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# Evaluate Fibre Reinforced Composites

**Prashanth kumar S[1], Subhash**
[1]Department of Mechanical Engineering,

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**Abstract**

Axial particles implanted in fitting matrices are the basic building blocks of fiber-reinforced composites. The main goal of fiber-reinforced composites is to create materials that are both strong and also very elastic. The applied load, the type of the fibers, the interfacial connection between the fibers and the matrix, the relative alignment of the two, and the overall material characteristics are all factors that influence the strength enhancement. But, depending on the final uses, the fiber alignment could be either continuous or random. The needs of the application should also be considered while selecting the fiber reinforcement and the matrix that fits it. Fiber reinforced composite systems using diverse production procedures have been developed to achieve improved material behaviors in recent years, thanks to the introduction of composite technology. With a focus on carbon fibers, we provide a comparative assessment of the many synthetic fibers and their importance as possible reinforcements.

**Keywords:** Fibers; E-glass; Carbon; Kevlar; Low elastic modulus (LM)

## Introduction

Composites' great fatigue resistance and high strength-to-weight ratio make them a leading contender for use in aeronautical applications [1,2]. The synergistic mixing of functional fillers with highly processable polymers in polymer-based composite systems allows them to provide numerous functions, which in turn expands their application window [3,4]. Composites used in construction are frequently considered high performance systems because of the synthetic materials used to make them and the impressive strength-to-weight ratios they provide. However, these materials may be difficult to work with without a well regulated production environment. Another well-known use for fiber reinforced polymers is in the electrical and military industries, where they might serve as high-tech, high-quality materials. However, fiber reinforced plastics are currently only used for smaller reinforced plastic components, such as girders, handrails, reinforcing bars, staying cables, and portions of bridge decks [5–11]. Reinforced plastics have recently gained a reputation for being well-suited for use in the construction industry, along with transportation and electronics. Fiber Reinforced Plastics (FRP) find widespread use in a variety of transportation-related industries, including the automobile, airline, shipping, and more. High voltage switches, cryostats, dry transformers, and many more products are made using FRP in the energy and electronics industry. More recent examples of high-tech uses for carbon fiber reinforced plastics include rocket nozzles. Market shares of FRPs in several application areas are shown in the pie chart below (Figure 1), which provides a complete view of the data [12–14]. There are several benefits to reinforcing fibers onto a polymeric matrix, including improved mechanical behaviors of the polymeric host, reduced maintenance costs, a high strength-to-weight ratio, enhanced dimensional stabilities, and excellent weathering stability [15]. The mechanical, tribological, thermal, and water sorption behaviors of the resultant composites have been improved by experimenting with different kinds of fibers with different polymers in order to get tailor-made qualities that meet the needs of certain applications. However, with isotropic fibers implanted in a single direction and almost limitless length, one may anticipate enormous outcomes. On the other side, mechanical performance would be worse if the fibers were both more anisotropic and shorter in length. The observed great flexibility in terms of fiber type, direction, and length greatly expands the range of applications for FRP composites. In addition, the composite may be modified to meet the unique mechanical requirements of each project, leading to improved efficiency in the final product. These days, natural fibers, glass fibers, carbon fibers, and aramid fibers are the most popular, followed by cotton and polyester. Ideally, all of these reinforcements would be less thick, so they are all there.

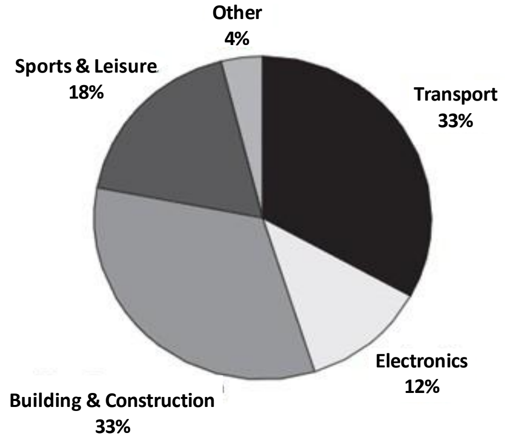


**Figure 1:** A pictorial representation of market shares of FRPs.

the matrix that is more rigid and strong. However, low fiber densities are responsible for composites' outstanding strength/stiffness to weight ratio. Carbon fibers are much stiffer and lighter than glass fibers, however all fibers act quasi-elastically until rupture. As a result, they are now more suited to a wide variety of high-performance applications.

## Important Types of Fiber Reinforcements

### Glass fibers

The principal factor influencing the mechanical properties of fiber-reinforced composites is their capacity to transmit stress, which is influenced by the fiber's strength, the matrix's strength, and the strength of the adhesive bond between the fiber and matrix [16]. In order to improve the mechanical and tribological characteristics of fiber reinforced composites, glass fibers (GFs) have been used in a variety of forms, including longitudinal, woven mat, chopped fiber (distinct), and chopped matting. The qualities of these composites, however, were very sensitive to the kind and orientation of the fibers used in their production [17]. Nearly 90% of all FRPs are composed of glass fibers, making them one of the most used polymer reinforcements. Among them, E-glass, sometimes known as electrical grade glass, is both the most common and the most traditional. Alkali glass (A-glass), chemical resistant glass (C-glass), and high strength R-glass and S-glass are among the other varieties of glass fibers. Commercially available glass fibers have a tensile strength of 2800 to 4800 N/mm2 [18], but under controlled laboratory conditions, this number rises to around 7,000 N/mm2 (Figure 2).

**(a)** **(b)**

**Figure 2:** Digital images of (a) Unwound glass fibers; (b) Woven glass fiber.

| Classes of GFs | Physical properties |
|---|---|
| A glass | High durability, strength and electrical resistivity |
| C glass | High corrosion resistance |
| D glass | Low dielectric constant |
| E glass | Higher strength and electrical resistivity |
| AR glass | Alkali resistance |
| R glass | Higher strength and acid corrosion resistance |
| S glass | Higher tensile strength |

**Table 1:** Physical properties of various classes of glass fibers.

**Classification of glass fibers:** The major classes of GFs and their inherent physical properties are depicted in Table 1 [19], while their chemical composition is tabulated in Table 2. The physical and mechanical properties of different classes of GFs are shown in Table 3.

Various commercially imperative products have been developed using glass fibers. Each of which defer in its overall material performance. Table 4 summarises the mechanical properties of various glass fibre products.

### Carbon fibers

Graphitic and non-crystalline areas come together to form carbon fibers (GFs), a novel kind of high strength material. Carbon fibers have the strongest and most specific modulus of any reinforcing fiber. Carbon fibers are resistant to moisture and may maintain their tensile strength even when heated. Carbon fibers, in contrast to glass and other organic polymer fibers, do not always shatter under tension [20]. In addition to having a low coefficient of thermal expansion, carbon fibers have strong electrical and thermal conductivities [21–24]. Carbon fibers are perfect for use in the aerospace, electronics, and automotive industries due to their inherent quality. Axial compressive strength is 12–20% of carbon fibers' tensile strength [25,26] and transverse compressive strength is 10–60% of carbon fibers' axial compressive strength [27]. The greatest strength that carbon fibers can provide is 7Gpa. As a forerunner to carbon fiber, poly-acrylonitrile (PAN) is widely used in aerospace and sports/recreational product structural material composites because to its high tensile strength and elastic modulus. The PAN precursors are used to create several types of carbon fibers, such as high tenacity (HT), intermediate modulus (IM), high modulus (HM), and ultra-high modulus (UHM), which are defined by the ultimate curing temperature. Petroleum pitch (PP) is used as a precursor in an alternative production method. High stiffness components that make use of high thermal and electrical conductivities often use these carbon fiber types due to their lower tensile

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**strength and greater E-modulus [28] (Figure 3).**

Carbon fibers' properties include: The remarkable strength-to-weight and stiffness-to-weight ratios of carbon fibers make them very adaptable. On top of that, they have no chemical reactions, conduct electricity, and cannot be dissolved. Carbon fibers may have a modulus of elasticity three times greater than steel and a rigidity anywhere from glass to steel. The modulus of the most popular varieties ranges from 200,000 to 400,000 N/mm2. The mechanical behaviors of several carbon fiber products are shown in Table 5.

Carbon fibers may either be directly processed as finished product or as pre-product. Finished products may appear as woven tubes or pultruded sections. While, pre-products may include short fibers, twisted or non-twisted yarns, continuous filament, tows and so forth. Table 6 gives a detailed picture of important types of commercially important carbon fiber tows, with a comparative view of its physico- mechanical behaviours.

| Type of GF | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | $B_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|---|
| E-glass | 55 | 14 | - | 0.2 | 7 | 22 | 1 | 0.5 | 0.3 |
| C-glass | 64.6 | 4.1 | - | - | 5 | 13.4 | 3.3 | 9.6 | 0.5 |
| S-glass | 65 | 25 | - | - | - | - | 10 | - | - |
| A-glass | 67.5 | 3.5 | - | - | 1.5 | 6.5 | 4.5 | 13.5 | 3 |
| R-glass | 60 | - | - | - | - | 9 | 6 | 0.5 | 0.1 |
| EC-Glass | 58 | 12.4 | | - | - | 23 | | - | - |
| AR-glass | 61 | 1 | - | - | - | 5 | 1 | 14 | 3 |

**Table 2:** Chemical compositions (wt %) of glass fiber types.

| Type | Density (g/ cm³) | Tensile strength GPa | Young's modulus (GPa) | Elongation (%) | Coefficient of thermal expansion ($10^{-7}$/ºC) | Poison's ratio | Refractive index |
|---|---|---|---|---|---|---|---|
| E-glass | 2.58 | 3.445 | 72.3 | 4.8 | 54 | 0.2 | 1.558 |
| C-glass | 2.52 | 3.310 | 68.9 | 4.8 | 63 | - | 1.533 |
| S-glass | 2.46 | 4.890 | 86.9 | 5.7 | 16 | 0.22 | 1.521 |
| A-glass | 2.44 | 3.310 | 68.9 | 4.8 | 73 | - | 1.538 |
| R-glass | 2.54 | 4.135 | 85.5 | 4.8 | 33 | - | 1.546 |
| EC-Glass | 2.72 | 3.445 | 85.5 | 4.8 | 59 | - | 1.579 |
| AR-glass | 2.70 | 3.241 | 73.1 | 4.4 | 65 | - | 1.562 |

**Table 3:** Physical and mechanical properties of GFs.

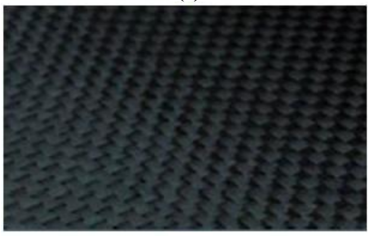
| Types | Unit | Woven cloth | Chopped strand mat | Continuous roving |
|---|---|---|---|---|
| Glass content | % | 55 | 30 | 70 |
| Tensile strength | $N/mm^2$ | 300 | 100 | 800 |
| Compressive strength | $N/mm^2$ | 250 | 150 | 350 |
| Flexural strength | $N/mm^2$ | 400 | 150 | 1000 |
| Flexural modulus | $N/mm^2$ | 15000 | 7000 | 40000 |
| Impact strength | $kJ/m^2$ | 150 | 75 | 250 |
| Coefficient of linear thermal expansion | $\times 10^{-6}$/°C | 12 | 30 | 10 |
| Thermal conductivity | W/mK | 0.28 | 0.2 | 0.29 |

**Table 4:** Mechanical properties of various glassfiber products.

| Types | Ultra high elastic modulus type (UHM) | High elastic modulus type (HM) | Intermediate elastic modulus type (IM) | Standard elastic modulus type (HT) | Low elastic modulus type (LM) |
|---|---|---|---|---|---|
| Tensile elastic modulus | 600 GPa | 350-600 GPa | 280-350 GPa | 200-280 GPa | 200 GPa |
| Tensile strength | 2,500 MPa | 2,500 MPa | 3,500 MPa | 2,500 MPa | 3,500 MPa |

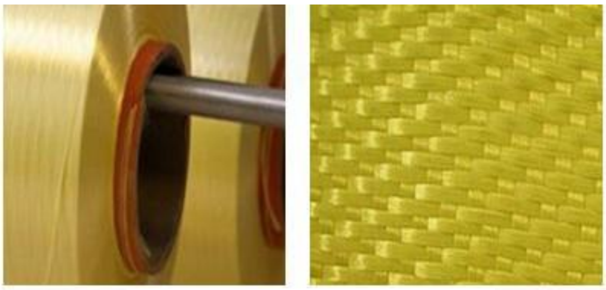
**Table 5:** Mechanical properties of different types of carbon fiber tows.

(a)



(b)

**Figure 3:** Digital images of (a) Unwound carbon fibers; (b) Woven carbon fiber.



(a) (b)

**Figure 4:** Digital images of (a) Unwound Kevlar fibers; (b) Woven Kevlar fibers.

### Kevlar fibers

Kevlar is an aramid fiber of Poly-para-phenylen-terephtalamide (PPTA) with a rigid molecular structure. Aramid like fibers were first developed in 1960s as an alternate for steel reinforcements in rubber tyres. However, once developed the aramid fibers were also found suitable for ballistics and as surrogate for asbestos. Kevlar fibers are often used for high-performance composite applications where light weight, high strength and stiffness, damage resistance, and resistance to fatigue are of utmost importance. Aramid fibers are often employed in those applications that demands high strength and low weight together with a high impact resistance. Some of the most frequent applications of aramid materials include bullet proof vests, cooling vehicles, ship hulls and lately towards structural strengthening of civil structures.

Nevertheless, aramid fibers often present low compression strength. Further, the compressive modulus of aramid is of the same order as its tensile modulus [18] (Figure 4).

**Types of aramid fibers:** In general, aramid fibers are grouped into two categories namely,

1. Meta-aramid
2. Para-aramid

The termsmeta and para refers to the relative position of chemical bonds in the aramid fiber structure. The chemical bonds of para-aramid fibers are more aligned in the long direction of the fibers. While, the meta- aramid fibers are relatively less and/or not aligned and hence they do not they develop higher tensile strength in contrast to para-aramid bonds.

***Meta-aramids*:** Fibers made from the meta-aramid fibers often present excellent thermal, chemical and radiation resistance. They are usually employed in the fabrication of fire retardant textiles such as outer wear for fire fighters and racing car drivers. Nomex and teijiconex are well established examples of meta-aramids.

***Para-aramids*:** Fibers made of para-aramids offer higher strength. These are more commonly used in fibers reinforcement plastics for engineering structures, Stress skin panels, and other high tensile strength applications. Kevlar and Technora are commercially important para-aramid fibers [28-31]. Table 7 gives a comparative account on different grades (kevlar 29, kevlar 49, and kevlar 149) of commercially important kevlar fibers and their innate mechanical properties.

Although, aramid fibers are compatible with almost any kind of polymeric matrix. Yet, thermoplastic matrices host aramid fibers with nearly 20% more efficiency. Owing to their higher ductility, they are more compatible to aramids [16,18]. Table 8 presents a comparative view of tensile properties of epoxy composites reinforced with different types of aramid fibers.

## Comparative Account of Glass, Carbon and Kevlar Fi- bers

Fibers in general play a crucial role in deciding the end property of the fiber reinforced composite systems. Thus, appropriate selection of fiber material and their relative orientation can lead to composite to composites with tailor made properties to suit specific application requirements. Herein, we present a comparative account of various properties of some of the technologically significant fibers (E-Glass, Low elastic modulus type carbon fiber (LM) and kevlar149), so as to ease the selection of appropriate fibers to satisfy the real time application demands. However, during, comparative studies, one has to take into account of property changes arising from difference in processing techniques, variation in precursor materials and also post-fabrication treatments, since all these factors influence the end properties of resultant fibers. E-Glass is commonly used glass fiber that offers higher strength and high electrical resistivity, LM is the type of carbon fiber with low elastic modulus, while kevlar 149 is one of aramid fibers which show significantly higher tensile strength.

## Density

The density values of E-Glass, Low elastic modulus type carbon fiber (LM) and kevlar149 display significant difference. Furthermore, kevlar and carbon fibre are much lighter, while E-Glass is the heaviest (Table 9) [32-35].

Thus, carbon fiber or kevlar fibers are preferred over glass fibers in those applications that involve any structures demanding higher strength within smaller sizes.

## Tensile strength

The tensile strength of glass, carbon and kevlar fibers are however similar. If tensile strength is only criteria for material selection, then cost of the material will be absolute (Table 10) [35].

## Tensile modulus

All details related to Tensile Modulus mentioned in Table 11 [35].

## Electrical conductivity

Carbon fibers are excellent conductors in contrast to kevlar and glass fibers. Nevertheless, kevlar is used for guy lines in transmission towers, owing to its ability to absorb water and the absorbed water conducts electricity. Since carbon fiber conducts electricity, galvanic corrosion is a concern when in contact with other metallic parts. Boaters, who have carbon fiber masts and spars, will have to insulate their aluminium fasteners and connections to avoid corrosion.

| Type | Unit | 55% CF SMC | Lowest grade CF epoxy fabric | Highest grade CF epoxy fabric | Carbon epoxy |
|---|---|---|---|---|---|
| Carbon fiber content | % | 55 | n.a | n.a | 67 |
| Density | g/cm$^3$ | 1.45 | 1.15 | 1.8 | n.a |
| Tensile strength ultimate | N/mm$^2$ | 289 | 50 | 2.100 | 1.362 |
| Modulus of elasticity | $10^3$ N/mm$^2$ | 55.1 | 6.6 | 520 | 140 |
| Flexural yield strength | N/mm$^2$ | 613 | 110 | 1600 | 1383 |
| Flexural modulus | $10^3$ N/mm$^2$ | 34.5 | 6.410 | 125 | 122 |
| Compressive yield strength | N/mm$^2$ | 275 | 50 | 1720 | 1084 |
| Compressive modulus | $10^3$ N/mm$^2$ | 31.7 | 8.2 | 140 | 136 |
| Shear strength | N/mm$^2$ | 65.6 | 0.8 | 120 | 87.4 |

**Table 6:** Comparison between three types of carbon fiber/epoxy products.

| Grade | Density (g/cm$^3$) | Tensile modulus (GPa) | Tensile strength (GPa) | Tensile elongation (%) |
|---|---|---|---|---|
| Kevlar 29 | 1.44 | 83 | 3.6 | 4 |
| Kevlar 49 | 1.44 | 131 | 3.6-4.1 | 2.8 |
| Kevlar 149 | 1.47 | 186 | 3.4 | 2 |

**Table 7:** Mechanical properties of different types of aramid fibers.

| Type | Units | Aramid fiber-standard modulus-UD | Aramid fibers-high modulus-Woven |
|---|---|---|---|
| Density | g/cm$^3$ | 1.31 | 1.27 |
| Tensile strength | N/mm$^2$ | 1400 | 560 |
| Tensile modulus | $10^3$ N/mm$^2$ | 76 | 30 |

**Table 8:** Comparison between two aramid fiber reinforced epoxy composites.

| Type of fiber | Density (g/cm$^3$) |
|---|---|
| E glass | 2.58 |
| LM-CF | 1.45 |
| Kevlar 149 | 1.47 |

**Table 9:** Computed density of commercially important fibers.

| Fiber | Tensile strength (GPa) |
|---|---|
| E glass | 3.445 |
| LM-CF | 3.5 |
| Kevlar 149 | 3.4 |

**Table 10:** Tensile strength of various types of fibers.

| Fiber | Tensile modulus (GPa) |
|---|---|
| E glass | 72.3 |
| LM-CF | 200 |
| Kevlar 149 | 186 |

**Table 11:** Tensile modulus of various types of fibers.

### Fatigue resistance

If a composite part is made to bend and straighten repeatedly, it is bound to fail due to fatigue. However, when reinforced with carbon fibers is somewhat sensitive to fatigue and tends to fail catastrophically without showing many signs of distress, while kevlar is more resistant to fatigue. Glass is somewhere in between and can be quite fatigue resistant depending on the type of glass and the setup conditions.

### Abrasion resistance

Kevlar has a strong abrasion resistance, which makes it difficult to cut. One of the common applications of kevlar is as a protective glove, while using sharp blades. Carbon fiber and glass fiber have less abrasion resistant.

### Chemical resistance

Aramids are sensitive to strong acids, bases, and some oxidizers, such as the chlorine bleach. Carbon fiber is however more stable and is not sensitive to chemical degradation.

## Conclusion

To highlight the significance and intrinsic qualities of different kinds of fibers is the motivation for the offered review. Since they are the most often used fiber reinforcements, we provide three synthetic fibers: glass, carbon, and kevlar. The production processes, kinds, and qualities of each fiber are distinct. The process and kind of manufacture also affect the fiber's characteristics. With a focus on mechanical behaviors, we provided a comprehensive table of fiber kinds together with their intrinsic qualities. A comparative description on the qualities of various fibers is provided for better understanding and easier choosing. E-Glass, LM carbon fiber, and kevlar 149 fiber are some of the fiber reinforcements that are compared. The studied literature states that:

• Fibers made of glass are denser than those made of carbon or kevlar.

• All of the offered fiber kinds have almost identical tensile strengths.

• In contrast to glass and kevlar, LM carbon fiber has a somewhat greater tensile modulus.

Carbon fiber outperforms kevlar and glass in terms of conductivity.

• Kevlar has a higher fatigue resistance than carbon and glass, which are somewhat but not completely fatigue sensitive.

When compared to carbon and glass fibers, Kevlar's abrasion resistance is far higher.

• Carbon fiber has a high degree of stability and is not easily damaged by chemicals.

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