

Review

CFRP: Breakthrough material in Vietnam's construction industry

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Abstract: As Vietnam's construction industry accelerates modernization, carbon fiber-reinforced polymer (CFRP) emerges as a pivotal material for sustainable, high-performance infrastructure. With its lightweight, corrosion-resistant, and highly durable nature, CFRP enhances structural longevity, minimizes maintenance, and reduces environmental impact, aligning with global sustainability goals. Widely applied in bridges, high-rise buildings, and coastal structures, CFRP addresses Vietnam's unique environmental challenges, providing resilience against humidity, chemical exposure, and seismic activity. However, high costs and limited expertise in CFRP application remain obstacles. Strategic investment in cost-reducing technologies and workforce training is crucial for widespread adoption. As CFRP's benefits become increasingly recognized, Vietnam's construction sector has the opportunity to lead in sustainable infrastructure, creating lasting, eco-friendly solutions that reflect the country's commitment to both innovation and environmental responsibility.

Keywords: carbon fiber-reinforced polymer (CFRP); sustainable infrastructure; high-performance materials; Vietnam construction industry; environmental resilience; workforce training in CFRP

1. Introduction

CFRP is emerging as a revolutionary material in contemporary construction. With a high strength-to-weight ratio, CFRP has demonstrated advantages over traditional materials like steel and concrete [1,2]. Carbon fiber weighs only about 25% of steel yet can exhibit superior strength, significantly reducing the load on structures such as bridges, high-rise buildings, and large-scale frameworks, leading to cost savings in design and construction [3]. Additionally, carbon fiber composites offer exceptional fatigue resistance, making them ideal for applications requiring high durability and minimal maintenance. The load-bearing capacity of CFRP is impressive not only under static loads but also when subjected to dynamic forces, a crucial benefit for structures exposed to vibration or impact [4]. Importantly, CFRP performs well in humid, high-temperature, and chemically exposed environments, ensuring long-lasting durability without frequent maintenance. The blend of light weight, remarkable strength, and resilience against environmental factors has positioned carbon fiber composites as a top choice for modern designs, from bridges and roadways to high-rise buildings. These advantages mean CFRP enhances performance and safety in construction while paving the way for more sustainable and efficient solutions in the industry [5,6].

Vietnam's construction industry is undergoing rapid expansion, driven by urbanization, economic growth, and the pressing need for modern infrastructure. The country's high-rise developments, bridges, transportation networks, and coastal structures are under increasing strain, both from the demands of a growing

population and from Vietnam’s unique environmental challenges [7]. Traditional materials, including steel and concrete, have been the mainstays of construction, but they present limitations, particularly in the face of high humidity, saltwater exposure, and seismic activity. Against this backdrop, advanced materials such as CFRP have garnered attention as potential solutions to the limitations of conventional materials [8].

CFRP is a composite material known for its exceptional strength-to-weight ratio, resistance to corrosion, high tensile strength, and fatigue endurance [9]. These properties make it a prime candidate for modernizing Vietnam’s infrastructure, where conditions often test the durability and resilience of traditional materials. The lightweight nature of CFRP offers significant advantages, particularly for high-rise buildings and large-span bridges, by reducing dead loads and improving seismic performance. Moreover, its superior corrosion resistance makes CFRP especially suited for coastal and humid regions, reducing the need for frequent maintenance and thereby lowering life-cycle costs [10].

Globally, CFRP is already established in various sectors, including aerospace, automotive, and marine industries. In the construction field, its use has been steadily rising, particularly in the United States, Japan, and Europe [11], as **Figure 1** illustrates. In these regions, CFRP has not only demonstrated effectiveness but also provided an impetus for sustainable building practices by enhancing structural durability and reducing maintenance requirements. As Vietnam seeks to meet its sustainable development goals, adopting CFRP aligns with the global shift towards eco-friendly, long-lasting construction solutions. Despite its high initial cost, the potential benefits of CFRP in reducing repair needs and extending the life of structures make it a valuable consideration for Vietnam’s infrastructure growth [12].

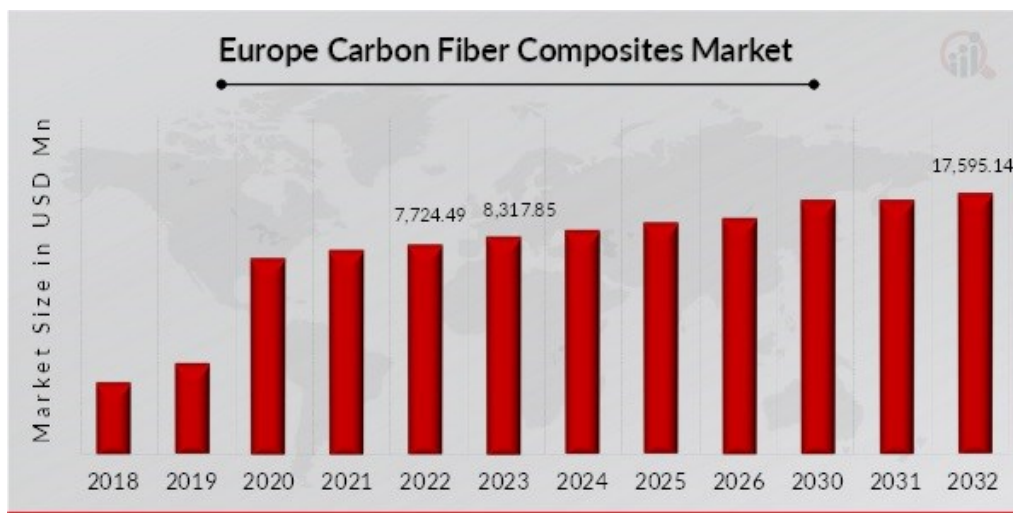


Figure 1. Europe carbon fiber composites market growth chart.

This study explores CFRP’s viability within Vietnam’s construction sector, with a focus on applications in transportation infrastructure, high-rise buildings, and coastal facilities. Through an in-depth analysis of CFRP’s mechanical properties and use cases, this research aims to provide insights into the potential benefits and

challenges of CFRP adoption, paving the way for broader understanding and more strategic applications within the industry [13].

The **Table 1** summarizing the typical mechanical properties of Carbon Fiber Reinforced Polymer, widely used in the construction industry [14]. These values can vary depending on the production process, the type of carbon fiber, and the polymer matrix used.

Table 1. Carbon fiber composite properties.

Property	Unit	Typical Value
Density	g/cm ³	1.6–1.8
Tensile Strength	MPa	500–3500
Tensile Modulus	GPa	70–300
Elongation at Break	%	1.5–2.0
Compressive Strength	MPa	200 – 1500
Compressive Modulus	GPa	70–300
Flexural Strength	MPa	600–1200
Flexural Modulus	GPa	80–280
Impact Strength	kJ/m ²	40–60
Thermal Expansion Coefficient	1/K	-0.1–0.2 × 10 ⁻⁶
Thermal Conductivity	W/mK	5–10
Maximum Service Temperature	°C	80–200
Corrosion Resistance	-	Very High
Dimensional Stability	-	Excellent

In recent years, the application of Fiber Reinforced Polymer (FRP) composites in the construction industry has gained significant attention due to their superior mechanical properties, durability, and corrosion resistance. Despite extensive research in this field, the rapid pace of developments necessitates a comprehensive review of the state-of-the-art to position this study within the broader research landscape. Recent advancements by leading research groups, such as those of Naser, Hawileeh, Nanni, and Hollaway, have highlighted critical areas, including the long-term durability of FRP materials, advanced modeling techniques for structural behavior, sustainable reinforcement strategies, and novel applications in extreme environments. These studies underscore the growing importance of FRP in addressing challenges associated with traditional materials, such as steel and concrete, particularly in harsh environmental conditions.

This work contributes to the existing body of knowledge by addressing current gaps in the literature, focusing on the integration of advanced computational models with experimental validation to optimize the design and application of FRP composites. To ensure a robust foundation, the literature review has been expanded to include a detailed examination of recent contributions, emphasizing their relevance to the methodologies and findings presented herein. Additionally, this study discusses the influence of building codes, such as American Concrete Institute (ACI) and Eurocode, on the practical implementation of FRP systems, highlighting the interplay between theoretical advancements and regulatory frameworks. By

situating this research within the context of these recent developments, we aim to provide a comprehensive understanding of FRP composites' potential and limitations, paving the way for future studies to further enhance their application in the construction industry.

2. Literature review applications of CFRP in Vietnam

2.1. Transportation infrastructure

In Vietnam, amidst the rapid development of transportation infrastructure, CFRP composites are increasingly favored in bridge and roadway projects, especially in coastal areas or regions with harsh climate conditions. This choice reflects the construction industry's responsiveness to natural challenges and marks a significant advancement in adopting modern technology.

The use of carbon fiber in construction is not merely a material choice; it's an intelligent solution that helps minimize maintenance costs and extend the service life of structures. Engineers and designers have recognized that CFRP not only enhances load-bearing capacity for bridges and roads in complex climates but also provides exceptional durability, making it a top choice for essential infrastructure. In particular, lightweight suspension bridges made with CFRP, featuring outstanding strength and low weight, are easier to construct while also offering excellent load-bearing capacity and corrosion resistance, as **Figure 2** illustrates. This resilience protects structures against natural corrosive elements like sea winds and high humidity, as well as the ongoing impact of heavy traffic.

Images of sleek, elegant suspension bridges spanning across scenic blue waters symbolize the vitality and growth of the nation. Choosing CFRP is not just a technical decision but also a testament to Vietnam's commitment to building a sustainable future where technology and nature harmonize, creating structures that are both beautiful and resilient over time.

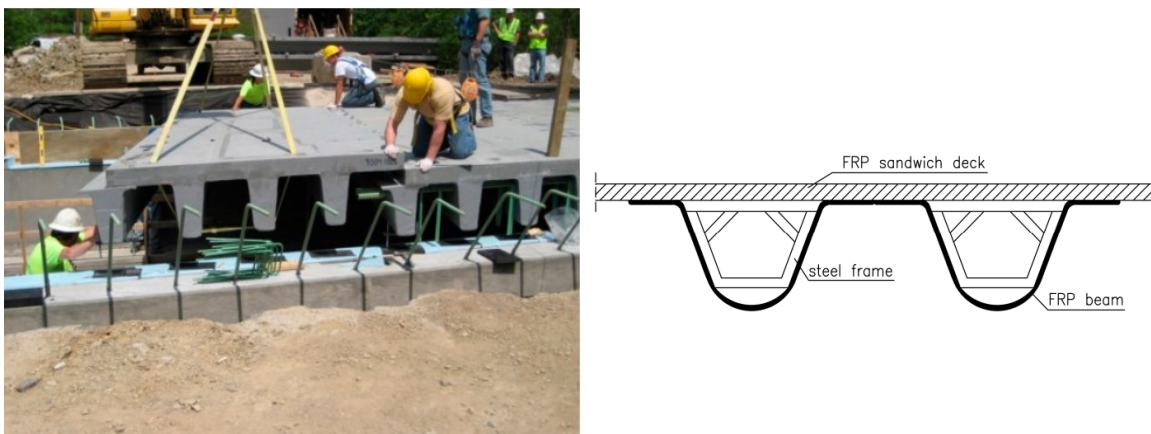


Figure 2. Construction with prefabricated composite panels.

2.2. High-rise buildings and modern architecture

As major cities in Vietnam, like Hanoi and Ho Chi Minh City, continue to expand rapidly, the demand for high-rise buildings and multifunctional architectural structures is surging. CFRP has emerged as an effective, cutting-edge solution

widely applied to reinforce floors, columns, and structural frames in modern buildings, as **Figure 3** illustrates. With its high load-bearing capacity and lightweight nature, CFRP not only enhances seismic resilience but also significantly reduces the load on foundations, optimizing architectural design and lowering construction costs.

Beyond enhancing performance and durability, carbon fiber also elevates aesthetics. CFRP allows architects to create innovative and striking designs, from sleek lines to unique structural forms, delivering fresh experiences for urban residents in contemporary city spaces. High-rise buildings constructed with the perfect blend of technical functionality and design artistry are not only symbols of economic progress but also cultural landmarks, reflecting the character and spirit of the city.

Clearly, the application of CFRP in construction is not merely a technological leap; it represents a strong commitment to creating sustainable, innovative, and modern architectural works. As these high-rise buildings stretch toward the sky, they also play an essential role in improving quality of life, offering comfortable, safe, and eco-friendly spaces for living and working.

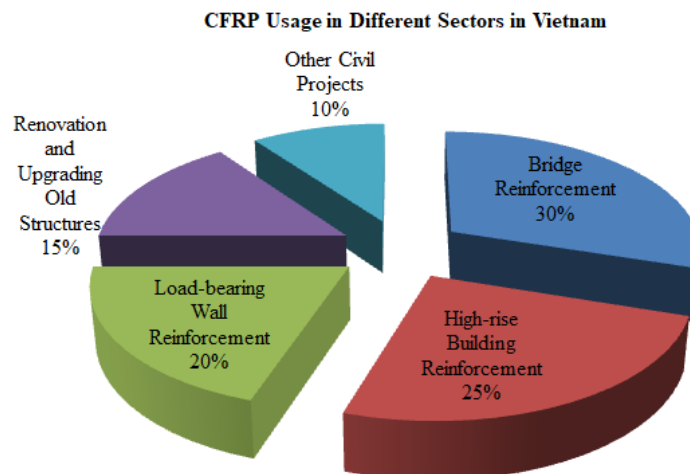


Figure 3. CFRP usage distribution in Vietnam.

2.3. Coastal and harsh environment structures

With an extensive coastline and humid tropical climate, Vietnam faces significant corrosion challenges for coastal structures and infrastructure. Harsh factors like sea salt, high humidity, and corrosive environments have increased the demand for corrosion-resistant construction materials, particularly CFRP. CFRP's high tensile strength, along with its resistance to chemicals and sea salt, helps protect structures from rapid degradation. Its application is on the rise in coastal projects across Vietnam, including coastal plants, ports, bridges, and coastal roads. Using CFRP substantially lowers long-term maintenance costs due to its effective corrosion resistance. This not only extends the lifespan of structures but also ensures safety and stability throughout a project's lifecycle. Consequently, CFRP has become a priority material in the design and construction of coastal infrastructure, contributing to the sustainable development of national projects.

3. Sustainability and economic efficiency

A major factor driving the robust development of composite materials, particularly carbon fiber-reinforced polymer, is their ability to meet sustainability demands and offer exceptional advantages across various fields, especially construction and industry. CFRP not only significantly reduces the weight of structures while maintaining strength and load-bearing capacity but also minimizes the use of traditional materials like concrete and steel. This conserves natural resources and mitigates environmental impact over a structure's lifespan.

Although CFRP has a relatively high initial production and investment cost, it is considered a strategic investment for its long-term benefits. CFRP's corrosion resistance and durability extend structural lifespans and drastically reduce future maintenance costs. Moreover, CFRP's lightweight properties reduce loads on foundations and structural components, leading to lower construction costs and improved energy efficiency. These characteristics not only yield economic benefits but also help reduce greenhouse gas emissions, contributing to environmental protection.

As global awareness of sustainable development's importance grows, the demand for CFRP continues to rise, creating new opportunities in sectors like construction, transportation, aerospace, and renewable energy. Applying CFRP is not just a technical solution but also a long-term strategy for a greener future, where buildings and products increasingly meet stringent energy efficiency and environmental protection standards.

In this context, investing in the research and development of advanced composites like CFRP is essential, not only to enhance sustainability but also to create technological solutions for new economic and environmental challenges. CFRP's outstanding advantages in extending the lifespan of structures, lowering operational costs, and reducing environmental impact make it a strategic and sustainable choice for both the present and the future.

4. Discussion

Despite the promising benefits, several significant challenges remain in expanding CFRP applications across Vietnam. One primary barrier is the high cost of this material, which is much greater than traditional materials like concrete and steel. This cost factor requires investors and construction companies to carefully consider the resources allocated to large-scale projects. In today's construction market, where projects often need to optimize costs to remain competitive, CFRP's high expenses may limit its use. Contractors may worry that investing in composite materials could impact profit margins and project returns.

Additionally, technical construction challenges are noteworthy. Many workers and engineers in Vietnam's construction sector currently lack the necessary knowledge and skills to work effectively with CFRP. This technical gap not only affects construction quality but also poses safety risks. Addressing this issue requires comprehensive training programs to improve awareness and skills among construction personnel. Furthermore, investing in specialized construction equipment for CFRP is essential to ensure smooth and efficient construction processes.

Nevertheless, despite these challenges, the advancement in production technologies and the sustainability trend in construction make the widespread use of carbon fiber-reinforced polymers feasible and promising. Manufacturers are continuously exploring new methods to lower CFRP production costs, which may make it a more economical choice in the near future. As technical expertise in handling this material becomes more common, a highly skilled workforce capable of working with CFRP will emerge, leading to quality construction outcomes.

Moreover, the application of composites like CFRP benefits not only construction projects but also contributes to sustainable development and environmental protection. These materials are typically lighter and more resource-efficient, minimizing negative environmental impacts. As investors realize the long-term benefits of CFRP, from reduced maintenance costs to enhanced durability, the adoption of these materials is set to become an inevitable trend in Vietnam's construction industry.

Ultimately, as producers make significant strides in reducing CFRP production costs and as technical knowledge of this material's application becomes more widespread in construction, CFRP will undoubtedly become a cornerstone of Vietnam's construction sector. This shift will not only elevate construction quality but also boost the economy and enhance the safety of coastal structures, aligning with sustainability standards amid global development trends.

The application of CFRP in Vietnam's construction industry provides substantial technical benefits while offering significant opportunities for sustainability and long-term cost savings. First, CFRP reduces structural loads, lowering the demands on foundations and primary structural elements. This not only minimizes construction costs but also contributes to energy efficiency in large-scale buildings and structures. The light weight and durability of CFRP enable savings in traditional materials like concrete and steel, reducing environmental impact and conserving natural resources.

Another key advantage of CFRP is its high corrosion resistance, particularly valuable for coastal projects and humid environments in Vietnam. CFRP's durability helps extend the lifespan of structures, significantly reducing maintenance and repair costs and ensuring stability and safety throughout the project's lifecycle. In other countries, CFRP usage has demonstrated a reduction in maintenance costs and an increase in sustainability by minimizing environmental impacts. In Vietnam, where climate and natural conditions can be challenging, CFRP represents a material solution that is both resilient and strategic, contributing to longer-lasting structures that withstand adverse conditions.

However, several significant challenges need to be addressed to broaden CFRP adoption. The primary issue is the high initial cost of CFRP, which is considerably greater than traditional materials like concrete and steel. This requires investors and construction firms to carefully assess resource allocation for large-scale projects. Another notable challenge is the technical gap in the knowledge and skills among Vietnam's construction workers and engineers regarding CFRP. Addressing this requires comprehensive training programs to raise awareness and develop the skills necessary for effective CFRP use. Furthermore, investment in specialized equipment for CFRP construction is essential to ensure efficient and safe implementation.

Despite these challenges, advancements in production technology and a trend toward sustainable construction are making CFRP more feasible. Manufacturers are actively exploring new methods to reduce production costs, potentially making CFRP a more economical choice in the near future. As technical expertise in handling CFRP becomes more widespread, a skilled workforce capable of working with this material will lead to higher-quality construction outcomes. CFRP applications benefit not only individual construction projects but also contribute to broader goals of sustainability and environmental protection.

CFRP has substantial potential to meet sustainability standards and enhance construction efficiency in Vietnam. Its application is not merely a technical solution but a long-term strategy for a greener future, where buildings and products increasingly adhere to stringent energy efficiency and environmental standards. Collaboration among manufacturers, contractors, and regulatory bodies will be crucial in promoting the widespread adoption of CFRP, positioning it as the new standard in Vietnam's construction sector in the near future.

One of the primary challenges that the construction industry in Vietnam faces is the lack of expertise in FRP technology. While there is a growing interest in using FRP for reinforcement and repair, the relatively limited number of trained professionals proficient in FRP applications has slowed its widespread use. Many construction projects, particularly in the infrastructure and building sectors, have struggled to implement FRP solutions effectively due to the absence of skilled labor and technical knowledge. This knowledge gap not only impacts the quality of the implementation but also leads to delays and increased costs, as additional training or external consultancy is often required.

Furthermore, the high cost of FRP materials remains a significant barrier to their widespread adoption, especially in developing countries like Vietnam. Despite the long-term benefits, such as improved durability and reduced maintenance costs, the initial investment for FRP materials is considerably higher compared to traditional construction materials like steel and concrete. For instance, in bridge reinforcement projects, the higher upfront costs for FRP tend to deter many local contractors and project owners, who often prioritize cost-saving in the short term over the long-term benefits of FRP. A notable example is a recent bridge rehabilitation project in Ho Chi Minh City, where despite the proven advantages of FRP, the project was delayed multiple times due to budget constraints, and traditional materials were ultimately chosen over FRP as a cost-effective solution.

These examples highlight the need for greater education and awareness of the potential benefits of FRP, alongside efforts to reduce material costs through improved manufacturing processes or local production. By discussing these challenges with specific real-world examples, readers will gain a more concrete understanding of the obstacles faced in Vietnam and other developing countries when trying to incorporate advanced materials like FRP into construction projects.

5. Conclusion and future prospects

CFRP is rapidly emerging as a game-changer in Vietnam's construction industry. With exceptional technical qualities, CFRP brings lightweight durability,

remarkable chemical resistance, and advanced design flexibility that make it ideal for infrastructure projects like bridges, high-rise buildings, and industrial frameworks. By effectively mitigating corrosion and minimizing maintenance needs, CFRP extends the lifespan of structures while reinforcing Vietnam's commitment to sustainable development.

As the demand for environmentally conscious construction rises, CFRP's high recyclability supports sustainable building practices, reducing construction waste and paving the way for greener urban growth. This shift toward eco-friendly materials isn't limited to large-scale projects; CFRP's adaptability positions it to play a significant role in smaller ventures as well. Coordinated efforts among material producers, contractors, and regulatory bodies will be essential to ensure CFRP's integration as a new standard across Vietnam's construction landscape.

Despite these promising attributes, CFRP faces hurdles in cost and accessibility. The material's higher price point compared to traditional options like concrete and steel may delay widespread adoption, particularly in cost-sensitive markets. Moreover, a limited familiarity with CFRP among construction professionals in Vietnam could impact project outcomes and safety standards. However, as production technology advances, driving down costs, and as targeted training programs enhance workforce competency, these barriers can be overcome. Strategic investments and supportive policies will be instrumental in making CFRP a feasible option for Vietnam's builders.

In time, CFRP's transformative potential in reducing structural weight, cutting long-term maintenance expenses, and opening new possibilities for resilient, sustainable architecture could make it a cornerstone of Vietnam's construction sector. Embracing CFRP not only raises the bar for construction standards but also positions the country as a leader in green infrastructure, offering a sustainable pathway for future development.

Conflict of interest: The authors declare no conflict of interest.

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