beam configurations. The retrofitting reduced crack propagation and changed crack patterns by keeping them contained within strengthened areas. Furthermore, the failure mode changed from brittle shear failure in the control beams to more ductile flexural-shear behavior in the retrofitted beams, with no debonding or composite rupture. Overall, the study finds that locally available sisal mat composites are a good, low-cost, and eco-friendly option for strengthening and repairing damaged RC structures, particularly when applied strategically in critical areas.

Sanyawit Siriluk et al., (2018) [11] This study investigates the shear strengthening of reinforced concrete (RC) deep beams using hemp fiber reinforced polymer (HFRP) composites applied externally with epoxy resin. Experimental results from three-point loading tests showed that hemp fiber composites significantly improved load-carrying capacity and ductility, with increases in ultimate load ranging from 29% to 48% depending on fibre thickness and configuration. Failure modes included inclined shear cracks, fibre rupture, and occasional debonding, but overall behavior was more ductile than unstrengthened beams. The study concludes that hemp fibre composites are an effective, sustainable, and economical solution for strengthening RC deep beams in shear applications.

Akhila Padanattil et al. (2017) [12] investigated the study compared hybrid composites with conventional systems like CFRP, GFRP, and sisal FRP under axial compression. Results showed that HSGFRP significantly improved load-carrying capacity (up to ~148%) and ductility, with performance close to CFRP. The hybrid system also demonstrated high energy absorption and enhanced stress–strain behavior, indicating improved structural safety. Increasing the number of HSGFRP layers further enhanced strength and confinement efficiency. Durability studies revealed that FRP-confined specimens performed better under environmental conditions compared to unconfined concrete.

Bo Wang et al. (2019) [13] the experimental results showed that FRP strengthening significantly improved load-carrying capacity, stiffness, and ductility of wood beams, with improvements increasing as the number of FRP layers increased. Among single fibres, flax FRP exhibited comparable performance to glass FRP in terms of load capacity, while providing better deflection due to higher strain capacity. Hybrid FRP systems did not significantly increase load capacity but enhanced ductility and maximum deflection. The study also found that failure modes shifted from tensile failure to debonding at the FRP–wood interface with increasing strength.

Mohammed M. Attia et al. (2024) [14] studied the tensile and pull-out behavior of hybrid natural fiber reinforced polymer (FRP) bars made from flax, sisal, jute, glass fiber, and steel core combinations. The research showed that hybridization significantly improves mechanical properties, where flax fibers exhibited the highest tensile strength among natural fibers, and adding a steel core greatly increased the elastic modulus. The pull-out tests demonstrated that bond strength increases with concrete strength, with ultra-high-performance concrete (UHPC) showing the best performance. Overall, the study concluded that hybrid natural FRP bars are a cost-effective, eco-friendly, and corrosion-resistant alternative to traditional steel reinforcement, with improved strength, stiffness, and bonding behavior.

Taufiq Saidi et al. (2023) [15] investigated the bond strength between Natural Fiber Reinforced Polymer (NFRP) sheets and concrete by testing specimens made with different fiber types (jute, silk, pineapple, and abaca), adhesive types, and varying layer thicknesses. The study proposed an empirical model to predict bond strength and found that factors such as fiber type, adhesive type, fiber density, and NFRP thickness significantly influence performance. Results showed that abaca and jute fibers provided higher bond strength, while increasing the number of fabric layers greatly enhanced strength, stiffness, and toughness. Most specimens failed due to NFRP rupture at crack locations, and the developed model closely matched experimental results, demonstrating that NFRP is an effective and eco-friendly alternative for strengthening reinforced concrete structures.

Sikiru Oluwarotimi Ismail et al. (2022) [14] presents a comprehensive analysis of natural plant fibre-reinforced polymer (FRP) hybrid composites for structural applications, emphasizing their sustainability, lightweight nature, and cost-effectiveness compared to synthetic fibres like glass and carbon. The paper also examines various fibre types, matrix systems, manufacturing techniques (like hand lay-up, resin transfer moulding, and pultrusion), and factors affecting performance, including fibre orientation, surface treatment, and volume fraction. Additionally, it highlights applications in automotive, construction, and aerospace industries while addressing challenges such as moisture absorption, thermal instability, and limited predictive modelling.

Asadi et al., (2023) [17] 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.

Mariana Doina Banea et al., (2022) [18] The paper discusses factors affecting performance such as fiber type, surface treatment (physical and chemical), matrix selection, and fiber orientation, and summarizes findings from multiple studies showing enhanced tensile, flexural, and impact properties through hybridization. It also analyzes thermal behavior using techniques like TGA, DSC, and DMA, and explains moisture absorption mechanisms, emphasizing how treatments and synthetic fiber layers can reduce water uptake. Finally, the study identifies challenges like poor fiber–matrix bonding, variability in fiber quality, and durability issues, but concludes that with advancements in fiber treatment and hybrid design, these composites have strong potential for applications in automotive, aerospace, construction, and sustainable engineering materials.

Ntsie et al. (2025) [19] reviewed the role of natural fiber-reinforced composites (NFCs) in sustainable civil engineering. The authors highlighted that natural fibers such as jute, flax, hemp, coir, and bamboo are eco-friendly, lightweight, and cost-effective alternatives to synthetic materials. They classified fibers into industrial, agro-waste, and forest-based categories and analyzed their mechanical, thermal, and durability properties. The study emphasized that NFCs improve properties like tensile strength, crack resistance, and thermal insulation when used in concrete and composites. However, challenges such as moisture absorption, poor durability, and lack of standardization were identified. The authors concluded that with proper treatment techniques and hybridization, natural fiber composites have strong potential for structural and non-structural applications in sustainable infrastructure development.

A. Shalwan et al. (2023) [20] The authors highlighted that natural fibres are sustainable, lightweight, and cost-effective alternatives to synthetic materials, with good mechanical and insulating properties. Previous studies showed that adding natural fibres like date palm fibre reduces thermal conductivity but may decrease compressive strength beyond an optimum content. Similarly,the coconut and durian fibres improve insulation while maintaining acceptable strength for construction. The review also discussed fibre treatments (e.g., alkali, silane) that enhance bonding and mechanical performance. Overall, the authors concluded that sisal fibre-reinforced composites can improve thermal insulation and are suitable for sustainable building applications, although issues like moisture sensitivity and durability require further research.

Deven et al., (2023) [21] examined the effectiveness of externally bonded FRP composites, particularly basalt fiber fabrics, for strengthening and retrofitting reinforced concrete (RC) beams. The study highlighted that FRP techniques can restore or enhance load-carrying capacity without increasing section size. Comparative analysis of different FRP materials showed that basalt fiber offers performance comparable to carbon fiber while being more economical and easier to produce. Although carbon fiber has slightly higher tensile strength, basalt fiber demonstrates superior resistance to chemical attack, fire, and weathering. The findings suggest that basalt fiber is a cost-effective and durable alternative for strengthening and retrofitting applications in structural engineering.

Hossein Abdollahiparsa et al. (2023) [22] presented a comprehensive review on natural fiber-reinforced composites (NFRCs) for structural applications. The authors highlighted that NFRCs are gaining importance in civil engineering due to their sustainability, low cost, lightweight nature, and environmental benefits. They discussed various natural fibers such as sisal, jute, hemp, and flax, emphasizing that their mechanical properties depend on factors like fiber type, treatment, and environmental conditions. The study also reviewed bio-composites and their classifications, noting their increasing use in construction materials like panels, roofing, beams, and bridges.

Furthermore, the authors identified key challenges such as high moisture absorption, poor fiber-matrix bonding, variability in properties, and lack of standardization, which limit large-scale structural applications. They also reviewed different structural uses including beams, roofing systems, and pedestrian bridges, demonstrating that NFRCs can be used for low to moderate load-bearing applications. Finally, the study concluded that although NFRCs show strong potential for sustainable construction, further research is needed to improve durability, mechanical performance, and long-term reliability.

Ruaa Haitham Abdel-Rahim et al. (2025) [23] reviewed the role of natural fibers as reinforcements in polymer composites, focusing on their mechanical and environmental applications. The review also discusses factors affecting composite performance, including fiber orientation, fiber-matrix bonding, moisture absorption, and processing techniques. According to the discussion on fiber orientation significantly influences strength, where aligned fibers show higher tensile performance compared to randomly oriented fibers. Additionally, the paper outlines wide applications of natural fiber composites in industries such as construction, automotive, aerospace, biomedical, and packaging.The study concludes that despite these challenges, natural fiber-reinforced polymer composites have strong potential as sustainable alternatives to synthetic materials, especially with further research and improved treatment techniques.

Kittipoom Rodsin et al. (2023) [24] reviewed the use of Fiber-Reinforced Polymer (FRP) composites for strengthening reinforced concrete (RC) beams, highlighting their advantages such as high strength, light weight, and corrosion resistance. Previous studies showed that FRP significantly improves shear capacity, but a major limitation is premature debonding between FRP and concrete, leading to brittle failure. Researchers have emphasized the importance of anchorage systems, such as bolts and wraps, to enhance bonding and prevent failure, thereby improving ductility and load capacity. The literature also indicates that while Carbon FRP (CFRP) is highly effective, low-cost alternatives like Glass FRP (GFRP) and natural fibers (such as sisal) are gaining attention due to economic and environmental benefits. However, their application, especially in shear strengthening, is still limited and requires further investigation for practical structural use.

Odarkor Diody Nah et al., (2024) [25] Research indicates that sisal fibers provide good tensile strength, ductility, and crack control, making them suitable for strengthening applications. Additionally, studies on post-fire retrofitting show that natural fiber systems can enhance ductility and prevent brittle failure while reducing costs compared to synthetic fibers. However, as highlighted in the reviewed study, there is still limited research on the performance of sisal fiber mats specifically for restoring load-bearing capacity of fire-damaged reinforced concrete beams, indicating a need for further investigation in this area.

Jagdeesh Prasad Prajapati et al., (2023) [26] The study emphasizes that natural fibers can effectively enhance shear strength, load-carrying capacity, and stiffness while reducing deflection in RC beams. Retrofitting with natural fibers increased failure load significantly, especially with U-wrap configurations, which showed better performance compared to side wrapping. However, issues such as debonding and shear failure still exist in some cases. Overall, the paper concludes that natural fiber composites are sustainable, economical, and effective materials for strengthening and rehabilitating RC structures, though further research is needed to improve bonding and durability.

Tara Sen et al. (2013) [27] The study showed that thermal conditioning significantly improves the mechanical properties of sisal FRP, increasing both tensile and flexural strength due to enhanced fibre–matrix bonding and reduced moisture content. Experimental results demonstrated that RC beams strengthened with thermally treated sisal FRP exhibited higher first crack load, increased ultimate load capacity, and improved ductility compared to control beams. Fully wrapped beams showed the highest improvement, with shear strength increasing by about 77.8%, while strip wrapping provided moderate enhancement (around 33.4%). Additionally, strengthened beams showed no debonding and failed in a more ductile manner. Overall, the study concludes that thermally conditioned sisal FRP is an effective, sustainable, and economical material for enhancing the shear performance of RC structures.

Lysa Benaddache et al., (2025) [28] This study investigates the effectiveness of heat-treated jute fiber reinforced polymer (JFRP) as a sustainable alternative to synthetic FRP for strengthening pre-cracked high-performance concrete beams. The results show that externally bonded jute composites significantly enhance flexural performance, with load-carrying capacity increasing as the number of layers increases, and further improvement achieved through heat treatment due to better fiber–matrix bonding and reduced moisture content. Experimental findings (from three-point bending tests on 30 beams) indicate that heat-treated JFRP can achieve up to 120% improvement in peak load, while also improving stiffness and crack control compared to untreated fibers. Additionally, comparisons with glass fiber reinforced polymer (GFRP) reveal that optimized JFRP systems can provide comparable strength performance with lower environmental impact. Overall, the study concludes that heat-treated jute FRP is an effective, eco-friendly, and economical material for structural strengthening applications.

III. SUMMARY OF LITERATURE REVIEW

The natural fiber reinforced polymer (NFRP) composites such as sisal, jute, hemp, flax, and their hybrids are increasingly being explored as sustainable alternatives for strengthening and retrofitting reinforced concrete (RC) beams and structural elements. Across the literature, these materials demonstrate notable improvements in flexural and shear strength, load-carrying capacity, ductility, and crack control, primarily due to their crack-bridging ability and effective stress transfer within the matrix. Many researchers emphasize that performance depends strongly on parameters such as fiber treatment (alkali or heat treatment), number of layers, fiber orientation, and strengthening configuration (soffit, U-wrap, or full wrap), with treated and multi-layer systems showing significantly better bonding and reduced debonding failures. Hybrid composites combining natural and synthetic fibers further enhance mechanical properties and durability, often achieving performance close to conventional FRPs like CFRP and GFRP. While synthetic FRPs still provide higher stiffness and strength, the reviewed studies highlight that optimized natural fiber systems can deliver comparable structural performance with advantages of lower cost, reduced carbon footprint, and environmental sustainability.

IV. RESEARCH GAP

From the literature review, the following observations were made:

1. Limited studies on hybrid natural fiber systems
2. Existing studies mainly focus on single natural fibers such as jute, sisal, or coir, or on synthetic FRPs like CFRP and GFRP. Very limited research has been conducted on hybrid natural fiber systems, where two or more natural fibers are combined to improve strength, ductility, and crack control in RC beams.
3. Many experimental studies focus either on flexural strengthening or shear strengthening, but combined flexure–shear behavior of retrofitted RC beams using natural fibers is not sufficiently explored.
4. Bond characteristics between natural fiber composites and concrete, including debonding, interfacial behavior, and anchorage efficiency, are not studied in sufficient depth compared to synthetic FRPs.

V. CONCLUSION

The Natural fibre reinforced polymer (FRP) composites as well as hybrid FRP composites have been found to offer great promise as an environmentally friendly alternative to synthetic FRPs used in reinforcing RC beams. The materials have consistently proved capable of enhancing load bearing capacity, flexural strength, shear strength, ductility, and crack resistance. These improvements become possible if appropriate methods such as fibre pretreatment, layering, and optimal wrapping patterns are employed. The benefits associated with natural and hybrid FRPs can be exploited effectively by taking advantage of their strengths. This entails combining natural fibres with other synthetic fibres or resin matrices to enhance performance characteristics of natural FRPs without sacrificing their inherent advantages. Such characteristics include low cost, light weight, biodegradability, and environmentally friendly nature. Nevertheless, problems regarding durability, consistency, adhesion behavior, and lack of design guides make it difficult to implement the natural and hybrid FRP composites.

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