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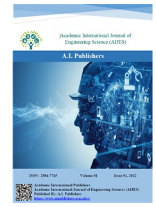

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State Of Art: Carbon Fiber Reinforced Concrete A Review

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Abstract

Because plain concrete can break easily, checking how well it can bend, and handle being pulled apart is important. Even though plain concrete is tough and strong, it's not so good at resisting being stretched. To fix this, the construction industry uses different kinds of fibers to make concrete more flexible, lasting, and able to resist being pulled. Steel fiber is often used because it's strong but can get rusty. Conversely, Carbon Fiber (CF) is a viable choice for Fiber-Reinforced Concrete (FRC). because it doesn't rust, is lightweight, and has strong tensile strength. However, some researchers have noticed that CF hasn't been used as much as it could be. This research gives a summary of CF, its use in fixing and restoring projects, and the properties of CF Reinforced Concrete (CFRC). It looks at the strength, toughness, and bending qualities of CF, and studies if different types of CF can be used to fix and rehab buildings.

Introduction

Carbon fibers (CF) are produced by heating pitch and polymers until they break down and are commonly used as plasters in lightweight polymer-matrix composites. On the other hand, carbon filaments are made from carbon-rich gases at 500 to 700 °C and have distinct properties that appeal to engineers. A key difference is size: carbon fibers have diameters of 7 to 15 micrometers (µm) and can be continuous or discontinuous, while carbon filaments are smaller, ranging from 0.01 to 0.2 µm, are always short, and feature a centered hollow channel.

Fibers and filaments have different structures. Fibers typically have aligned carbon layers along their length, while filaments do not. In the USA, one filament type has carbon layers angled like a fishbone, and another has a tree-ring pattern. The manufacturing process influences filament structure, but the relationship between processing conditions and microstructure is not covered here.

Filaments and carbon nanotubes differ mainly in size and structure. Nanotubes have a smaller diameter and consist of carbon layers in cylindrical shapes. Single-wall nanotubes have one layer, while multi-wall nanotubes have several, featuring a hollow channel in the center.

Filaments are cheaper and easier to find than nanotubes. Nanotubes can be made using techniques like arc discharge, catalytic growth, or laser ablation. Vapor-Grown Carbon Fibers (VGCF) are different from Carbon filaments. VGCF are made by heating carbon-rich gases to create carbon deposits on very small carbon filaments. This process takes place at temperatures between 950 and 1100°C. VGCF usually have larger diameters, similar to those of regular carbon filaments.

This review examines the carbon filaments performance in composite materials compared to carbon fibers (CF) as fillers, focusing on their electromechanical, mechanical, electromagnetic, and electrical properties. Mechanical behavior is crucial for structural requirements, while electrical behavior relates to conductivity. Electromagnetic behavior is important for EMI shielding, lightning protection, electrostatic discharge protection, and guidance in automatic highways. Electromechanical behavior involves stress and strain sensing in smart structures, traffic monitoring, vibration control, and weighing motion vehicles [1].

Literature Review

Yeou-Fong Li and his team investigated concrete cylinders of varying strengths using uni-axial compression tests and wrapped them with carbon fiber-reinforced plastic (CFRP). They aimed to propouse a model known as the L–L model for strengthening reinforced concrete structures, which estimates peak strength based on the Mohr-Coulomb failure theory. This model relates peak strength to unconfined concrete strength, lateral confining stress, and the angle of internal friction. Through regression analysis, they determined the strain at peak strength, using a polynomial of a second-order to describe the relationship of stress-strain. Testing 108 CFRP-confined cylinders confirmed the model's accuracy. They also created a modified L–L model for CFRP-supported concrete with steel reinforcement, tested with 18 cylinders measuring Ø30 × 60 cm [2].

Zuxiang Lei and colleagues investigate foamed concrete (FC), a lightweight building material that faces tensile and compressive strength challenges. Their research examines the effects of short-cut CF on enhancing the mechanical properties of FC, aiming to reduce cracks and improve overall strength. Using Digital Image Correlation (DIC), the study analyzes failure modes and structural changes at varying densities, fiber lengths, and amounts. Results show that adding CF significantly boosts FC performance; at a density of 500 kg/m³, tensile strength can increase by up to 250%, and

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compressive strength can rise by 88.5%. The conclusions suggest that optimizing mix ratios can enhance FC's tensile and compressive capabilities, improving its application in civil engineering [3].

Plain concrete is fragile and requires careful attention to its flexural and split tensile strengths, as it is weak in tension but strong in compression. To enhance these properties, builders incorporate various fibers. Steel fibers are common but prone to rust, while CF offers corrosion resistance, is lightweight, and has high tensile strength, making them suitable for FRC. Despite these advantages, the use of CF in construction remains limited. This study examines these constraints and explores CF's potential in restoration and repair projects, focusing on its strength, toughness, and flexural properties [4].

Yanying Bai, Yuan Jia, and their team have highlighted significant environmental issues, such as red mud (RM),carbide slag (CS), and fly ash from municipal solid waste incineration (MSWIFA). This study builds on a previous method using RM and CS activated by MSWIFA to create cement-like material, now enhanced with polypropylene fibers and iron tailings sand to develop FRC. It investigates how various factors, such as cementitious materials, aggregates, and fiber characteristics, impact concrete's resistance to impacts. A two-parameter Weibull distribution model was created to predict damage over time. Findings indicate that while cementitious material has minimal impact resistance, adding fibers significantly improves it, changing the failure mode from brittle to ductile. Notably, 12 mm long mesh polypropylene fibers at 1.0% volume showed outstanding impact resistance, with initial and final crack counts increasing by 136.4% and 200.0% compared to control concrete. These results suggest new ways to reuse waste materials and provide a theoretical basis for using waste-based RFC in construction [5].

CFs enhance concrete strength, and eco-friendly concrete, made from industrial by-products, is gaining popularity. This study uses tests and simulations to investigate CF-reinforced eco-friendly concrete (CFREFC) for 3D printing. Nine CFREFC mixes were tested by varying water-binder (w/b) ratios and superplasticizer (SP) amounts. Key findings showed a relationship between workability and printability, with the M7 mix (w/b = 0.4, SP = 0.5) crucial for simulations. Printability was optimal, consistent with 56.34 and 65.61 mm, and fluidity between 172.18 and 183.30 mm. For successful 3D printing, consistency must be between 48.99 and 81.96 mm and fluidity between 166.72 and 200.93 mm. As more layers were printed, deformation was observed, consistent with the experimental results [6].

Firas Hassan Saeed, Farzad Hejazi, and their team developed a method to strengthen RC slabs using CFRP rods with an Ultra-High Performance FRC (UHPFRC) jacket and a Mechanical Anchorage System (MAS). The MAS, consisting of high-carbon steel plates and a Mechanical Expansion Anchorage Bolt System (MEABS), prevents early debonding. They tested three types of slabs—control, UHPFRC jacket only, and CFRP rods with UHPFRC jacket—under cyclic loads. Results showed the new method significantly enhanced load-bearing capacity and delayed diagonal cracks, with ultimate load capacity increasing by 82% with CFRP bars. The team also created Finite Element and analytical models that closely matched experimental data, confirming the method’s reliability. Overall, this approach effectively improves RC slab performance and reduces debonding risks [7].

In this study, Jingting Huang, Peng Gao, and their team examined the performance of circular RC columns during earthquakes by varying concrete strength. They tested twelve columns—eight confined with FRP (basalt FRC and CFRP) and four without—using strengths of concrete ranging from 22.4 MPa to 57.8 MPa. Results indicated that all confined columns failed due to bending, but confinement significantly enhanced their strength, flexibility, and energy absorption. While BFRP and CFRP confined columns reached similar peak loads, BFRP columns with lower and moderate strengths exhibited better ductility and energy absorption. Conversely, CFRP columns at the highest strength performed slightly better than those confined with BFRP. The research also offered equations for determining the load-bearing and ductility capabilities of circular reinforced concrete columns confined with FRP [8].

BA. Solahuddin, F.M. Yahaya CFRP composite material significantly enhances the structural behavior of RC beams(RCB) when used as external reinforcement. This review paper summarizes the benefits of CFRP in strengthening RCBs. Experimental studies and numerical modeling indicate that CFRP improves flexural strength, Young's modulus,stiffness, load-deflection behavior, load-axial performance, ultimate load capacity, failure mechanisms, stress-strain distribution, and fracture patterns. Due to its high strength,load-bearing capacity, corrosion resistance, adhesive qualities, and anchoring capabilities, CFRP is an effective reinforcement material. Its use in civil and structural engineering, particularly in the construction industry, enhances the structural performance and behavior of RCBs [9].

Vikas Choudhary and Haobam Derit Singh highlight the significant impact of concrete on the global carbon footprint, prompting the search for sustainable alternatives like Self-Compacting Concrete (SCC). SCC flows naturally, saving time, labor, and energy in construction. Research indicates that adding CFs improves the properties of concrete, enhancing its flow and compressive and flexural strength. This paper investigates the fresh and hardened qualities of SCC with CFs, using tests like the V-Funnel and Slump Flow for fresh properties and compressive and flexural strength tests for hardened properties. CFs were mixed into SCC at 0.1%, 0.15%, and 0.20%, with optimal results at 0.15%.[10].

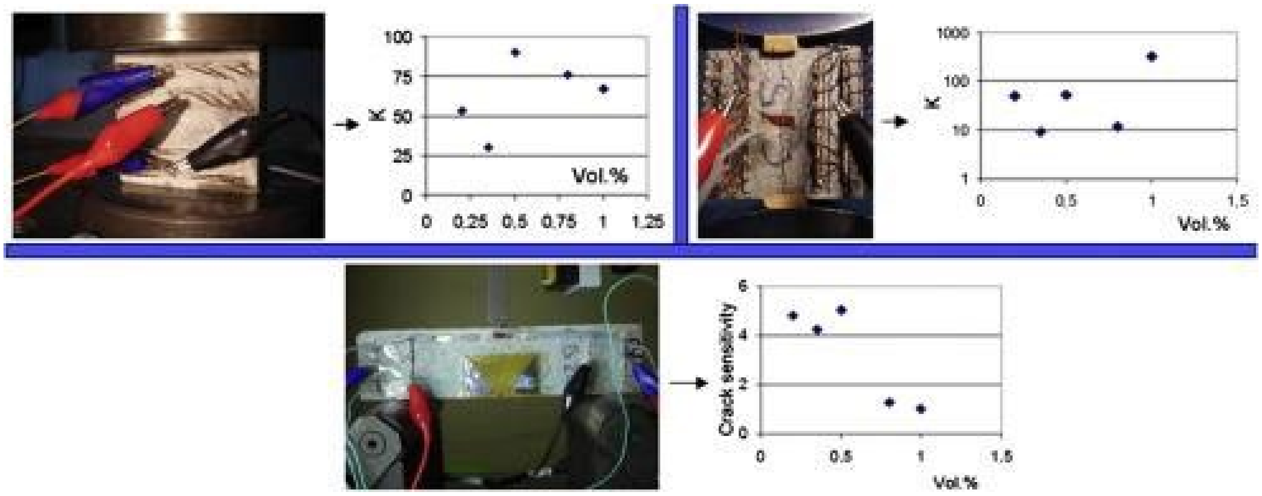
Dawei Liu, Fengjiang Qin, and their team studied the improvement of RC beams using carbon fiber reinforced polymer (CFRP) mixed with engineering cementitious composite (ECC). While CFRP alone caused layers to peel, adding ECC resolved this issue. This combination enhanced beam performance, increasing cracking load by 23–31%, yield load by 4–6%, and ultimate load by 5–10%, improving stiffness, flexibility, and energy absorption. The prediction model demonstrated high accuracy, with less than a 5% difference between predicted and tested bending capacities [11].

This study by Rawan Al-Shamayleh and Huda Al-Saoud investigates the performance of RC beams strengthened with two types of CFRP composites: laminates and sheets. The researchers tested twenty-four full-scale beams with compressive strengths of 17, 32, and 47 MPa and applied CFRP in six different ways. Results indicated significant increases in shear and flexural strength, though effectiveness diminished with higher concrete strength. Beams wrapped in CFRP U-wraps had a shear strength increase of 28.9% to 29.6%, while those with laminate strips increased by 14.4% to 23.8%. Flexural strength improvements ranged from 22.4% to 46.2% for half U-wraps and 17.8% to 38.4% for laminate-strengthened beams. The study also highlighted discrepancies between experimental results and theoretical predictions from ACI 440.2R-14 due to the equations' practical nature [12].

Fernando Cos-Gayón López, Javier Benlloch Marco, and others highlight that corrosion in reinforced concrete can cause significant economic issues. To mitigate this, using materials resistant to water, like CFRP bars, is preferable to traditional steel. This study examines the bond strength of CFRP bars with concrete under high temperatures and extended exposure. The experimental plan includes pullout tests on CFRP rods at different ages and thermal conditions, comparing them to ribbed steel bars and sanded surfaces. Compression tests were also performed on the same concrete mixes. Results indicate that high temperatures significantly reduce the bond strength of ribbed CFRP bars, while sanded CFRP bars remain unaffected. The discussion focuses on the differences in behavior and the impact of high temperatures on concrete strength at 180 days [13].

Tan D. Le, Thong M. Pham, and others studied CFRP tendons as alternatives to steel tendons in precast segmental prestressed concrete beams for elevated bridges, addressing steel's corrosion issues. They tested four large T-shaped beams with different tendon bonding and joint conditions under four-point loading. Results indicated that CFRP tendons effectively replace steel with strong load capacity and flexibility. Bonding influences bending ability, while joint type affects initial stiffness but not overall capacity. Unbonded tendons lose strength at ultimate loads for various reasons. AASHTO-1999 accurately predicted tensile stress for bonded tendons but was less reliable for unbonded ones. The researchers proposed an empirical formula for predicting deflection in beams with unbonded tendons, which aligned well with experimental results [14].

Egemen Teomete developed five types of cement mixed with 13 mm long carbon fibers, varying the fiber amount in each mix. He cast six 5 cm cubic samples and three 4 × 4 × 16 cm prism samples for compression, split tensile strength, and notched bending tests while measuring electrical resistance. A strong correlation was found between strain and electrical resistance changes, with notable effects at the percolation threshold, influencing the highest gauge factor. He also explored the microstructure mechanisms and innovatively combined mechanical tests with crack length measurements, strain, and simultaneous electrical resistance [15].



João P. Firmo, João R. Correia, and others studied the fire behavior of RC beams strengthened with carbon CFRP laminates. They aimed to test various fire protection systems for building floors using a medium-sized furnace. They focused on calcium silicate boards and cement-based mortar with vermiculite and perlite applied to the beams' undersides in 25 mm and 40 mm thicknesses. The team insulated the CFRP laminate anchorage zones and monitored deflection and temperature during tests. Without protection, anchorage debonded after 23 minutes, while with fire protection, debonding occurred after 60 to 89 minutes for 25 mm and 137 to 167 minutes for 40 mm thicknesses. They developed thermal models that predicted temperature distribution within the materials, aligning well with experimental results [16].

This study by Antanas Laukaitis, Jadvyga Kerienė, and their team examines the impact of CF additives on the structure and properties of autoclaved aerated concrete (AAC) under different mechanical treatments. Various processing methods were used to create different sizes of CF particles. The findings reveal that smaller CF particles enhance the crystallinity of the AAC binding material, resulting in a 6–22% increase in compressive strength, a 5–20% reduction in thermal deformation at 700°C, and a 7–20% reduction in mass loss. Adding 0.1% untreated CF increased flexural strength by 29%, but mechanically treated CF showed diminishing returns, with strength increases dropping from 21% to 4% as particle size decreased. The study indicates that smaller CF particles improve the overall performance of AAC through enhanced crystallinity [17].

Habibur Rahman Sobuz, Ehsan Ahmed, and their team demonstrated that CFRP sheets can effectively repair and strengthen RC structures. They tested fourteen RC beams reinforced with CFRP sheets and subjected them to four-point bending tests. The study explored various strengthening methods and applied sustained loads on uncracked and cracked beams. They measured the ultimate strength increase by adjusting the number of CFRP layers and adding end anchorage. A deflection reduction coefficient was proposed to assess stiffness post-cracking. The

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analytical values obtained through the effective modulus method (EMM) were generally conservative compared to experimental outcomes. A graphical abstract compared experimental and analytical results for the deflection performance of cracked RC beams reinforced with one or three CFRP layers, with and without modified tension stiffening methods [18].

Umit Serdar Camli and Baris Binici investigated using FRPs to enhance reinforced concrete structures. They found FRPs easy to apply and had a high strength-to-weight ratio. Their study involved 57 double-shear push-out tests to assess the strength of CFRPs on concrete prisms and hollow clay tiles, both with and without a plaster finish. Results indicated that plaster weakens the bond between CFRPs and masonry, and CFRPs on hollow clay tiles were significantly weaker than those on concrete. Embedded anchors as shear connectors notably increased CFRP strength, regardless of plaster finish. The researchers also created a simple strength model based on their findings, integrating it with existing data and models [19].

Patrick X.W. Zou and Shouping Shang highlight the increasing interest in CFRP for strengthening concrete structures due to their rust resistance and high strength. While research has focused on testing, there is a need for better theoretical understanding. This paper presents a method to predict the time-dependent behavior of concrete beams prestressed with CFRP tendons, examining concrete strains, curvature, deflection, and prestress loss under constant loads. The findings, illustrated with three examples, show that CFRP's performance is comparable to steel tendons, making it a viable alternative for concrete prestressing [20].

Wei Wang, Sigang Wu, and their team studied the behavior of CFRC under four-point bending to assess its fatigue life and deformation. They discovered that CFRC's fatigue deformation occurs in three stages with increasing fatigue life. As load cycles progress, residual resistance builds up; higher stress accelerates strain and fatigue damage, leading to significant changes in residual resistance. This suggests that measuring residual resistance can predict CFRC's fatigue life [21].

Conclusions

1. CFRC exhibits three fatigue stages similar to plain concrete. Adding fibers reduces cracking and enhances durability and energy absorption.
2. Damage in CFRC can be monitored through changes in electrical resistance, with increased loads leading to higher strain.
3. The study found that adding fibers enhances CFRC's mechanical properties, particularly tensile strength, although excessive fiber can decrease strength.

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