IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Study On Fiber Reinforced Polymer For Repair Of Concrete Structure

[1] Dr. Vijaya Kumar Y M, [2] Dr.Shruthi R, [3]Mr.Akash
[1] Professor, [2] Associate Professor, [3]M.tech student
[1]Department of Civil Engineering Structural Enggineering,
[1]Adichunchanagiri Institute of Technology, Chikkamagaluru, India

Abstract: The repair and strengthening of existing reinforced concrete (RC) structures continue to gain significance as global environments deteriorate and infrastructure ages while the demands of service increase. Traditional strengthening techniques such as steel jacketing and the incorporation of synthetic fiber-reinforced polymer (FRP) systems are useful and broadly accepted methods of strengthening concrete yet can gaps or weaknesses of their own by adding unnecessary weight, contrived corrosion issues, or high environmental costs. There is an increasing effort in research towards using natural fibers--such as jute, basalt, and sisal--as sustainable alternatives to synthetic fibers in FRP applications. Natural fiber-reinforced polymers (NFRPs) provide advantages including biodegradability, renewability, cost, and desirable mechanical properties. Presented here is a thorough literature review, of recent work identifying advances in natural and hybrid fiber composites that were utilized in strengthening concrete elements. The reviewed works had various techniques employed such as full wrapping (encapsulation) and strip wrapping of columns, beams, and piles, as well as the use of textile-reinforced mortars (TRMs) that combined both natural and synthetic fibers. The reviewed works consistently showed improvements in the compressive, flexural, and shear capacities of the concrete elements, improvements in ductility and energy absorption were also seen in all works covered. Additional proof that the durability of the systems held up in heavy environmental conditions such as the acidic, alkaline, marine, and potable water conditions were also validated. The hybrid options (untarred configurations) of most of the studies that were used as natural fiber combinations stood out in their performance.

Index Terms - Natural Fiber- Reinforced Polymer Concrete Strengthening Jute and Basalt Fibers Textile-Reinforced Mortar Structural Retrofitting

I. Introduction

As existing reinforced concrete (RC) structures continue to age and be subjected to increased service loads, with the added effects of environmental deterioration, seismic and structural design code changes, a greater need for rehabilitation and strengthening of infrastructure is necessary. Traditional retrofitting methods, with respect to the above two definitions, involve many modifications of existing infrastructure with some form of added strength including; steel jacketing and concrete overlays - while these methods do provide improvements in strength, they offer unwanted challenges and issues typically including, dead load increases and corrosion potential due to installation processes, increased labor and complexity of details such as projects, etc., making them environmentally harder and ethical than their many contrasting installations. Consequently, they have not examined some of the environmental and ethical implications of existing organic or biosynthetic structures which they have achieved. As such, a focus on rehabilitation and strengthening of infrastructure utilizing a non-traditional, alternative method that offers structural performance and durability while also incorporating more environmental and ethical responsibilities has encouraged engineers and researchers to seek development of new to the world sustainable alternatives, looking for alternative new technologies to sustainable strengthening solutions with FRP's (Fiber-Reinforced Polymers) one of the most promising options, due to their strength to weight ratios, resistance to corrosion, and the ease in method of application, FRP's have traditionally been used with synthetic fibers (including Carbon, Glass, and Aramid) and have offered significant and increased performance for flexural capacity while improving shear capacity and compressive capacity predicted with conventional structural designs; but as researchers began to observe the environmental concerns of synthetic fibers production (energy and oil from non-renewable resources) and they, in general, are not biodegradable. Researchers have also slowly began to shift towards looking at natural fiber-reinforced polymers (NFRP's) with natural fibers such as jute, sisal, and basalt, with these more appealing fibers providing benefits of low cost, biodegradable, renewable, and acceptable mechanical properties.Many studies have demonstrated that both natural fibers and hybrid systems can enhance the structural performance of RC elements. For instance, hybrid composites using natural fibers in combination with synthetic ones (e.g. E-glass) not only take advantage of the ductility and environmental benefits of natural fibers, but also the stiffness and strength offered by synthetic counterparts (Sakthimurugan and Baskar, 2021; Yinh et al., 2021; Zulfikar and Syah, n.d.). Furthermore, there has been research into textile-reinforced mortars (TRMs) incorporating natural fibers as replacements for the typical epoxy-based FRP systems. With these TRM systems there are other benefits, such as vapor permeability, not being as reliant on existing substrates, and typically better fire performance when objectives and criteria are focused on sustainability (Debnath and Sen, 2024)Environmental durability is a persistent concern with FRP applications specifically regarding situations where they are exposed to found in aggressive environments (e.g., marine, acidic, or alkaline). More recently, researchers have investigated the performance of FRP and TRM systems with natural fibers and established their behavior and effectiveness exposed under such conditions with improvements in axial load capacity, ductility, and energy absorption (Abishek et al., 2025; P et al., 2024; Varma et al., 2024b, 2024a; Zulfikar et al., 2023). There have been great efforts put into finite element analysis (FEA) models to predict the behavior of confined columns which continued to provide significant predictions, confirm experimental work, and provide valid predictive tools for practical design (Varma et al., 2024b, 2024a; Zulfikar and Syah, n.d.).

II. Type Style and Fonts

1) Sen and Paul (2015) – Jute and Sisal FRP Confinement

Sen and Paul (2015) conducted a seminal study examining the use of natural fiber-reinforced polymers (FRP), specifically jute and sisal, as environmentally sustainable alternatives for synthetic versions of FRP (CFRP and GFRP) to confine concrete cylinders. The impetus behind the research was the need to find alternatives to synthetic- frp (i.e. CFRP and GFRP) materials that are based on fossil fuels. This work was focused on using heat treated woven sisal and jute fibers in order to improve the mechanical properties of the composites. A set of concrete cylinders wrapped with jute and sisal were confined with swivel test stands under monotonic axial compressive loading to fail cylinders and determine the strength and modulus of confinement. The study found that the axial capacity of concrete cylinders confined with sisal FRP improved by 66% and jute FRP by 48% when compared to the unconfined controls. Importantly, the axial capacities for CFRP and GFRP were also improved by 83% and 180% respectively. Thus, sisal and jute FRP was a true compromise between performance and strength. This work also addressed the growing trend in 'green construction', by validating that natural fibers can be a good option for demonstrating not only the betterment of structural performance, but also addressing an environmental sustainability focus. The work also provided the first step for further investigation into more sustainable reinforcement techniques with natural materials. It has established a narrative illustrating the potential for natural fiber composites to be adopted into structural engineering systems where environmental performance is prioritized over pure mechanical performance(Sen and Paul, 2015).

2) Soupionis et al. (2020) - CFRP Under Aging Box 1 The authors,

Soupionis et al. (2020) researched carbon fiber-reinforced polymer (CFRP) composites as a means to strengthen cementitious structures while assessing their performance under aging conditions. Protocols involved the impregnation of cement specimens with unidirectional and bi-directional carbon fabrics, with the use of both liquid and paste epoxy resins. Testing of mechanical attributes of specimens relative to compressive strength, flexural strength, and shear strength was conducted before and after artificial aging that incorporated different heat treatment regimes conducted at a range of 65-75 degrees celsius for a period of 1 to 16 days. As observed from the results, CFRP significantly improved mechanical performance with compressive strengths reaching 74 MPa for unaged specimens and a reduction in compressive strength of only 7% after the engineering aging period. The authors noted the durability of CFRP materials was favorable in terms of retaining most mechanical attributes after being subjected to an environmental scenario, albeit minor depreciation of mechanical attributes occurred. The data produced from this research aided deciphering the long-term durability of CFRP and provided evidence for its applications to potentially replacing traditional methods to retrofit concrete structures used in harsh environments. Although the manuscript mainly focused on synthetic fibers and inclusions such as CFRP, it also hinted for future comparisons with natural fiber and hybrid fiber systems for this reason. This study confirmed that CFRP strengthened both structure and service life, although environmental and sustainability issues still motivate research toward more environmentally friendly alternatives(Soupionis et al., 2020).

3) Sakthimurugan et al. (2021) – Basalt Textiles in Beam-Column Joints

Sakthimurugan et al. (2021) considered the retrofitting ability of basalt textiles fabrics in reinforced concrete beam- column joints under static loading. Beam-column joints were selected for the study since they are the failure point of a reinforced concrete structure in seismic events and play a critical role in ensuring structural integrity. In total, eleven specimens were used in this study (three control specimens, and eight specimens were damaged after being preloaded to 50% of their ultimate capacity, and were then retrofitted with the basalt fabric in several configurations). The tests showed significant improvements in load-carrying capacity, ductility, and stiffness for the retrofitted specimens. The authors concluded that basalt textiles represent a practical and cost-effective way of improving the resilience of structural joints, especially in designated earthquake areas, and concluded that basalt fiber offered a natural, effective alternative to synthetic CFRP's while also providing the added benefits of sustainability and negative environmental impact. This work established basalt fiber as an environmentally acceptable and cost-effective alternative to synthetic FRPs with the added opportunity of sustainability, while showing evidence of improvement of structural action (without the typical consequences associated with jacketing using concrete or steel - such as increased weight and labour). The authors realized that their study was a contribution to society by motivating and encouraging the adoption of natural FRPs to be used in the regional built environments when strengthening and retrofitting for seismic loads purposes(Sakthimurugan and Baskar, 2021).

4) Archana et al. (2021) – Jute FRP for Post-tensioned Beams

Archana et al. (2021) focused on flexural strengthening of post-tensioned beams with Jute Fiber-reinforced Polymer (JFRP). The experimental program compared beams that were control to beams that had wrapping in JFRP with either full wrapping, or strip wrapping. The results showed that using full wrapping, the flexural capacity increased by 23%, while strip wrapping resulted in a capacity increase of 10%. The beams that were enhanced with JFRP also showed better crack control, ductility and load-deflection performance. The authors were quite clear about the high deformability index, and energy dissipation of JFRP, which would permit seismic retrofitting applications. Archana et al. (2021) supported JFRP as an environmentally friendly natural fiber to synthetic FRP accomplished with a sustainable goal. The study results confirmed that natural fibers provided reasonably acceptable improvements to the structural performance, and perhaps provided cost-effective alternatives to strengthen aging infrastructure. The study also contributed to the established knowledge of natural fiber composites for use in civil engineering, and to realize that sustainable materials have a positive role in structural rehabilitation applications. The applicable findings can only help to advance the usage of JFRP in construction and support research into natural fiber applications into flexural strengthening, or other actionable structural performance improvements where sustainability might co-exist(Archana et al., 2021).

5) Yinh et al. (2021) - Natural Fiber Reinforced Polymer (NFRP) Dimensions for Concrete Members

This research studied the static laboratory axial and flexural improvements to concrete cylinders and beams using a natural fiber reinforced polymer (NFRP) composite based on sisal fibers. NFRP composite was selected because it could incorporate natural fibers and exploit the benefits of standard polymer matrix materials. Therefore, Yinh et al. (2021) focused their study on testing the compressive and flexural behavior of concrete-shaped cylinders and beams wrapped in natural fiber reinforced polymer composite (NFRP) composed of a polyester and epoxy matrix, and evaluate the axial and flexural performance of the tubular concrete specimens and reinforced concrete beams following specifications of wrapping configurations. The study described how NFRP thickness could improve load capacity and ductility, thereby confirming the ability of natural fibers to provide structural enhancement over concrete alone. The study outlined typical failure modes, with a chief example being delamination failures between concrete and NFRP, and proposed an anchoring system to alleviate this issue, achieving confinement and limiting debonding, thus improving structural performance. The results of the study showed full wrapping geometry provided the given member improved capacity greater than partial wrapping and greater than manufactured strips of NFRP that can be purchased. Sisal fibers had properties that yielded an environmental advantage, being biodegradable, a renewables, and presenting fewer health risks compared to synthetic fiber reinforced polymers. This contribution increased the available literature focused on sustainable methods of utilizing natural fibers for reinforcement in the review of literature, demonstrating the potential of NFRP composite opportunities for performance improvement and life enhancement of reinforced concrete elements in the built environment(Yinh et al., 2021).

6) Zulfikar et al. (2023) - Hybrid E-Glass and Jute Laminate

Zulfikar et al. (2023) examined Hybrid Laminate Composite (HLC) materials made of jute and synthetic E-glass fibers with the goal of increasing the compressive strength of cylindrical concrete columns. The study aimed to optimize layer sequencing and hybrid configurations so that compressive strength would be maximized while capturing the environmental benefits of natural fibres. The specimens were made using vacuum bagging methods in accordance with ASTM C39. The specimens were tested using various layer combinations. The key findings from this study were that three layers of jute laminates achieved up to 100% increase in compressive strength, and the hybrid configurations with E-glass achieved increases of up to 150% in compressive strength. The study suggested that hybrid composites are able to utilize the ductility of natural fibres and the stiffness of synthetic materials to achieve better results. This study reinforced the idea of hybrid systems being relevant for achieving performance, cost, and sustainability targets for infrastructure projects. In addition, the study provided important findings related to the mechanical behaviour of hybrid composites that will aid in real world applications, where environmental performance and structural performance are both very important considerations, in expanding the opportunities for natural and synthetic fibres to be combined in future construction innovations(Zulfikar and Yaakob, n.d.).

7) Zulfikar et al. (2023) – Jute Laminate for Concrete Columns

Zulfikar et al. (2023) - Jute Laminate on Concrete Columns In another investigation, Zulfikar et al. (2023) extensively studied natural jute laminate composites to improve the compressive and tensile strength on concrete columns. Using vacuum bagging methods to fabricate jute wrapped specimens controlled by ASTM C39 and C496 to test the compressive and splitting tensile strength respectively, the findings indicated that there was a doubling, or 100% squat increase, in the compressive and tensile performance compared to unconfined controls. The research provided evidence that it is possible to use natural fibers, like jute, in structural performance applications, where the sustainability of the environment and economic efficiency are important. Results from the study showed there was a clear relationship between the number of laminate layers and the performance improvement, making the case better for worker design of layers for strengthening infrastructure. Through leveraging jute's biodegradable and natural fiber properties, the research could support the legitimate movement towards using sustainable materials in construction. The contributions of the research were practical empirical data supporting the objective of using natural fiber composites in structural retrofitting and rehabilitation, affirming the use of "green", or sustainable, materials to further sustainability in infrastructure(Zulfikar et al., 2023).

8) Altering concrete columns with jute laminate by Zulfikar et al. (2023)

Zulfikar et al. (2023) examined again the success of jute laminates in mechanically superior concrete cylinder performance. Utilizing the more common vacuum bagging process and ASTM guidelines, cylindrical specimens were wrapped, either in layered jute fabric laminates, with variations on wrapping and sample numbers. Strength testing showed increases in both compressive and splitting tensile capacities of 100% over the existing unconfined specimens. This research presented another convincing case for use of low-cost and biodegradable jute fibres in strengthening applications, especially where sustainable projects are the objective. The authors noted a direct link with the increase laminate layers and mechanical properties, as well as identified which certain natural fibres would be suitable replacements to synthetic FRPs in some contexts. This overarching investigation provided additional quantitative evidence to support the growing quantity of documented academic literature about natural fibres for structural strengthening applications, supporting the global transition towards the use of more environmentally- associated materials in civil engineering applications. The population provided additional evidence further proving potential of jute composites as a structural strengthening application to the existing methods for concrete infrastructure(Zulfikar and Yaakob, n.d.).

9) Gnanamoorthy et al. (2024) - AFRP and CFRP Wrapping on M30 Concrete

Gnanamoorthy et al. (2024) conducted an experimental study of the effect of Aramid Fiber-Reinforced Polymer (AFRP) and Carbon Fiber-Reinforced Polymer (CFRP), by means of external wrapping on M30-grade concrete to provide additional strength. The destructive and non-destructive testing processes used in the study included but were not limited to: compression, split tensile, and flexural strengths; rebound hammer; and ultrasonic pulse velocity, which was used to study the mechanical behavior of FRP-confined concrete. The CFRP specimens provided better overall performance parameters compared to the AFRP specimens in terms of increased strength, ductility, and durability for single and double wrapped carbon fiber strengthened concrete specimens. The study found that CFRP provided the greatest enhancement to the mechanical strengths of the M30 concrete specimens, compared to AFRP which provides a more cost efficient option without sacrificing efficiency. The authors advised that although AFRP showed relatively lower strength enhancement, it had particular advantages in circumstances where moderate performance, cost, or a more vapour permeable fiber were of greatest consideration. The authors also emphasized the significance of the orientation of the fiber, number of layers, and compatibility of the materials used in optimizing performance. In conclusion, the study reinforced and ongoing growing acceptance of FRPs, synthetic and natural for the sustainability and load-bearing performance of reinforced concrete structures when being subjected to a variety of mechanical stresses(P et al., 2024).

10) Varma et al. (2024) - Textile Reinforced Mortar with Hybrid Jute/Basalt in Concrete Columns.

Varma et al. (2024) studied the use of textile reinforced mortar (TRM) systems with hybrid jute and basalt fibers for the confinement of concrete cylinders under axial compression. This study was designed to evaluate a more sustainable alternative to conventional reinforced polymer (FRP) alternatives and substituted epoxy with high- strength mortar as a binding matrix. Concrete specimens were confined with TRM systems utilizing jute, basalt, and hybrid jute-basalt textiles and were subjected to different types of exposure in acid, alkaline, marine, and potable water conditions. The results indicated a 51.93% increase in axial load capacity for hybrid TRM wrapping versus unconfined controls, and durability benefits were observed in every type of environment. Hybrid TRM circumvention systems took advantage of stiff mechanical properties for confinement capacity using basalt and flexible properties of jute, resulting in better confinement efficiency. The hybrid systems were modeled using finite element analysis (FEA) and the behaviors in FEA were corroborated with the experimental tests with good correlation. The research demonstrated that hybrid TRM confinement could represent an actual, environmentally prudent remedy for structural retrofitting with mechanical performance plus moisture and chemical resistance bonus. These findings help further the use of sustainable natural fiber composites in construction by meeting the structural durability and environmental performance criteria of modern building codes(Varma et al., 2024).

11) Varma et al. (2024) - Hybrid Jute/Basalt FRP Columns and Durability

Varma et al. (2024) performed a comprehensive study of the axial compressive capacity of concrete columns confined with hybrid jute/ basalt Fiber-Reinforced Polymer (FRP) systems. It was determined that the various test series were conducted under acidic, alkaline, marine, and drinking water environments to assess the performance pertaining to strength, durability, and energy absorption aspects. For the hybrid FRP wrapping type, there was a 63.64% load carrying capacity increase and a 287% energy absorption increase in terms of performance (compared to unconfined controls). The benefits of using both jute's natural ductility and basalt's rigidity and chemical resistance were discussed, and the contributors recommended the use of basalt wraps over jute wraps in general, given there are significant increases in durability and/or strength. The addition of basalt wraps on jute wraps significantly increased both durability and strength. Finite element analysis (FEA) using ABAQUS software was used to depict the stress strain curve and investigate the effectiveness of the hybrid FRP system. It was shown that the simulations corresponded closely with the experimental test results. The hybrid system removed many limitations associated with natural fibers, notably moisture rapture, through using basalt for the outermost protective elements. Overall this study illustrates the possibility of hybrid natural-synthetic FRPs for sustainable durably retrofitting or construction options in all environmental exposures. The overall findings correlate with wider industry trends of using green materials for construction decisions that are consistently measure and apply performance reporting. It is clear the contribution of natural fibres (i.e., jute, hemp etc.) and consideration of hybrid natural-synthetic FRPs to enhance infrastructure resilience in an uncertain and rapidly changing future(Varma et al., 2024).

12) Thansirichaisree et al. (2025) - Hybrid B-CSM Confined Concrete

Thansirichaisree et al. (2025) studied the effect of hybrid Basalt-E-glass Chopped Strand Mat (B-CSM) composites on the compressive behaviour of concrete columns. The aim was to address the inherent brittleness of concrete under axial loads by testing specimens with start strengths of 18.43 MPa and 24.43 MPa, confinement was provided with three layers of B-CSM. The results showed that ultimate strength improved by 258% and sustained strain improved by over 500% for the lower-strength specimens. The higher-strength specimens also showed improved values. The researchers proposed a regression-based analytical model to predict the stress-strain behaviours much better than FRP models have historically done. The results indicated that B-CSM is not only technically feasible, but it is also economically feasible when compared to synthetic FRPs. The study also had implications for sustainable construction by showing that optimal performance (e.g. flexural strength, stiffness, etc.) can be achieved with a hybrid composite that provides both natural fibers and synthetic fibers. This study provided much information for engineers who are looking for durable, cost-effective, and environmentally friendly strengthening solutions. It also further developed the idea that hybrid confinement strategies are a relevant solution for the practices of modern civil engineering in improving the performance of RC structures in extreme conditions(Thansirichaisree et al., 2025).

13) Debnath and Sen (2025) – Woven Basalt and Jute Textiles in Cylinder Strengthening

Debnath and Sen (2025) investigated the potential of woven basalt and jute textile materials in strengthening concrete cylinders using full and strip wrapping methods. A total of fifteen specimens were assessed to measure the benefits to axial load capacity. Both full wrapping with basalt and jute specimens produced axial capacity increases of 42.73% and 34.18%, respectively. The use of strip wrapping produced capacity increases of 32.05% and 25.6% with the basalt and jute textiles, respectively. The data with regard to the load-deformation data further supported the successful use of full wrapping. The research involved in this study demonstrated the suitability of natural fibres such as jute for confinement given that mechanical behaviour was achieved without compromising the sustainability of the project. This study further illustrates, through the use of natural fibres such as jute and basalt, we have viable alternatives to synthetic fibre options, particularly in contexts with limiting economic or ecological realities. This study adds to the body of knowledge regarding textile reinforcement behaviour and the impact of geometry and orientation of wrapping on final performance. The findings from this study by Debnath and Sen further advances the case for the deployment of environmentally considerate materials, as they can demonstrate the ability to meet performance requirements, while also assisting to lessen our negative impact on the planet. The study by Debnath and Sen supports existing movements to study and define sustainable, resilient, and cost-effective options for repairing concrete structures, while also recognizing the growing expectation for all facets of the construction industry to act on the growing demand for green construction products(Debnath and Sen, 2024).

14) Abishek et al. (2025) - AFRP (Kevlar) for Piles in Lateral Loads

Abishek et al. (2025) investigated the lateral load performance of reinforced concrete (RC) piles retrofitted with an Aramid Fiber-Reinforced Polymer (AFRP), also known as Kevlar. This project was aimed at reducing the impacts of lateral load failures, which can occur in pile foundation systems from wind, seismic, and soil movements. The researchers wrapped conventional RC piles with AFRP and performed static lateral load tests to compare to CFRP and GFRP wrapped specimens. The tests showed that the brittle failure would not occur with AFRP wrapping, which would lead to an increase in the lateral load capacity, delay in stiffness deterioration, and improvements in energy dissipation compared to unwrapped RC piles. It was noted that although AFRP wrapping provided valuable improvements in the mechanical properties of the piles, it exhibited a lower ultimate load capacity than the CFRP and GFRP. The authors mentioned the function of AFRP wrapping was not limited to lateral loads, stating that "AFRP is expected to provide some level of durability from moisture, alkalis, and heat, making it a viable option for marine and offshore applications," which is a strong recommendation for piles located on (or near) the shore. The researchers performed modelling in MATLAB to verify the performance of lateral load applied to the RC piles. The modelling provided insights into the performance metrics of lateral loads applied to RC piles, and therefore provided knowledge on potential practical applications of the AFRP wrapping in a marine or corrosive environment. The authors highlighted that, "despite the fact that AFRP did not outshine CFRP by raw strength measures or lateral capacity, it provided a sufficient and acceptable durable alternative—recognising that environmental durability and resilience may be a more important consideration than maximum strength." These contributions provided design evidence of the behaviour of natural and synthetic FRP systems under lateral loading and have significant implications relating to their use in critical infrastructure applications([14] Abishek et al., 2025).

III. *Conclusion*

The overall findings of the review highlight the great potential for natural fiber reinforced polymers (FRPs) and textile reinforced mortars (TRMs) with jute, sisal, and basalt fibers to provide structure improvements to concrete members through strain capacity, compressive, flexural, and shear capacities. The case study natural materials and hybrid systems also follow sustainable principles as not only do all natural fibers degrade and have lower carbon footprints than the synthetic counterparts, but hybrid systems are encouraged because they couple with the natural fibers unique characteristics to develop optimal performance by balancing strength, ductility, and environmental durability. In addition to the performance and sustainability, other considerations include their durability to withstand extreme environmental exposures (acidic, alkaline, marine) in structural applications. Although the industry uses CFRP and GFRP as the dominant materials for FRP components because of their superior mechanical properties, natural fiber FRP and hybrid FRP systems that utilize natural fibers, are becoming growingly accepted and can be a low or even a zero carbon alternative to synthetic FRP systems. In conjunction with consistent promising finite element analyses in various published research, and combining findings from experimental work which leads to discussions of introduced predictive tools for future designers to adopt through FRP and TRM systems will provide the construction industry would take notice. Researchers have outlined a path to mainstream acceptance in developing resilient, sustainable, or environmentally friendly infrastructure aligned with modern engineering, and environmental requirements

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