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Carbon Fiber and Carbon Fiber Reinforced Epoxy Composites for Automotive Applications-A Review

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ABSTRACT

Lightweight materials have recently received much attention for the fabrication of various components for industrial usage, particularly in the automotive and aerospace fields. Nowadays, though, recycling epoxy-based composite at the end of its life is very complicated but due to its lightweight and enhanced properties "fiber-reinforced" epoxy based polymer composites are most preferred materials instead of conventional heavy metals. The composites based on epoxy resins reinforced with high-performance fibers such as carbon fiber (CF) are in extensive use for industrial and structural applications. Moreover, Thermoplastics are less expensive, simple to work with and simple to recycle but they can't give desired properties like Thermosets. The current study encompasses about CF and multiple attempts done over the decades to enhance the mechanical attributes of CF-reinforced thermo-set (epoxy) based composites and to understand the part of many parameters on their performance.

1. Introduction

Carbon fibres have a carbon substance of at least 92% by Weight (Wt), whereas graphite fibres have a carbon content of 99% by weight [1]. It is 5 times stronger than steel and one-third the weight. Carbon fibres [CF] [2] are carbonaceous substances having a dia. of 5-10 micrometers and a fibrous structure. CFRP composites are created by the pyrolysis of organic fibres, with carbon fibres serving as the primary phase [3]. Chemical degradation of CFs is relatively slow and stable [4]. Carbon fiber is made up of carbon atoms that are linked together to create a lengthy strand. Because of their high rigidity, low weight, great strength, and other relevant features, they are regarded as outstanding building materials for any high-end structure [4]. The strength to weight ratio and specific stiffness of a carbon fiber component are significantly greater than that of metals or polymers. As a result, CFRP is favored over any conventional metals or polymers since increasing weight, mainly for structural designs, frequently occurs in subpar performance or complete failure [5]. By utilizing

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carbon composites to keep the weight down, it is possible to enhance the performance, safety and fuel economy of vehicles in the transport sector [6].

Carbon fibres are commonly employed as reinforcement in composite materials such as, carbon-carbon composites, and carbon fiber reinforced materials, carbon fiber reinforced polymers due to their maximum specific strength and modulus of all reinforcing fibres [7]. For use in automotive applications, Carbon fiber composites are ideal because of their lighter density, maximum strength, good fatigue characteristics, stiffness, high electrical conductivity, stress fracture failures, thermal transfer, chemical inertness, elevated heat, and low linear coefficient of expansion, among other properties [8]. CFRP has a strong capacity to perform in a variety of challenging and changing environmental situations [9].

There is a growing realization that greater attention should be made to the research of carbon fibres and carbon fiber reinforced epoxy composites filled with different fillers to improve properties. The purpose of this review is to study about carbon fiber (CF), manual hand lay-up process and to study the various research findings of researchers on the behavior of epoxy-based hybrid composites reinforced with CF and other micro and nano-fillers. With the addition of reinforcement particles and CF to the epoxy matrix, all of the composite's properties were improved while the density of the composite was reduced. The impact of the category, size, and form of the reinforcing materials (CF and fillers) on the properties of epoxy-based hybrid composites is investigated, as well as the probable causes of increases/decreases in physical/mechanical properties were reported.

2. Objectives

The objectives of present review article are shown in Figure 1 are as follows:

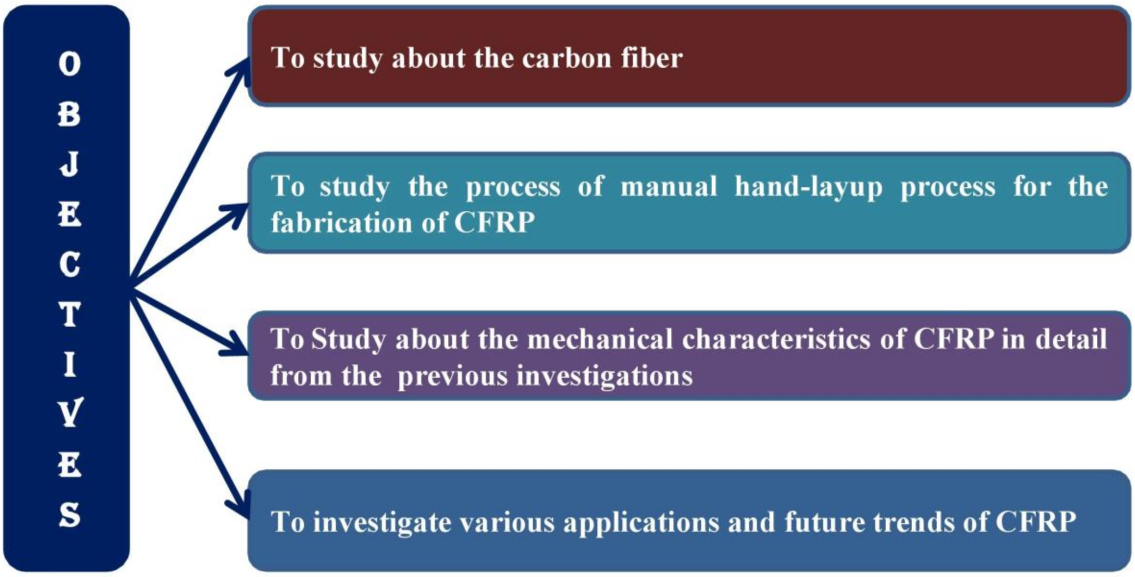

Fig. 1. Objectives of Present Work

3. Literature Review on Carbon Fiber (CF) and CF Reinforced Epoxy Composites

3.1 Carbon Fiber

A carbon fiber is a fibrous carbon material with a tiny graphite crystal structure that is formed from the fibrillation of acrylic resin, a popular textile material, or from oil/coal pitch and then is subjected to a specific heat treatment. Carbon fibers in industrial manufacturing are divided into three types: PAN-based, pitch-based and rayon-based. Among these, PAN-based carbon fiber is the most widely produced and utilized. In Japan, commercial manufacturing of PAN-based and isotropic pitch-based carbon fibres began on a considerable scale in the early 1970s. Anisotropic pitch-based carbon fiber producers entered the market in the second part of the 1980s. As a result of relentless scientific advancement and commercial development, Japanese carbon fiber producers have maintained their position as the world leader in carbon fiber quality and manufacturing volume.

The use of carbon fiber alone is not the rule. Customers frequently use carbon fibers for reinforcement and/or functionality in composite materials produced with a resin, ceramic or metallic matrix. Carbon fibers are widely used in a wide range of situations due to their superior mechanical properties (specific tensile strength, specific modulus) and other carbon-related properties (heat resistance, low density, chemical stability, low coefficient of thermal expansion, self-lubricity, etc.).

3.2 Type of Carbon Fiber Products

Due to their exceptional qualities, carbon fibres are used in a wide range of applications. By utilizing various raw materials and utilizing various production techniques, suppliers are able to offer a broad variety of fibres with various requirements. Figure 2 shows the list of several fiber varieties and their corresponding characteristics.

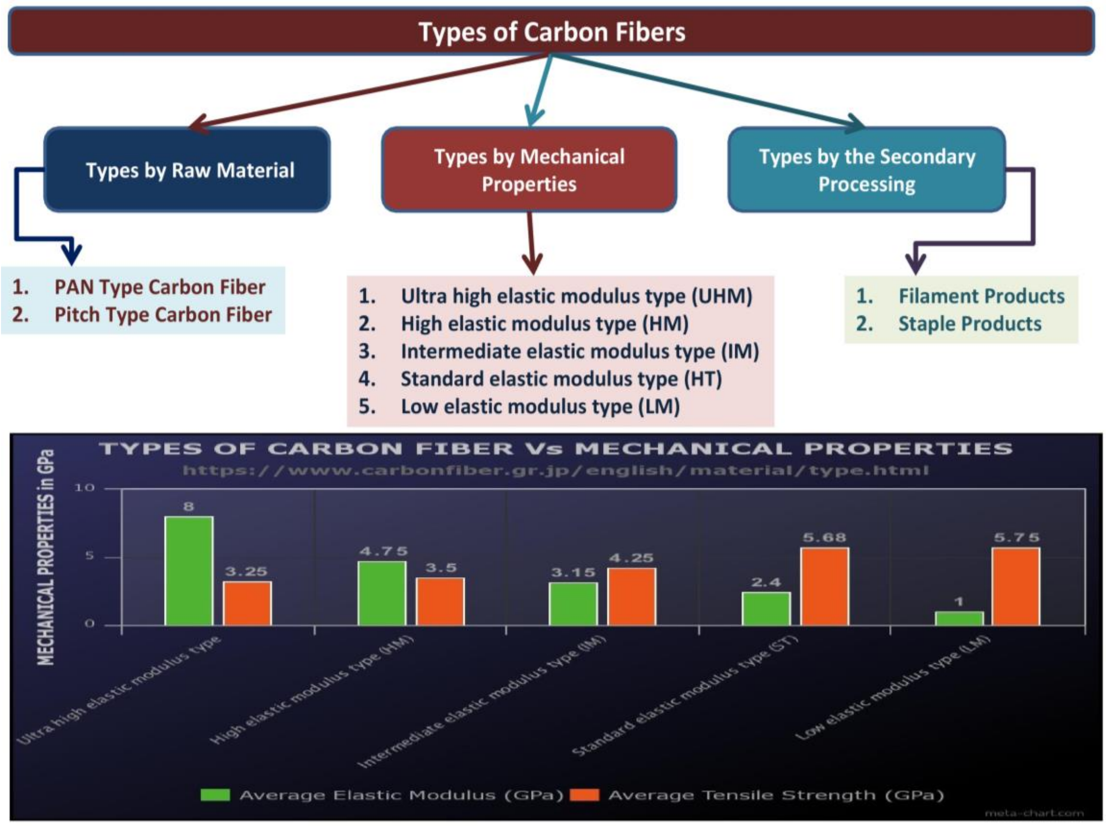

Fig. 2. Types of Carbon fibers and their mechanical properties

3.3 Special Features and Characterizing Performances of carbon fiber

"Light-weight, strong and long-lasting!" Carbon fibres are a high-tech substance from the twenty-first century. The fibres have a low specific gravity, excellent mechanical properties (relatively high ultimate tensile, high elastic modulus and so on) and compelling performance characteristics like heat resistance, electric conductivity, self-lubrication property, low thermal expansion coefficient, high heat conductivity, chemical stability, etc as shown in Figure 3. These characteristics have encouraged Carbon Fiber users to create a wide range of applications.

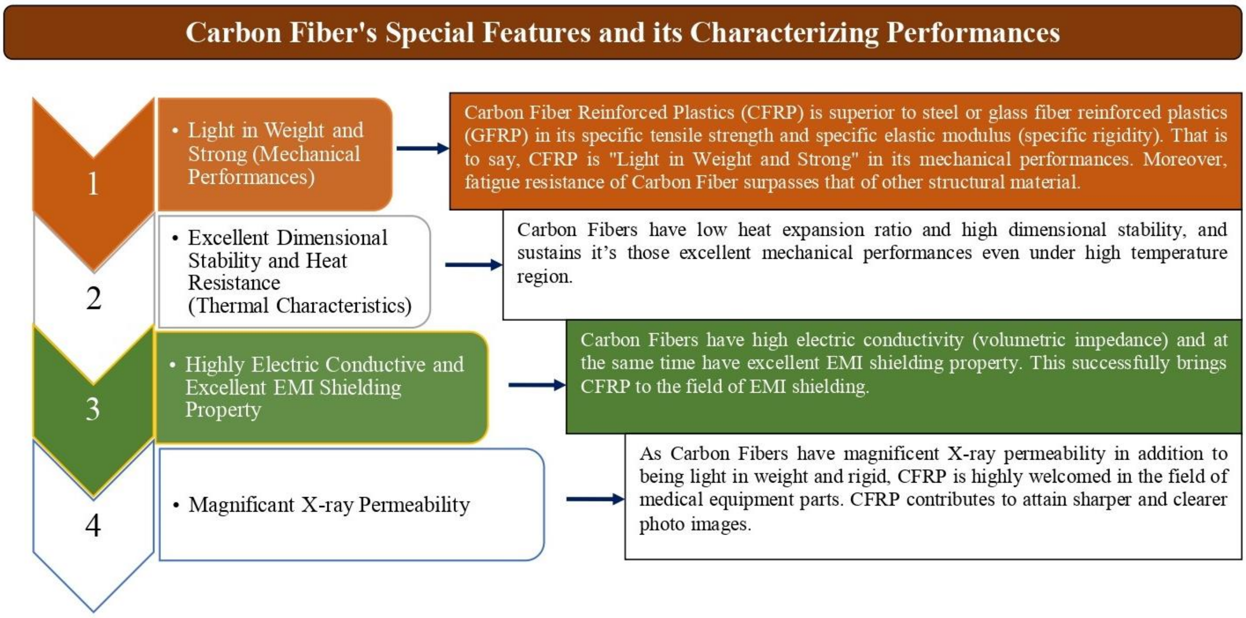

Fig. 3. Carbon fibers special features and characteristics

3.4 Manufacturing processes of carbon fiber

The following industrial procedures are used to fabricate carbon fibres as shown in Figure 4 and Figure 5. The fibres are produced by manufacturers under various processing settings to provide a variety of product grades.

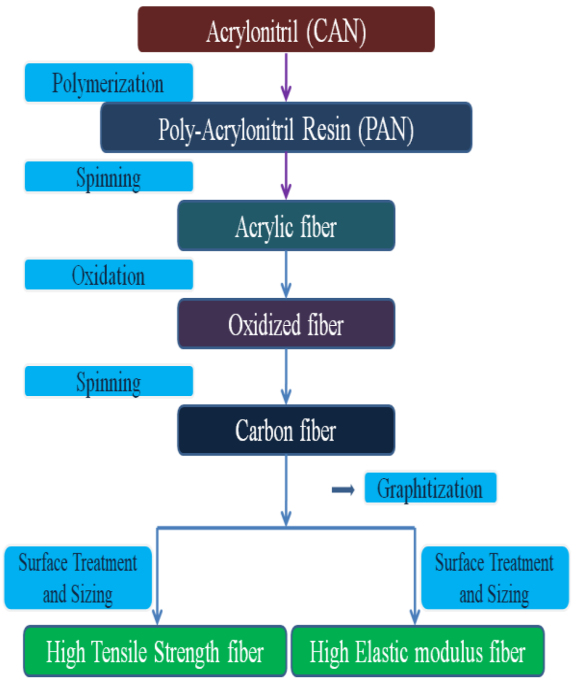

Fig. 4. Manufacturing Process of PAN type carbon fiber

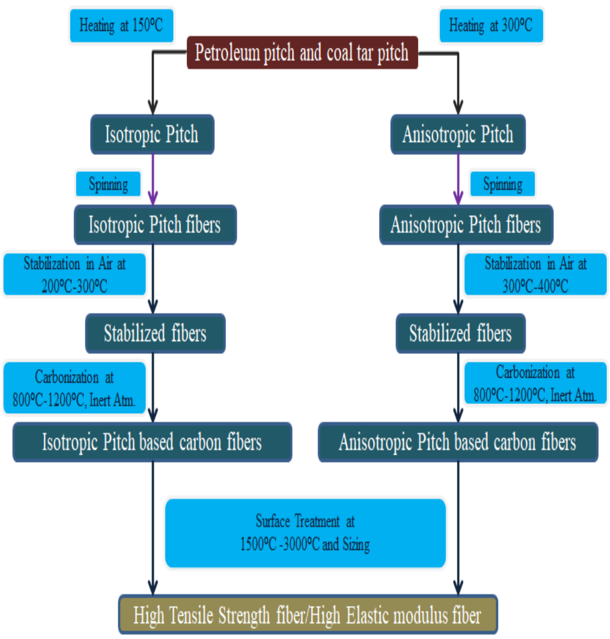

Fig. 5. Manufacturing Process of Pitch type carbon fiber

3.5 Types and uses of carbon fiber

Carbon Fiber users have created a wide range of applications for the fibres that make the greatest use of the fiber's advantageous features, as shown below in Table 1.

Table 1
Advantageous features

S. No	Type of Carbon Fiber	Usage
1	Filament/ Woven fabric	Resin reinforcing material for C-C Composites, CFRP and CFRTP, used in products including equipment for aircraft and space travel, sporting goods and industrial equipment.
2	Tow	Resin reinforcing material for C-C Composites, CFRP and CFRTP, used in products including equipment for aircraft and space travel, sporting goods and industrial equipment.
3	Staple Yarn	Anti-friction material, C-C composite parts and Heat Insulator
4	Braid	Particularly appropriate resin reinforcing material for tubular products
5	Chopped fiber	Compounding is used to enhance the mechanical properties, abrasion resistance, electric conductivity and heat resistance of polymers, resins or Portland cement.
6	Milled	Rubber or polymers that have been compounded to increase heat resistance, electric conductivity, abrasion resistance and mechanical performance.
7	Felt/ Mat	Rubber or polymers that have been compounded to increase abrasion resistance, electric conductivity, heat resistance and mechanical performance
8	Paper	Manufacturing of speaker-cone, electrodes, anti-electrostatic sheets and heating plates
9	Pre-Preg	Manufacturing of recreational products, industrial equipment and aircraft/aerospace parts that need low weight and high performance
10	Compounds	Manufacturing of "Housing and other OA equipment components" that benefit from electrical conductivity, stiffness and low weight

4. Process of Manual Hand lay-up Process for CFRP Fabrication

The earliest approach for creating woven fiber composites is the hand lay-up process [10]. A few stages are taken in the preparation of the samples. To prevent epoxy resin polymer from adhering to the mould surface, release anti-adhesive agent (mansion white wax polish/silicone spray) is first applied to the surface [11]. The mould plate is then covered with a thin plastic sheet to create a flat surface for the composite slab.

The woven CF reinforcement layers are cut into the necessary forms and put on the mold's surface. As a result, as was already described, the resin was combined with other materials and injected onto the surface of the CF reinforcement that was already set up in the mould [11]. The remaining CF mats are then positioned on top of the previous polymer layer and pressed with a roller to remove any trapped air bubbles and extra epoxy polymer. To produce a single mat, the mould is then shut and the pressure is let go. The Epoxy based woven CF composite is removed from the mould surface after it has finished curing at room temperature [12].

Figure 6 illustrates the hand lay-up concept. According to ASTM Standards, flat slabs of CFRP Composites are prepared as test specimens to determine the mechanical properties, wear behavior, and other structural properties.

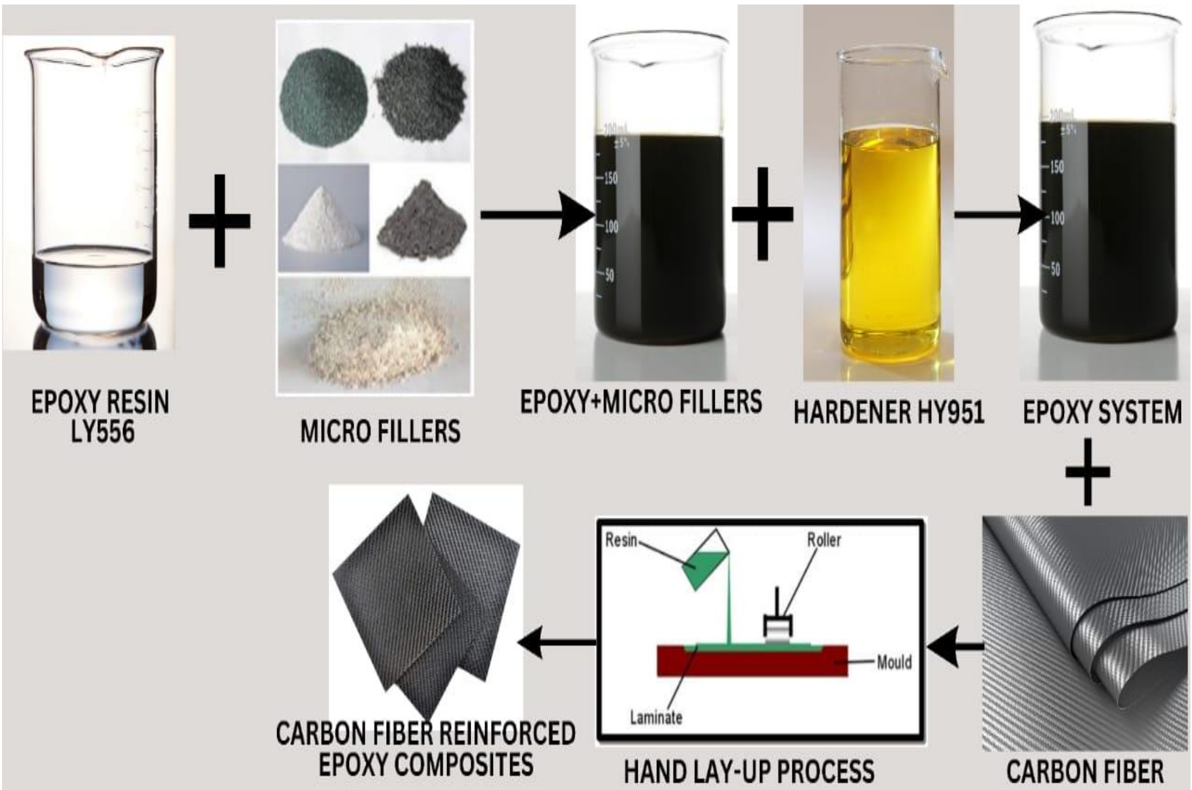

Fig. 6. Flow chart for Manual Hand lay-up process for CFRP Composites fabrication

5. Mechanical Properties of Carbon Fiber Reinforced Epoxy Composites

Initially, the CF-Epoxy composites were fabricated with 55 weight percentage (wt.) % T300 carbon fiber and 45 weight percentage (wt.) % LY-556 epoxy resin with no barite particle filler were used for control experiments. By changing the percentage of barite particles from 2.5 weight percent to 15 weight percent in increments of 2.5 weight percent, CF-Epoxy composites with barite filler were produced for mechanical characterization by Benin *et al.,* [13]. From the results, It is found that the greatest impact strength, tensile strength and hardness were produced by CF-Epoxy composites containing 10 weight percent barite particles. Compared to the CF reinforced epoxy composite without barite filler, the impact strength, tensile strength and hardness all increased by 18.68%, 13.18% and 5.6% respectively. It was found that the CF-Epoxy composite with 15 weight percent barite filler had a compressive strength that was more than twice as high as the CF-Epoxy composite without barite filler. However, as barite particles were introduced, the flexure strength steadily declined.

Suresha *et al.,* [14] developed epoxy-based carbon fiber (at 60 wt. %) reinforced composites filled with aluminum oxide/molybdenum disulfide fillers at 0, 5, and 10 weight percentages. They discovered that when the weight % of fillers increased, the Barcol hardness number risen. The hardness of the composites filled with molybdenum disulfide is greater than that of the unfilled and Alumina filled CF-Epoxy composites. Tensile and flexural strength are likewise high and increasing with the increase in MoS_2 filler concentration in CF-Epoxy composites when compared to unfilled or Alumina filled composites.

In this work, Liu *et al.,* [15] demonstrated that strengthening the matrix with stiff nano-particles considerably improves the compressive and flexural characteristics of carbon fiber/epoxy composites made using a VARIM technique. Because of the unique strengthening action of halloysite nano-tubes, the compressive and flexural characteristics of bulk matrices and composite laminates are substantially improved as a consequence of the introduction of halloysite nano-clay. The influence of filler content on the compressive characteristic of fiber/epoxy composites was more pronounced than in epoxies. The matrix behavior affects the compressive and flexural characteristics of CF-Epoxy composites significantly. Their strength and modulus both rise with stiff nano-particle concentration, but diminish by soft particle (CTBN liquid rubber) loading.

Suresh *et al.,* [16], Developed the CF-Epoxy Hybrid Composites filled with 0, 5 and 10 weight percentages of graphite powder to study the mechanical behavior. They found that the addition of graphite powder to the epoxy based carbon fiber composite improves the mechanical characteristics of the produced specimens. As a result, it is possible to say that CF-Epoxy composites containing graphite powder as a reinforcing filler exhibit enhanced characteristics when compared to unfilled Carbon-Epoxy composites. However, the percentage of filler particles and epoxy introduced to the CF has a significant influence on the interfacial qualities. The results of tensile, impact and flexural tests on several samples demonstrate that the addition of graphite powder in the CF-Epoxy composite enhances the tensile, impact and flexural strength by 15.9%, 32.11% and 23.18% respectively. Ali *et al.,* [17] Have developed the Carbon fiber (fixed weight percentage of 15)-Epoxy composites with the addition of fillers Alumina/ SiC/ Alumina and SiC. Due to this hybridization affect, the composite filled with (5 wt. % Al_2O_3+10 wt. % SiC) has exhibited the maximum Vickers hardness number of 69.6Hv.

Carbon fiber composite materials are produced by Baptista *et al.,* [18] Through the use of an epoxy matrix filled with graphite filler. Graphite filler is introduced in to the epoxy in amounts ranging from 5% to 30% by weight. The specimen was produced in conformity with the ASTM D638-14 specification. The results of the examination of every sample demonstrate that the samples with 7.5, 10 and 11.5 wt. %-graphite have the perfect balance of physical (deformability, strength, strain) properties, since the distribution of graphene particles seems to be more uniform.

CF-Epoxy composites with a fly ash as epoxy modifier were fabricated by Reddy *et al.,* [19]. On the basis of flexural testing and tensile testing as per Standard specification of ASTM, they found that, the sample with 6 grams of fly ash gain the higher tensile strength whereas, the sample with 8 grams of fly ash showcases the maximum tensile elasticity modulus and the sample with 4 grams of fly ash provides highest flexural strength. Many investigation works were carried out by the researchers on carbon fiber reinforced polymer based hybrid composites filled with various micro and nano fillers and the addition of these fillers to matrix has enhanced the mechanical characteristics. Enhancement in mechanical characteristics may be influenced by elements including manufacturing process, kind of reinforcement and fiber content. A very less work has been carried out on the CF-Epoxy composites which are filled with agro wastes as well industrial wastes as fillers.

6. Applications and Future Trends of CFRP

Carbon composites demonstrate an important variation in electrical activity when placed under external pressure. Due to their particular quality, they are beneficial for monitoring the condition of structural components [20]. To prevent fractures/ cracks/ flaws from growing and spreading, carbon fibers can indeed be incorporated into the concrete to reinforce and make it more resilient. Carbon - fiber - reinforced concrete is produced by blending CFRP with regular concrete. Improved earthquake resistance is attained through efficient reinforcing [21].

Numerous industries use these CFRP materials as shown in Fig.7, including the manufacture of musical instruments, hybrid smart memory composites, high-end audio equipment, aerospace, high-end sporting goods, wind energy, textile industries, engineering constructions (turbine blades, bearings, cams, gears and fans), marine, telecom and the automotive industries, medical and prosthetic devices, thermoplastic applications etc. [22-24].

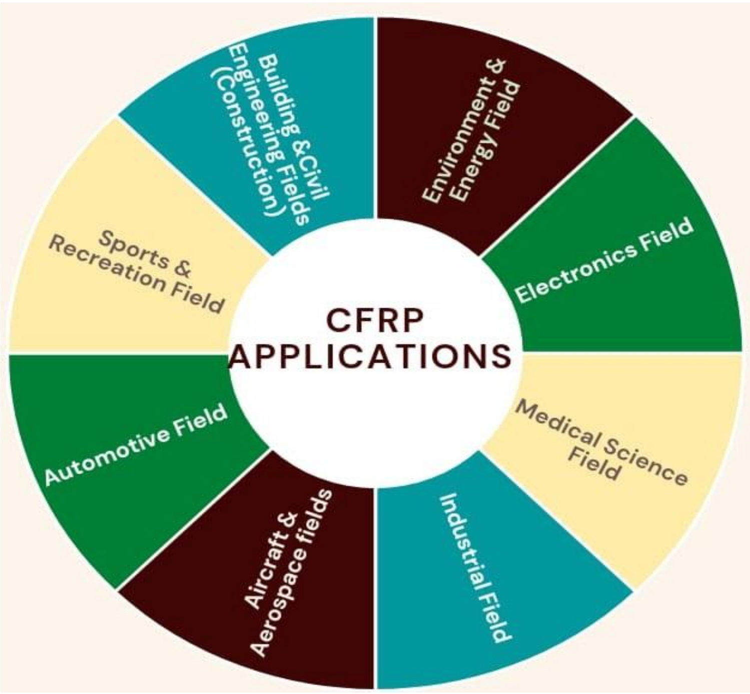

Fig. 7. Various Applications of CFRP

Future CF research will concentrate on low weight, property enhancement and cost savings (speed, strength and efficiency). Modern carbon fibres are three times lighter and nearly five times stronger than steel. Due to these characteristics, carbon fiber is very intriguing for a variety of industries, particularly the automotive and aerospace sectors. There has been little research on the impact of modifying processing parameters on fiber qualities to maximize crystallite size, shape, and distribution. Innovating and cost-effective disposal and recycling techniques will be a big future challenge for CFRP business.

There is a fantastic chance to recycle composite materials without negatively impacting the environment. Analyze quantitatively inherent safety variables utilizing modern composite structure simulations and physical damage information. All forms of composite materials must be classified based on their various qualities, manufacturing procedures, and production costs. It is necessary to develop low-cost, portable, non-destructive equipment for assessing undesirable flaws in hybrid composites. Professionals in the industry are positive about the prospects of carbon fiber. Professionals anticipate lower-cost fibres within the coming decades, together with cheaper input resources and more efficient manufacturing techniques.

7. Knowledge Gap Present in The Earlier Investigations

We identified some of the gaps indicated in Figure 8 from the literature discussed in this paper, as shown below:

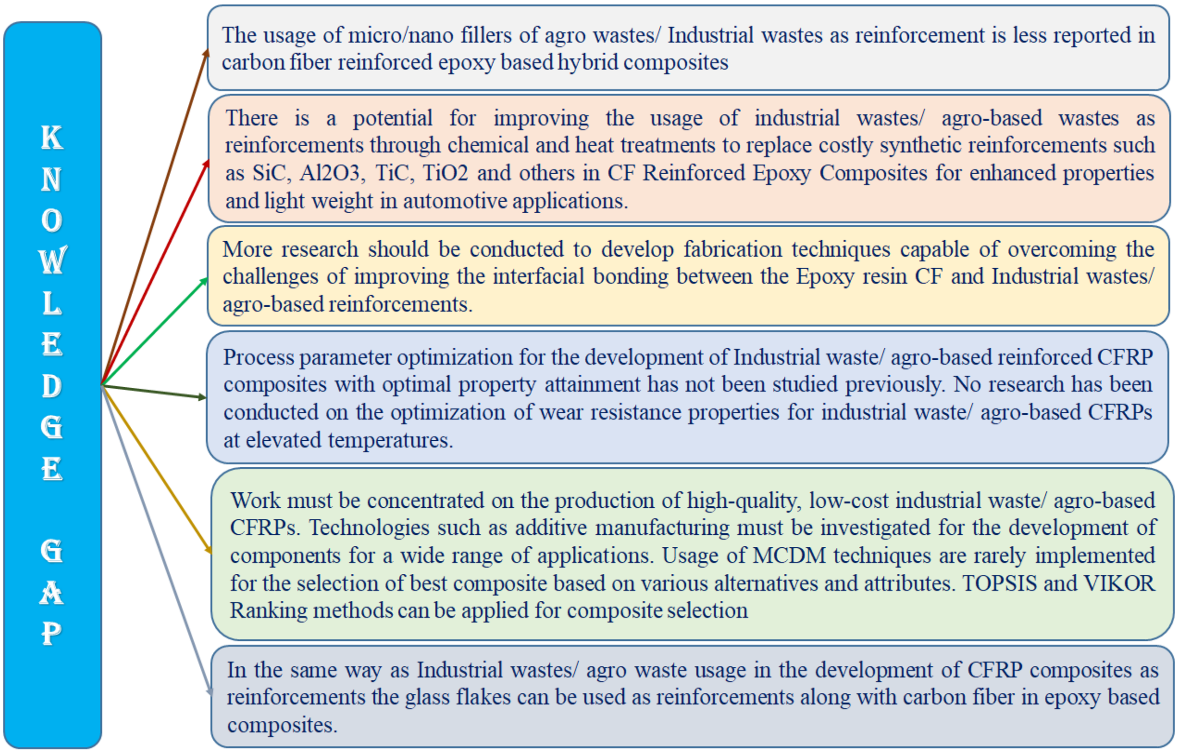

Fig. 8. Knowledge gap Present in the earlier investigations

8. Conclusions

This review has covered a wide range of expensive ceramic powders and elements in detail, along with their influence on mechanical qualities and the production processes involved. The main conclusions are:

i. CFRP's properties are improved by the inclusion or accumulation of strengthening materials as reinforcements in the form of fillers.
ii. The use of readily accessible industrial wastes, agricultural wastes, and aquatic animal shells and bones as reinforcements can lower the cost of fabricating CFRP. By using these fillers, environmental pollution and disposal issues can be reduced.
iii. The weight of the composites can be decreased by using various combinations of these industrial wastes, agricultural wastes, and aquatic animal shells/bones as reinforcements

in CF-Epoxy composites. Therefore, one can employ these reinforcing fillers to reduce weight.

iv. These agricultural wastes have the potential to be utilized as raw materials in the production of CF composite car parts.

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