International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 10 | Oct 2020 www.irjet.net p-ISSN: 2395-0072

Applications and Future Trends of Carbon Fiber Reinforced Polymer Composites: A Review

Bhaskar Dhiman[1], Vijay Guleria[2], Parikshit Sharma[3]

[1]*Assistant Professor, Mechanical Engineering, Abhilashi University, Mandi, H.P., India*
[2]*Assistant Professor, Mechanical Engineering, T.R. Abhilashi M.I.E.T., Mandi, H.P., India*
[3]*Associate Professor, School of Basic Sciences, Abhilashi University, Mandi, H.P., India*

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Abstract – *Nowadays in the engineering field, conventional metals are being largely replaced by composite materials due to their great mechanical behaviors. Among all composite materials, carbon fiber reinforced composites have proved to be a phenomenal success and also called superhero of the material world due to their impressive chemical, electrical, mechanical, thermal properties and best strength to weight ratio. Material selection for particular structures plays a major role in the success of any industry as well as for safety aspects. CFRP has a wide area of applications including aeronautics, automobile, manufacturing, chemical and electronic industries, wind power plants, sporting goods, naval, nuclear sector, etc. This review attempts to study various applications and future trends of CFRP for structural applications worldwide.*

Key Words: Carbon Fiber Reinforced Polymers (CFRP), Carbon Fiber Composites, Light Weighting Polymers, High Strength, and High Modulus Polymers.

1. INTRODUCTION

Fibers which contains at least 92 weight % of carbon are called carbon fiber, while if carbon percentage is 99 weight % known as graphite fiber ***[5]***. It possesses strength up to five times that of steel and being one-third of its weight. Carbonaceous materials with a diameter of 5-10 µm and in fibrous shape are popularly called carbon fibers [CFs] ***[12]***. CFRP composites are prepared by the pyrolysis of organic fibers in which carbon fibers constitute the elemental phase ***[9]***. CFs are highly inert to chemical degradation and highly stable ***[32]***.

Carbon fiber consists of carbon atoms bonded together to form a long chain. They are considered excellent building materials for any high-end structures due to their high stiffness, low weight, high strength, and other suitable properties ***[32]***. While comparing CFRP with steel or plastics the strength to weight ratio and stiffness to weight ratio of a carbon fiber part is much higher. Particularly in structural designs, the addition of more weight may lead to unsatisfactory performance or total failure so CFRP preferred instead of any traditional metal or material ***[33]***. We can achieve greater fuel efficiency, more safety, and high speed by decreasing the weight of automobiles in the transportation sector by using carbon composites ***[34]***.

Carbon fibers mostly used as reinforcements in composite materials like in carbon fiber reinforced plastics, carbon-carbon composite, carbon fiber reinforced materials, and carbon fiber reinforced cement due to its highest specific modulus and highest specific strength among of all reinforcing fibers ***[38]***. Carbon fiber composites are best suitable for critical situations where strength, stiffness, lower weight, outstanding fatigue characteristics, stress rupture failures, high temperature, good electrical conductivity, thermal conductivity, low linear coefficient of thermal expansion, chemical inertness, and high damping, etc. are important ***[2]***. CFRP has a great capacity to give a sustained performance under harsh and varying environmental conditions ***[3]***.

2. OBJECTIVES

The aims and objectives of the present study are as follows: -

- **a.** To study the CFRP in detail.
- **b.** To investigate various applications and future trends of CFRP.
- **c.** To analyze the economical and environmental effects of CFRP.
- **d.** To review an increase in safety measures by using CFRP.
- **e.** To discuss methods of reducing wastage and recycling of CFRP.

3. LITERATURE REVIEW

B. L. Klasson (1995) [1] studied some basic concepts of theory and practical experimental data for the practitioner concerning carbon fibers. Also, he has studied carbon fiber and fiber lamination techniques in especially for prosthetics and orthotics.

S. Chand (2000) [2] analyzed the various developments made in the field of high-performance lightweight CFs. He focused primarily on the aerospace industry and nuclear-related areas, where the performance is considered as the major factor as compared to the cost factor.

Bhavesh G. Kumar et. al (2002) [3] conducted an experimental investigation to characterize the physical, chemical as well as mechanical degradation of carbon fiber composite exposed to UV radiation and water vapor condensation.

M. C. Kuo et. al (2003) [4] lightened the performance of low-density magnesium-based laminated composites. They fabricated material utilizing AZ31 Mg with the carbon fiber through hot pressing.

Xiaosong Huang (2009) [5] reviewed polyacrylonitrile and mesosphere pitches are the two most useful carbon fiber precursors. He studied how carbon fiber strength can be improved by optimizing its microstructure.

S. R. Bakshi (2010) [6] carried out the work related to carbon metal matrix composites. They achieved mechanical property improvements by the addition of carbon nanotube inlet of matrix systems for various metals.

Soraia Pimenta et. al. (2011) [7] summarized various environmental and economy-related factors important in the recycling of reinforced carbon fiber polymer waste. They focused on re-manufacturing processes, reclamation, and the commercialization and specific applications of recycled CFs goods.

Gururaja M N et. al (2012) [8] investigated hybrid composites for a better knowledge of the phenomena associated with cutting-edge technology. They studied glass and carbon fiber composites in detail.

Soo-Jin Park et. al. (2012) [9] found carbon fibers are great material having high strength, high stiffness, and low weight thus they are having great significance for the aerospace industry. They realized that carbon fibers can provide remedial solutions for many problems associated with the deterioration and strengthening of infrastructure.

G.V. Mahajan et. al. (2012) [10] investigated various composites that have attractive internal and outer material properties that can be utilized in the automobile sector and aerospace programs. They realized that composite uses require an integrated approach between user and designer/manufacturer to ensure functionality.

Francisco Lopez Jimenez et. al. (2013) [11] presented their study on implications of carbon fiber silicone composites in the design of space structures. They concluded deployable materials made of these carbon fiber materials can be packed effectively and tightly.

Ting Lee et. al (2014) [12] concluded that activated carbon fiber is one of the best absorbents in adsorption applications because of its considerable advantages over other commercial storage materials. They found that activated carbon fiber is a promising microporous material with a great fiber shape and having a good defined porous structure.

Pardeep Ranga et.al. (2014) [13] investigated practical uses and applications of various fibers as reinforcement in composites. With the innovation in science and technology, the new means of depiction and evaluation of physical, chemical, thermal, and mechanical properties of the composite have been used that have explored the new scope of utilizing them for various purposes.

Varun Katyal et.al (2014) [14] observed the electrical and mechanical behavior and various properties of the carbon composite materials. They found major causes of composite failure in composites are due to delamination and fiber pullout.

Halil L. Tekinalpa et. al. (2014) [15] studied highly oriented carbon fiber polymer composites via a technique called additive manufacturing. They distinguished additive manufacturing techniques from traditional manufacturing by its great ability to deal with complex shapes with better design flexibility and without serious waste.

Mohit Sharma et. al. (2014) [16] concluded how CFRP has a great ratio of mechanical performance to weight. They suggest these smart materials should be preferred under critical situations for advanced structural applications.

S. Tiwari et. al (2014) [17] concentrated on various methods and techniques which can be used to surface treatment of the carbon fiber. They discussed how treatment leads to the improved surface area of the fiber surface, chemical bonding, and adhesion between fiber and matrix.

Jayanta Bandyopadhyay et. al (2015) [18] called the carbon fiber “the superhero” of the material world. They discussed how the carbon fiber achieved phenomenal success due to its great ability to combine with other materials to form a suitable composite structure.

Midan L et. al (2015) [19] prepared carbon fibers through hot compression molding of phenolic resin with natural graphite powders. They investigated mechanical and tribological aspects related to the percentage of carbon content in various composites.

Layth Mohammed et. al (2015) [20] compared natural fiber reinforced polymer composites with synthetic composite products. They evaluated the behavior and properties of natural fiber reinforced polymer composites.

M. Shinohara et. al (2015) [21] discussed the benefits and importance of the carbon fiber composite materials in the aerospace as well as the automobile sector. They showed results on how by using these composite lightweight materials productivities can be enhanced.

Fan-Long Jin (2015) [22] reviewed various experimental studies considering many surface treatment techniques for carbon fibers. They discussed methods of preparation and enhancement in properties for reinforced carbon fiber thermosetting materials.

Saleel Visal (2015) [23] worked on non-destructive testing and thermography by pulsed Eddy current for the carbon fiber composite materials. They concluded mechanical behavior and properties of these materials can be changed without a considerable reduction in electrical properties.

N. Ozsoy et. al (2016) [24] carried out an experimental study for carbon fiber composites for calculating tensile, bending, impact, and hardness properties. They tested hardness increased with the increasing amount of carbon fiber in composites.

Amaninder Singh Gill et. al (2016) [25] presented a cost estimation model for carbon fiber manufacturing based on polyacrylonitrile. They concluded this model can play a major role in the manufacturing of carbon fiber composites in a cost-effective method.

Sohel Rana et. al (2016) [26] reported an overview of health and performance monitoring of engineering structures by self-sensing composites. They discussed how these smart composites showed a detectable change in their electrical resistivity with applied stress or strain.

Eduard Kessler et. al (2016) [27] focused on the effect of thermal load on the mechanical behavior of basalt fibers and their composites. They have carried out the thermal analysis of carbon fibers for their unidirectional properties and tensile strength.

Yu-Chien Ho et. al (2017) [28] carried tests to investigate the mechanical behavior of the laminated carbon-fiber-reinforced plastic sheets. They developed multilayer plastic sheets by CFRP with various thicknesses.

Fang Liu et. al (2017) [29] showed the effect of various content particles on the compressive property of fibers. They showed that rigid nanoparticles have evident strengthening effects on the compression and flexural responses of the carbon fiber composite laminates fabricated from fabrics.

Dany Arnoldo Hernandez et. al (2017) [30] analyzed morphological characteristics of CFs in tension by using the electron microscopy scanning technique. They have done a micrograph analysis of CFRP before tensile tests to investigate intrinsic manufacturing defects, which can affect the properties of the composite.

V. L. Kadlag et. al (2017) [31] attempted to review applications of fibers reinforced polymer composite in the automotive industry and opportunities of FRP composite towards the industrial environment. They studied uses of carbon fibers in the chemical and aircraft industry, wind power plants, high-end sporting goods, marine, etc.

Prashanth S. et. al (2017) [32] presented a comparative analysis of various kinds of synthetic fibers and their importance as potential reinforcements for CFs. They studied various manufacturing methodologies to develop fiber-reinforced composite systems.

Pooja Bhatt et. al (2017) [33] studied applications of carbon fibers for the structural design field. They suggested these composites are the best building materials with suitable chemical, electrical, and mechanical properties.

R. Masilamani et. al (2017) [34] discussed the composite material used in the production of automobiles which has the greatest impact on fuel economy, high speed, and safety concerns. They concluded carbon fibers are lighter than the conventional materials and can be more beneficial for cost-effective production.

S.R. Naqvi et. al (2018) [35] investigated the utilization of CFRP in automotive, aerospace, and many other engineering fields. Also, they have discussed the negative impact of composite materials on an environment.

Shubham S Narwade et. al (2018) [36] examined the ability of a woven carbon fiber reinforced fabric wrapping to enhance the strength of various building components. The few concrete cubes were cast and were carbon wrapped to check the increase in strength.

Navya H A et. al (2018) [37] concluded that the modern construction world needs composite materials for future betterment. They studied the effect of doping the carbon composite on the concrete to enhance its properties.

A. Manikanta et. al (2018) [38] compared the normal concrete with the special concrete which contains carbon fiber. They concluded mechanical properties of the concrete can be enhanced by adding sea sand and seawater.

Pankaj Thakur et. al (2018) [39] presented a review on research carried in the field of CFs reinforced concrete, which includes experimentation studies, strength and, the effect on carbon fibers. They suggested adding carbon fibers into concrete to increase its tensile strength.

Elias Randjbaran et. al (2018) [40] highlighted various opportunities for innovation of new material frameworks in the field of carbon fiber composites. They examined different parameters that influence the reinforcing components in polymer fiber composite frameworks as a component of preparing.

Mohammad Faisal Haider et. al (2018) [41] studied damage caused in dielectric fibers matrix due to the flowing current. Due to the effect of the current state of material changes and significant change in the electrical and mechanical properties was observed.

Simon Hamblyn (2018) [42] documented the use of CFs in the aviation and automotive industries. They investigated the use of CFs composite materials for the manufacturing of shielding materials, corrosion resistive material, printing press, and printer rollers.

Belal Alemour et. al (2018) [43] provided a comprehensive review of electrical properties of conductive carbon composites, and how these composite materials can be utilized to improve and enhance the electrical properties of some polymers such as epoxy resin to be used in more applications.

A. Kausar (2019) [44] presented a state-of-the-art review on polyamide/carbon fiber composites. They stated various applications of carbon composite materials in the field of aerospace, automobile, construction, and other industries.

Abbasali Saboktakin (2019) [45] covered 3D textile accomplishments and composite specifications and various types of damages in these materials. NDT techniques developed for detecting defects in 3D preforms and composite were presented.

Belal Alemour et. al (2019) [46] presented various problems that aircraft faces in the air. They discussed the contribution of composite materials towards reducing their weight and gain more efficiency.

D. Suresh et. al (2019) [47] discussed how adding graphite powder in the CFs composite increases the mechanical behavior of the resulting specimen. They concluded that the inclusion of graphite powder in CFs reinforced epoxy composites increases its properties compared to the untreated one.

Suhyun Lee et. al (2019) [48] prepared various types of CFRP with improved mechanical behavior and electrical properties. They showed the electrical behavior of the composites was improved significantly with the addition of carbon fibers.

Yingwu Zhou et. al (2020) [49] researched the dual function of a carbon fiber-reinforced polymer bar working as reinforcement and impressed current cathodic protection anode for reinforced concrete structures.

Sankar Gopalraj et. al (2020) [50] proposed various recycling techniques for carbon fiber waste and prioritize the sustainably identified recycling methods based on economic and environmental values.

Anthony R. Bunsell et. al (2020) [51] explained how damage accumulation in many major composite structures is dominated by fiber failure but that the viscoelastic nature of the matrix induces time effects including delayed failure.

Deepak M.V.S. et. al (2020) [52] provided an orientation to optimize the present-day kevlar materials and a platform to explore and investigate new combinations. They contribute toward understanding the mechanical and tribological characteristics such as impact, tensile, wear, flexural, chemical, and thermal properties of various available fibers.

Arya Uthaman et. al (2020) [53] concluded that for long-term applications carbon fiber reinforced composites should be protected from acidic environments. They analyzed these composites thermally and mechanically for acidic reactions.

4. RESEARCH GAPS

Very less work is carried out on compassion between the conventional fibers and CFRP on basis of cost and productivity. Very less literature is available regarding the long-term service performance of CFRP. Big data collection on a large scale and performance analysis of CFRP as compare to natural or conventional fibers yet to be done properly worldwide. Literature regarding simulations of structures made of CFRP is yet limited. Very less research work available regarding the recycling and waste disposal for CFRP.

5. APPLICATIONS

Carbon composites show a significant change in their electrical behavior with applied external pressure. Due to this unique characteristic, they become useful for the health monitoring of engineering structures ***[26]***. Carbon fibers can be added to concrete to control the propagation of cracks, limit the crack width, and to increase its durability and strength ***[37]***. The carbon fiber reinforced concrete is made up of adding the CFRP to the normal concrete. Effective reinforcement leads to increase resistance against earthquakes ***[5]***. These materials have wide applications such as in the manufacturing of hybrid smart memory composites, aeronautical applications, wind power generation, marine applications, medical equipment and prosthetic devices, thermoplastic applications, for engineering constructions (bearings, gears, cams, fan, and turbine blades), in telecom applications, in automobile sectors, textile industries, in high-end sports equipment, for high-quality audio components and musical instruments, etc ***[38]***.

6. OPPORTUNITIES & FUTURE TRENDS

In the future, CFs research will be focused on cost reduction and property enhancements. As the research in the area of optimization of the crystallite size, shape, and distribution by changing processing parameters and their effect on the fiber properties is limited yet. Innovative cost-effective waste disposal and recycling methods are the major challenges for the CFRP field in the future. There will be large opportunities to recycle composite materials without causing any negative environmental impact. Quantitative analysis of intrinsic safety factors by using simulations for advanced composite structure based on a knowledge of the physical damage processes can be analyzed. There is an urgent necessity for the classification of all grades of composite materials based on their various properties, manufacturing techniques, and production costs. Economical and portable non-destructive kits to quantify undesirable defects in hybrid composites should be made.

7. SUMMARY

This work presents a detailed review of applications and future trends of CFRP composites in various fields. Through literature, we found CFRP significantly increases the life of structures, strengthened infrastructure, and minimized the maintenance requirements. Discrepancy related to tensile and compressive strengths of CFs observed in a significant amount. Therefore, integrated efforts may be used in the CFRP area to reduce the existing gap between theoretical and practically calculated tensile strengths, and work should be done to improve the compressive behavior of carbon fibers.

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BIOGRAPHIES

Er. Bhaskar Dhiman, M. Tech. from HPTU, 5 years of teaching experience in Mechanical Engineering. Research interests in design and optimizations.

Er. Vijay Guleria, M.E. Design from Pune University, 10 years of teaching experience in Mechanical Engineering, research expertise in machine design, system identification, vibration, and tribology.

Dr. Parikshit Sharma, Ph.D. (Physics) from H.P.U., More than 10 years of teaching experience, research expertise in material science, and nanotechnology.