Review Article

Journal of Environmental Nanotechnology

An Analysis of Structural Rehabilitation and Repair Projects Involving Carbon Fiber Reinforced Concrete

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Received: 15.03.2024 Accepted: 09.05.2024 Published: 30.06.2024
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ABSTRACT

Since plain concrete is brittle by nature, the flexural and split tensile strengths developed must be taken into consideration. Plain concrete is robust in solidity; nevertheless, with feeble cutting-edge tautness. Numerous fibres are commonly utilized in the construction sector to enhance concrete's flexural strength, ductile strength and durability properties. The great tensile strength of steel fiber makes it the fiber of choice for usage in the building industry. However, steel fibre has some disadvantages, including a propensity for corrosion. Carbon fibre is a promising substitute for fiber-reinforced concrete when compared to other fibers due to its corrosion resistance, low density, and superior tensile strength. According to the evaluation work conducted by numerous reviewers, carbon has only very few applications. This study gives an overview of carbon fiber, its structural uses in restoration and repair projects and the various characteristics of fiber-reinforced concrete with carbon. The strength, toughness, and flexural properties of carbon fiber as well as the feasibility research on repair and rehabilitation work using various carbon fibers have been reviewed.

Keywords: Carbon fiber; Tensile strength; Corrosive resistance; Reinforced concrete.

1. INTRODUCTION

1.1 General

Carbon fiber reinforced concrete (CFRC) stands as an innovative construction material that combines the durability and versatility of traditional concrete with the exceptional mechanical properties of carbon fiber. This hybrid material has gained significant attention in the construction industry for its ability to enhance the structural performance of concrete structures while reducing their weight and increasing their longevity.

1.1.1 The Need for Reinforcement

Concrete has been a fundamental building material for centuries due to its exceptional compressive strength, cost-effectiveness and versatility. However, it has inherent weaknesses, primarily in tensile strength and resistance to cracking. These shortcomings demand the growth of various reinforcement techniques. Recently, carbon fiber-reinforced concrete has emerged as a transformative solution.

1.2 Composition and Production

Carbon fiber reinforced concrete combines cement, water, and aggregates with carbon fibers. The carbon fibers, typically in the form of short or long filaments, are incorporated into the concrete mixture to provide tensile and flexural strength.

1.3 Key Features

In the construction industry, CFRC is a remarkable material known for its exceptional mechanical properties. The process of creating CFRC involves several crucial steps. Fiber selection is of paramount importance, and high-strength, lightweight carbon fibers are carefully chosen. Once the fibers are selected, the next step is mixing, where they are dispersed uniformly within the concrete mixture. This even distribution of reinforcement ensures that the resulting CFRC exhibits consistent and enhanced strength throughout the structure. Finally, in the casting stage, the CFRC mixture is poured and carefully cured, allowing it to solidify and form the desired structure. This construction method, combining the strength of carbon fibers with the versatility of concrete results in a durable and robust material well-suited for a variety of structural applications.

The integration of carbon fibers into concrete brings forth a host of essential properties that greatly benefit construction and other engineering sectors. Notably, carbon fibers enhance tensile strength, significantly reducing the risk of cracking and reinforcing the overall structural integrity of the concrete. Furthermore, CFRC offers a weight advantage, as it is lighter than traditional reinforced concrete, making it an optimal choice for projects where weight considerations are paramount, such as in bonds and high-rise structures. The corrosion-resistant properties of carbon fibers contribute to the extended life span of CFRC structures while simultaneously diminishing maintenance and repair expenses. The enhanced flexural performance of CFRC allows it to flex without failure and makes it well-suited for applications dealing with dynamic loads such as earthquake-resistant structures. Additionally, the reduced weight of CFRC promotes sustainability in construction practices by potentially reducing energy consumption during production and transportation thus, lessening the environmental impact of construction projects.

1.4 Applications

Carbon fiber-reinforced concrete finds a diverse array of applications across the realm of construction and engineering. It plays a pivotal role in the construction of critical components of infrastructure, like bridges, highways, and tunnels, significantly enhancing structural durability and reducing long-term maintenance costs. Beyond structural integrity, CFRC is employed for its aesthetic attributes in architectural elements, enabling the creation of visually appealing facades and cladding for buildings while maintaining durability. The material’s wear resistance and high load-bearing capacity make it an ideal choice for industrial flooring, providing a reliable surface in demanding environments. Additionally, CFRC is a vital asset in the area of repair and retrofitting, strengthening and extending the lifespan of existing structures. Furthermore, the inherent strength and ease of installation of CFRC offer a comprehensive solution for diverse engineering and construction needs by its utility as high-performance precast elements.

The CFRC represents a remarkable synergy of materials science and construction technology. Its potential to enhance the strength, durability and sustainability of concrete structures has made it a promising solution for the modern construction industry. As we delve deeper into this technology, the future holds exciting possibilities for safer, more cost-effective, and environmentally friendly infrastructure projects worldwide.

1.5 Carbon Fiber

Carbon fiber is a notable material that has revolutionized multiple industries, from aerospace and automotive engineering to sports and renewable energy. Its exceptional properties, which comprise weight relation, erosion confrontation and suppleness, have made it a material of choice for various applications.

1.6 Origin and Composition

Carbon fiber, at its core, is a composite material primarily composed of carbon atoms bonded together in long, thin strands. These carbon filaments are typically derived from organic polymers, such as polyacrylonitrile (PAN) or petroleum pitch. The carbonization process begins with the raw material being chemically treated and heated to extremely high temperatures in an oxygen-deprived environment. This step eliminates all non-carbon elements, leaving behind carbon atoms arranged in a hexagonal lattice structure, giving the material its unique properties.

2. LITERATURE REVIEW

This table concisely overviews the main studies, their focus areas, and key carbon fibers and composite materials findings. Ateeq *et al.* (2023) focused on using reinforced carbon fiber (rCF) in polymer composites to reduce carbon fiber left-over. They highlighted the importance of investigating fiber alignment techniques to achieve high fiber volume fractions for high-value applications and scaling up rCF recovery procedures while exploring chemical sizing to eliminate interfacial defects and enhance surface quality. Their research underscores the significant potential of recycled carbon fiber in additive manufacturing and emphasizes the need for advancements in materials, surface treatments, recycling methods, fiber alignment techniques and scaling efforts to maximize the performance of rCF-reinforced composites.

Madika *et al.* (2024) thoroughly investigated various properties of composite laminates. The investigation showed that Kevlar threads significantly enhance the yield and ductile strength of the compound laminates, whereas, carbon threads contribute to a higher modulus of elasticity. These distinct characteristics make the laminates exceptionally well-suited for applications requiring robust resistance to high-impact cargo. This study underscores the potential of tailored composite laminates inproviding superior anti-ballistic properties and mechanical strength for various practical applications. Chen *et al.* (2023) focused on neoprene composites for high-speed rubber track applications. They employed a dual approach to modify carbon fibers (CF) using dopamine and silane coupling agents (SCA) KH560, KH570, and KH590. The study revealed that the three SCA-modified CF/natural rubber (CF/NR) composites exhibited improved thermal conductivity and mechanical properties to varying degrees. Notably, CF grafted with KH590 in natural rubber demonstrated a remarkable 71.3% increase in thermal conductivity and an impressive 73.3% boost in tensile strength when compared to untreated natural rubber, making them particularly promising for high-speed rubber track applications. Baritto *et al.* (2023) delved into the possibility of asphaltene-founded carbon fibers (ACF) by way of a low-carbon precursor for carbon fiber manufacture, drawing comparisons with the standard PAN pathway. The research involved a comprehensive life span evaluation and extensive modelling to estimate greenhouse gas (GHG) releases across various stages of ACF production. Asphaltene-founded carbon fibers release 16.2 kg CO_2 eq/kg CF, a substantial 68.7% reduction when compared to the 51.6 kg CO_2 eq/kg CF projected for PAN-based carbon fiber. This marked decrease confirms the environmental advantages of ACF as a more sustainable option. Also, the study pinpointed the carbon fiber production stage as the most emission-intensive phase, with electricity consumption, particularly during carbonization, being a major contributor. This stage accounted for 39% of total emissions, underscoring the importance of enhancing energy efficiency in the carbonization process. Additionally, this research identified factors like overall yield, the nitrogen-to-stabilized mass ratio in carbonization, and energy consumption in finishing operations as highly sensitive to influencing ACF's GHG emissions. Monte Carlo simulations indicated a range of uncertainties in results, spanning from 10.4 to 21.8 kg CO_2 eq/kg CF, with a mean of 15.5 kg CO_2 eq/kg CF. The study highlights that the current bitumen production in Alberta is capable of meeting global demand for carbon fiber, shedding light on the potential of the asphaltene pathway to play a substantial role in the industry's more sustainable and environmentally friendly future.

Table 1. Overview, Main focus and Key Findings of carbon fibre Reinforced Concrete

Main Focus	Key Findings	Author Name
Reinforced carbon fiber (rCF) in polymer composites	Fiber alignment, scaling up rCF recovery, enhancing surface quality	Ateeq *et al.* (2023)
Properties of composite laminates (Kevlar and carbon threads)	Enhanced mechanical properties suitable for high-impact applications	Madika *et al.* (2024)
Neoprene composites for high-speed rubber track applications	Improved thermal conductivity and tensile strength of CF/NR composites with KH590 treatment	Chen *et al.* (2023)
Asphaltene-founded carbon fibers vs. PAN-based carbon fibers	68.7% reduction in CO_2 emissions with ACF; energy efficiency in carbonization	Baritto *et al.* (2023)
Machinability of PEEK reinforced with carbon threads	Impact of printing orientation and cutting parameters on machinability	Gómez-García *et al.* (2023)
Flax fiber-reinforced polymer composites with carbon fibers	Hybridization effect of flax and carbon fibers; significant improvement in mechanical properties	Wang *et al.* (2023)
Bonding properties of carbon fibers in Alkali-activated slag (AAS) medium	Effective plating treatment for improved bonding and mechanical performance	Huang *et al.* (2023)
Manufacturing optimization of CFRTP composites	Processability and cost-effectiveness; potential for cross-industry collaboration	Almushaikeh *et al.* (2023)
Flexural strength of carbon fiber earth-cement concrete-filled steel composites (CFSC)	Significant enhancement in rupture strength with carbon threads	Žmindák *et al.* (2017)
The bonding strength between concrete and externally bonded CFRP composites	Influence of CNT additives on bond strength; improvements in attachment properties	Jongvivatsakul *et al.* (2022)
Strengthening RC beams with externally bonded CFRP composites	Enhancement in shear and flexural strengths with varying compressive strengths of concrete	Al-Shamayleh *et al.* (2022)
Reinforcement of concrete beams using CFRP under blast loads	Improved flexural and shear strength; effectiveness of CFRP in blast-resistant applications	Al-Jasmi *et al.* (2023)
Improvement of concrete interface using multi-scale carbon nanotube-fiber (MCNF)	Enhanced pull-out resistance and mechanical properties with MCNF	Du *et al.* (2022)
Comparison of carbon fiber and carbon nanofiber in concrete (CFRC and CNFRC)	CFRC exhibits better ductility; CNFRC shows superior strength and deformation characteristics	Chen *et al.* (2023)
Motorized properties of carbon fiber textile-reinforced concrete (CTRC)	Improvement in bending strength with increased fiber content; a theoretical framework for bending behaviour	Zhang *et al.* (2023)
Flexural enhancement of textile-reinforced concrete with short carbon fibers	Enhanced load-carrying capacity and strain performance	Olcun *et al.* (2023)
Production of high-thermal-conductivity carbon fiber composites	Effective thermal conductivity up to 37.1 W/mK with specific carbon fiber content	Olcun *et al.* (2023)
Electrical properties of electrically conductive coupling composites (ECCCs)	Reduced electrical resistivity with carbon fibers and carbon black; improved efficiency in concrete curing	Gwon *et al.* (2023)
Optimization of CFRP design using genetic algorithms	Improved stiffness and reduced waste in CFRP production with IFM-GA	Fukui *et al.* (2023)
Electrical conductivity enhancement of CFRPs using graphene and silver nanowires	Enhanced through-thickness and in-plane electrical conductivities without compromising mechanical properties	Sha *et al.* (2023)
Production of carbon fiber cloth from end-of-life cotton textiles	Optimal conditions for producing high-grade carbon fiber with reduced energy requirements; application in environmental and electronic sectors	Wesley *et al.* (2023)
Mapping lithium distribution in carbon fibers for structural batteries	Even distribution of lithium at slow charge/discharge rates; potential for structural reinforcement and energy storage	Johansen *et al.* (2024)
Hybrid laminate concepts for enhancing impact response of CFRP composites	Zone-based laminates with up to 95% improvement in energy dissipation compared to baseline CFRP	Kazemi *et al.* (2023)
Fabrication of recycled short carbon fiber-reinforced magnesium matrix composites	Microstructural enhancement and mechanical property improvements with CF reinforcement; impact of fiber content and length on mechanical behavior and creep resistance	Kandemir *et al.* (2023)

Gómez-García *et al.* (2023) studied the importance of understanding the machinability of materials used in additive manufacturing processes. Strengthening polyether ether ketone (PEEK) by carbon threads improves its mechanical properties but affects its brittleness and machinability. The choice of printing orientation plays a crucial role in machining forces, and careful selection of cutting parameters is essential to achieve the desired results. In applications where surface quality and dimensional accuracy are critical, these findings can inform the manufacturing process to mitigate challenges related to machining. This study provides a scalable methodology that can be applied to various industrial cases and emphasizes the significance of addressing machinability concerns in the context of additive manufacturing for widespread use and practical applications.

Wang *et al.* (2023) aimed to enhance the mechanical properties of flax fiber-reinforced polymer composites by introducing carbon fibers in a cross configuration. They conducted a comprehensive investigation into the impact of several key factors, including the capacity portion of carbon fibers, and the thickness of the carbon fiber-reinforced polymer (CFRP) coating. Their findings and conclusions can be abridged as follows: First, the thickness of the CFRP layer was predicted by the carbon fiber volume fraction, with a lower fraction resulting in a thinner CFRP layer. This, in turn, highlighted the positive hybridization effect of the hybrid composite. Second, the study found that the most effective hybrid configuration involved using flax fiber as the outer casing and carbon fiber as the core. Conversely, placing carbon fibers on the superficial coating diminished the mechanical properties. The ductile stress-strain curve of F/CFHRP did not exhibit pseudo-ductility. Finally, by enhancing the hybrid composite process, the strength of F/CFHRP increased by 129.3% compared to the FFRP, and the toughness of the F/CFHRP improved by 32% compared to CFRP once the composite limited by 26.4% carbon fiber. These findings offer a promising avenue for enhancing the performance of composite materials.

Huang *et al.* (2023) studied various treatment methods that effectively enhance the bonding properties of carbon fibers in Alkali-activated slag (AAS) medium. The plating treatment by calcium silica slurry is particularly effective, resulting in substantial improvements in bonding strength, flexural strength, and crack propagation resistance. The formation of a dense connection between fibers and the matrix, along with the introduction of Si-rich phases through the reaction of slag and portlandite contributes to the improved performance. These findings offer valuable insights into the enhancement of AAS composites, which have the potential for a wide range of engineering applications and offer improved mechanical properties and durability.

Almushaikeh *et al.* (2023) emphasized the importance of optimizing the manufacturing techniques for Carbon Fiber Reinforced thermoplastic (CFRTP) composites to unlock their full potential extensively. It highlights need for addressing tests through novel practices. The continued growth in CFRTP processability, cost-effectiveness, and cross-industry collaboration are expected to drive increased production capacity to meet the growing demands. This work paved the way for innovative ideas and efficient production methods. By addressing the challenges and leveraging the recyclability of CFRTP, these composite materials can offer multifunctional solutions in various industrial sectors, contributing to sustainability and resource efficiency.

Žmindák *et al.* (2017) systematically focused on flexural strength of the carbon fiber earth-cement concrete-filled steel composites (CFSC). Effect of Carbon Fibers: The adding of carbon threads effectively improved the rupture strength of earth-cement and transformed the hard and brittle nature into a more ductile and plastic nature. The rupture strength of CFSC reached 0.509 MPa under standard conditions, representing a substantial 31.5% increase compared to plain soil cement. Soil Type and Cement Content: The rupture strength of CFSC varied by soil type, with clay exhibiting the highest strength. A linear relationship was observed between flexural strength and cement content, with an optimal economical cement content of 15%. They found a change in stress distribution. The introduction of the composite lamella led to a notable change in the delivery of pressures within the real and the steel strengthening. The maximum tensile stress of both concrete and the reinforcement was reduced, which is favourable for enhancing the overall performance of the concrete structure. Additionally, the study observed an increase in maximum compressive stress in the concrete. The maximum deflection values in both cases, with and without the lamella, were found to be very similar. This suggests that the presence of the bonded lamella did not significantly impact the overall deflection behavior of the reinforced concrete beam.

Adhesion and Delamination: The analysis indicated that the bond between real and lamella was generally decent. However, signs of delamination were observed in the cutting-edge material. The maximum calculated probability of delamination was approximately 94% in ANSYS and nearly 97% in MSC MARC. This suggests that while adhesion between the concrete and lamella is strong, there is a notable risk of delamination in specific areas. Crack behavior. The study observed that the addition of the lamella influences the concrete's cracking behavior and distribution.

Jongvivatsakul *et al.* (2022) conducted a study on the enhancement of bonding strength between concrete and externally fused carbon fiber-reinforced plastic (CFRP) composites, and the addition of carbon nanotubes (CNTs) remained explored as a potential additive. Two kinds of CNTs, single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) were incorporated into two different epoxy materials at varying concentrations of 0.25%, 0.5%, and 1.00% through heaviness of epoxy to determine best presentation. Single-shear tests examined the attachment conduct encompassing promise strength, final blunder, real promise distance, bond stress-slip association, interfacial break vigour, and blow creation amid the CFRP bowl and concrete. Epoxy adapted with 0.5% SWCNTs and 1.0% MWCNTs, through the heaviness of epoxy, significantly improved final weight and blunder and promise strength once likened to basic epoxy. It was observed that tall-thickness epoxy adapted by SWCNTs or MWCNTs exhibited reduced attachment possessions. The study explores the potential of CNT additives to improve the attachment strength amid CFRP and concrete cutting-edge repair and strengthening applications for deteriorated reinforced concrete structures.

Al-Shamayleh *et al.* (2022) conducted research on Armor-plated Real (RC) rays strengthened with outwardly fused carbon fiber reinforced plastic composites in form of covers and pieces subjected to disappointment tests. The study encompassed varying compressive strengths of 17, 32, and 47 MPa, by CFRP composites applied in six dissimilar shapes to enhance both the flexural and fleece load-carrying volumes of beams. The consequences demonstrated a significant enhancement in both shear and flexural strengths due to the application of externally bonded CFRP composites. Notably, the efficiency of CFRP physical contrariwise correlated. Increasing crushing strength from 17 to 47 MPa, beams reinforced by CFRPU-wraps exhibit a substantial development cutting-edge shear, reaching after 28.9% to 29.6%, compared to rays strengthened by laminate strips, which saw enhancements between 14.4% and 23.8%. In contrast, beams reinforced by half U-wraps displayed a noteworthy increase in rupture strength, with final load-carrying capacity developments ranging from 22.4% to 46.2%, while those strengthened with laminate exhibited enhancements ranging from 17.8% to 38.4% with upsurge cutting-edge real crushing strength. Lastly, theoretic forecasts based on the AC I440.2R-14 rules remained compared to new consequences, revealing relatively large changes due to experiential countryside of Cypher-foretold reckonings. These findings underscore the effectiveness of outwardly fused CFRP composites in enhancing the fleece and bending performance of RC rays, with response varying based on concrete compressive strength and the specific CFRP configuration employed.

They evaluated petite carbon fibers as a strengthening material to enhance the exhaustion confrontation of PLA (polylactic acid) involved in a thorough analysis of fatigue behavior through rotational bending fatigue tests. The study also examined the impact of various printing parameters affecting mechanical behavior, including coating width, printing fever, printing speed, on the motorized performance, dimensional correctness, and macro geometrical nonconformities of the published shares. Incorporation of short carbon fibers did not lead to an improvement in the motorized possessions of the published shares. Also, the fatigue behavior worsened due to deprived bond between the petite carbon fibers and the PLA medium, resulting in a 6% reduction in fatigue life compared to pure PLA. Regarding printing parameters, the study highlighted that using the upper most fever allowable improved the exhaustion behavior by 12%, while production the smallest influence, and layer thickness had the most significant impact, cumulative fatigue life by 15% when compared to 0.1 mm and 0.3 mm layers. The research provided a parametric relationship to correlate layer thickness with fatigue behavior, offering valuable insights for optimizing the use of short carbon fibers in PLA and the impact of printing parameters on fatigue resistance.

Al-Jasmi *et al.* (2023) focused on enhancing safety in oil and gas plants, with a specific emphasis on improving the structural reinforcement of concrete beams using composite materials. In the realm of structural engineering, concrete beams have historically seen enhancements through the application of various Fiber Reinforced Properties (FRP). The performance of CFRP composites below explosion loads and their suitability as support for armor-plated concrete rays was studied. Using the ANSYS software modeling program, the reply of RC rays to blasts was comprehensively analyzed, enabling the simulation of RC beam properties when reinforced with CFRP in concrete structures. CFRP was chosen as a material of interest due to its promising properties, characterized by strength, elasticity, and resistance to alkalis, making it well-suited for testing and analysis. The study incorporated both numerical and model analyses, revealing that CFRP significantly improved the flexural and shear strength of RC beams. In practical terms, RC beams reinforced with CFRP out performed control beams in factors such as deformation, equivalent stress, and shear stress, exhibiting a minimum percentage difference of 0.784% and a maximum of 7.09%, contingent on the number of CFRP layers and the applied load on the beams. Findings highlight the potential of CFRP composites in enhancing the structural integrity of concrete beams, particularly in scenarios where blast resistance and safety are paramount concerns, such as in Oil & Gas plant environments.

Du *et al.* (2022) aimed to address the feeble compulsory power and susceptibility to retreat between old-style carbon fibers (CF) and concrete interfaces. To achieve this, the study prepared 3-D multi-scale carbon nanotube-fiber (MCNF) by graft carbon nanotubes onto the superficial of carbon threads through cataphoresis. Processer imitations were conducted to assess the performance of MCNF, revealing that compared to regular carbon fibers, MCNF exhibited stronger attraction to the concrete interface and enhanced resistance to pull-out. Concrete samples were prepared, including Basic real (PC), CF real (with CF gratified at 0.1% of concrete capacity), and MCNF real (with MCNF gratified at 0.1% of real volume). Dynamic mechanical tests were conducted by means of a Φ100 mm Hopkinson weight bar examination new device, which demonstrated that MCNF's interface by concrete formed a tighter bond and was more resistant to pull-out compared to carbon fiber, thus contributing to concrete's enhanced mechanical properties. Additionally, the study introduced an enhancement effect of MCNF to a bridge and adapted the Zhu-Wang-Tang constituent perfect (traditionally used as a damage model). The basic perfect aligned with the real state of MCNF real, and the theoretic arc founded on this perfect closely resembled the actual test curve, confirming the model's accuracy. These research findings provide valuable insights for enhancing the influence weight confrontation of real in practical manufacturing applications.

Chen *et al.* (2023) compared the influence of carbon fiber and carbon nanofiber on the still and lively motorized possessions of concrete by conducting a series of mechanical tests on carbon fiber-armor-plated concrete (CFRC) and carbon nanofiber-reinforced concrete (CNFRC). The tests included still motorized examinations, lively density tests, and lively excruciating ductile tests, complemented by a micro-mechanism analysis through Mercury Interruption Porosimetry (MIP) and SEM. The findings demonstrated that both carbon fiber and carbon nano fiber needed a positive impact happening the mechanical properties of real and contributed to a refinement of the hole scope delivery within the concrete matrix. In still-motorized possessions, CFRC exhibited better ductileness, while CNFRC displayed superior strength and deformation characteristics. For lively density motorized possessions, CFRC demonstrated better energy consumption performance, whereas CNFRC exhibited stronger strength. In dynamic splitting tensile properties, CFRC outperformed in terms of strength, deformation, and energy consumption. Furthermore, carbon fiber exhibited pronounced crack confrontation ability under load. The research also revealed that carbon nano fiber needed a more significant optimization result on the hole construction of concrete than carbon fiber. These findings provide valuable insights for the assortment of CFRC than CNFRC in various manufacturing applications, based on specific project requirements and performance criteria.

Zhang *et al.* (2023) studied the impact of incorporating petite alkali-resistant cut-glass threads on the motorized possessions of powdered real matrices and further examined the bending behavior of carbon fiber textile reinforced concrete (CTRC) pieces through 4-point winding tests. In a comprehensive series of experiments, aentire of 19 examples were verified, taking into account varying factors such as petite fibre distances, gratified levels, and then strengthening ratios of carbon fibre textiles. The finding revealed that the thermalized possessions of the well concrete matrix better as lengths and gratified levels of the fibers increased. Bending tests conducted on CTRC sheets demonstrated significant enhancements in bending strength and deformability with higher fiber gratified and strengthening ratios of carbon fabrics. Notably, the utilization of short fibers resulted in an impressive 80.35% improvement in the fast load of the CTRC pieces, and the ultimate bending load showed an increase of more than six times when compared to samples deprived of carbon fiber fabrics and petite fibers. To provide a theoretical framework for this behavior, the study proposed a trilinear perfect to label the bending load-displacement arc of CTRC pieces armor-plated by short threads, and it remained strong minded that the foretold data closely aligned with the new results. The study's findings offer valuable insights into the benefits of combining short fibers and carbon textiles to improve the motorized possessions and flexural behavior of real, presenting a promising avenue for practical applications in construction and engineering.

Incorporation of short carbon threads as internal strengthening into textile-reinforced concrete one-way slabs to enhance their flexural capacity was studied by Olcun *et al.* (2023). The study investigated on 4 full-scale (1500 × 500 × 50) mm one-way lumps, with polyacrylonitrile fabric network serving as internal strengthening in mixture by petite carbon threads. Among these labs, 1 was constructed with ground real and petite carbon threads, while 2 textile-reinforced RC lumps were reinforced with 8coatings of cloth (textile-reinforced concrete, TRC 8 L) and varying fractions of petite carbon fiber (0.264% and 0.528%). Additionally, one orientation textile-reinforced real lump deprived of petite carbon fiber was used for comparison. The TRC with added short carbon fiber exhibited enhanced bending capacity, load-deflection, and load-concrete straining performances in comparison to pure TRC. Specifically, the novel TRC with 0.264% petite carbon thread sand TRC with 0.528% short carbon fibers increased the load carrying volume by approximately 24.19%and 31.56%, respectively, in comparison to TRC. Also, the strength of the blow design was also slow to assess the ductileness of TRC with short carbon fiber, highlighting its significant improvement over traditional TRC.

Olcun *et al.* (2023) introduced a novel method for 3D production of high-thermal-conductivity incessant carbon fiber composites, aiming to enhance their heat transfer properties. The process involved the use of a double extruder to selectively 3D pattern polylacticacid

(PLA) or PLA-coated pitch carbon threads. Experimental characterization of the real current conduction was conducted on unidirectionally 3D-printed examples, considering threads by dissimilar conductions and later varying capacity portions. 3 marks of pitch carbon threads, with conductions reaching from 140 to 800 W/mK were employed, and. Carbon fiber capacity portions were investigated within the range of 6.25% to 11.7%. The findings revealed all-out effective current conduction of 37.1 W/mK for a 9.5% volume portion of the K13D2U pitch carbon fiber, which notably exceeded the values measured in any 3D-published carbon-based composites in previous studies. Though, the slow real current transmissions fell meaningfully below the predictions made by the parallel model. Further analysis using micro-computed tomography confirmed post-printing fiber breakage, suggesting that even advanced real current conductions could be achieved by healthier managing fiber integrity during the production procedure. The study outlines potential directions for the future development of this technology, opening up possibilities for applications that benefit from enhanced heat transfer capabilities.

Gwon *et al.* (2023) examined the personality-boiler features of electrically conductive coupling composites (ECCCs) and developed a real and cost-efficient combination project for ECCC chunks, which could be employed in the faster curative of real using carbon dark and carbon threads as conductive go-betweens. XII different mix sizes were ready with variations in carbon dark and carbon fibre fillings. A specific power request protocol was intended to assess the self-heating capabilities of these combinations. The findings highlighted the critical role of carbon threads, as ECCCs by 0.2 vol% carbon fibers exhibited electrical resistivities that were less than 0.16% of those deprived of conductive go-betweens. For assumed carbon fiber content, an upsurge in carbon dark gratified up to 0.8 vol% significantly reduced electrical resistivity and attained the upper most regular surface fever of ECCC, reaching about 77 °C. Though, when the carbon black content was increased to 1.2 vol%, electrical resistivity began to rise. Additionally, two designated ECCC blocks (one with 0.4 vol% carbon fibre and another with either 0 vol % or 0.8 vol% carbon black) were utilized for the faster curative of normal adhesive, emotional on 25V DC for 24 hours. The adhesive paste preserved using the chunks with 0.8 vol% carbon dark exhibited a higher proportion of hydrous phases and at 11% discount in porosity after 24 hours of curation, demonstrating the potential of this approach for improving the efficiency of concrete curing processes.

Fukui *et al.* (2023) used an individual fitness method genetic algorithm (IFM-GA) for optimizing carbon fiber-reinforced plastic design. The strength of CFRP is closely tied to the allocation and orientation of carbon fibers, and an improper design can lead to the generation of waste carbon fibers, making CFRPs less cost-effective. To address this challenge, the authors optimized the allocation and orientation of carbon fibers as design variables. This problem is inherently a combinatorial optimization issue, where traditional genetic algorithms (GAs) may struggle to find optimal solutions due to the vast number of possible combinations. In response, the IFM-GA is developed, offering a GA-based method with a distinct fitness calculation approach. While genetic algorithms (GAs) calculate the fitness of each design, the IFM-GA calculates the fitness of each design element, resulting in a design that offers higher stiffness compared to traditional GAs. The IFM-GA is a valuable tool for achieving optimal fiber allocation and orientation, surpassing the capabilities of traditional GAs.

Sha *et al.* (2023) studied the enhancement of the electrical conductivity of carbon fiber-reinforced polymers for various applications, including the elimination of metallic meshes for electromagnetic interference and lightning strike protection. The proposed hybrid approach involved functionalizing carbon fibers with vertical graphene (VG) and modifying the matrix with silver nanowires (AgNWs). The outcomes of this innovative method demonstrated a remarkable improvement in both through-thickness and in-plane electrical conductivities, with increases of approximately 38 times and 39%, respectively, while not adversely impacting the mechanical properties of CFRPs. Further insights from finite element modeling indicated that this unprecedented enhancement is attributed to a significant reduction in contact resistance between carbon fibers, resulting from the combination of VGs on the fibers and AgNWs in the matrix. Additionally, computational modeling show cased the potential of increased electrical conductivity in reducing joule heat density by approximately one thousand times, particularly under simplified lightning strike conditions.

Wesley *et al.* (2023) studied the relationship between temperature, time, and carbon content in the production of carbon fiber cloth using end-of-life cotton textiles in order to identify the minimum energy requirements for textile recycling process. The composition of the resulting carbon fibers was thoroughly examined using elemental combustion instruments and X-ray fluorescence, while their structure was investigated through scanning electron microscopy and X-ray diffraction. The research determined that the optimal conditions for preparing high-grade carbon fiber (over 90% carbon content) involved a temperature of 1150 °C and a duration of 30 minutes. For the production of lower-grade carbon fiber (with 80% carbon content), the minimum temperature and time requirements were 650°C and 30 minutes. These findings support circularity efforts in the cotton textiles industry, enabling high-value applications in environmental management or electronic markets, resulting in reduced carbon footprint in industries and alignment with sustainable procurement objectives by incorporating greater proportions of recycled content materials.

Johansen *et al.* (2024) focused on structural batteries that are unique multifunctional devices capable of both storing energy and bearing mechanical loads. These batteries rely heavily on carbon fibers, serving not only as structural reinforcement but also as electrodes that reversibly host lithium ions (Li). Auger electron spectroscopy was employed to map the distribution of Li within polyacrylonitrile-based carbon fibers. The results revealed that at slow charge/discharge rates, Li is evenly distributed both transversely and longitudinally within the fibers, and upon full discharge, virtually all Li is expelled. Conversely, at faster rates, Li tends to be trapped within the core of the fiber, within stances of Li plating observed between the solid electrolyte interphase and the fiber surface in some cases.

Kazemi *et al.* (2023) introduced innovative zone-based hybrid laminate concepts designed to enhance the high-velocity impact (HVI) response of baseline carbon fiber-reinforced polymer composites while maintaining similar areal weights and preserving substantial in-plane mechanical properties. This achievement was realized by ensuring that approximately 80% of the baseline CFRP is retained in these hybrid concepts and by tailoring materials to perform specific roles within three distinct zones along the laminate's thickness during HVI. An array of materials encompassing various fiber reinforcements were considered such as, carbon (thin-and thick-plies), glass, zylon, and ultra-high molecular weight polyethylene, as well as a combination of shape memory alloy and carbon fabric; ceramic, alumina and titanium sheets. Despite having similar areal weights, the novel laminate concepts demonstrated remarkable improvements, with up to a 95% increase in energy dissipation compared to the base line quasi-isotropic CFRP configuration.

Kandemir *et al.* (2023) studied the fabrication of recycled short carbon fiber-reinforced magnesium matrix composites through a combination of stir casting and hot extrusion. The investigation aimed to assess the influence of CF content (2.5 and 5.0 wt.%) and fiber length (100 and 500 μm) on the microstructure, mechanical properties, and creep behavior of the AZ91 alloy matrix. Microstructural analysis revealed that the CFs, aligned in the extrusion direction, led to grain and intermetallic refinement within the alloy. Compared to the unreinforced AZ91 alloy, the composites with 2.5 wt.% CF exhibited a notable increase in hardness (16-20%) and yield strength (5-15%), depending on the fiber length, although ductility was reduced. As their enforcement content increased from 2.5 to 5.0 wt.%, the strength values showed fluctuations and declined, along with reduced ductility. These varying outcomes were discussed in the context of fiber length, clustering tendency due to higher reinforcement content, and the presence of interfacial products with micro-cracks at the CF-matrix interface. Tensile creep tests indicated that CFs did not enhance the creep resistance of extruded AZ91 alloy, suggesting that grain boundary sliding likely constitutes the dominant deformation mechanism during creep.

Zhang *et al.* (2023) studied the effects of incorporating short alkali-resistant cut-glass threads into the powered possessions of a powdered concrete medium. Additionally, it conducted four-point bending tests to analyze the flexural behaviors of carbon fiber textile-reinforced concrete (CTRC) sheets. Throughout the experiments, a total of 19 sequential examples were tested, systematically varying the lengths and content levels of short fibers, as well as there in forcing ratio of carbon fiber textiles. Tests demonstrated that the well concrete matrix exhibited enhanced motorized properties with increased fiber length and content. Moreover, the bending tests on the CTRC sheets revealed a significant improvement in bending strength and deformability as fiber gratified and the strengthening ratio of carbon fabrics increased. The incorporation of short fibers resulted in an impressive 80.35% improvement in the cracking load of the CTRC sheets. Furthermore, the ultimate bending load exhibited a maximum improvement over 6 areas compared to examples deprived of carbon fiber textiles and petite fibers. Lastly, the study proposed a trilinear perfect to label the flexural load-displacement curve of CTRC pieces armor-plated by petite fibers, and the predicted data closely aligned with the experimental results.

2.1 Summary

In a comprehensive overview of material advancements, researchers have explored the versatility of carbon fiber-reinforced concrete in various engineering applications. The potential benefits of CFRC in terms of its enhanced mechanical properties have proven effective for anti-ballistic applications. Additionally, the integration of CFRC has been found to significantly improve the flexural capacity of one-way slabs and offers new possibilities for accelerated curing of concrete. Overall, this article reveals multifaceted capabilities of CFRC in enhancing the performance and functionality of composite materials in different domains of engineering.

3. CONCLUSION

The review highlights significant advancements in the use of carbon fiber-reinforced concrete across various engineering applications, emphasizing its enhanced mechanical properties, especially in anti-ballistic scenarios. However, there are several notable research gaps in this field. The exact mix proportions and methods for optimizing CFRC in different applications require further exploration to ensure its consistent performance. While this (Olcun *et al.* 2023; Almushaikeh *et al.* 2023) review mentions CFRC's ability to improve the flexural capacity of one-way slabs, there is a need for in-depth investigation into the specific structural designs and construction techniques to fully harness this potential. Also, there is a possibility of accelerated curing with CFRC, but the specific techniques and mechanisms involved remain understudied. Addressing these research gaps will enhance the understanding and utilization of CFRC in engineering applications.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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