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A Review on the Industrial Applications and Properties of Fiber-Reinforced and Other Polymeric Composites

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Abstract

This paper presents a review on the industrial applications and properties of fiber reinforced and other polymeric composites. Composites have been discovered to be the most promising and discriminating material available in this century. Composites reinforced with fibers of synthetic or natural materials are becoming increasingly popular as the demand for lightweight materials with high strength for specific purposes. Fiber-reinforced polymer composites have exceptional properties such as high durability, stiffness, damping property, flexural strength, and corrosion, wear, impact, and fire resistance, in addition to a high strength-to-weight ratio. Due to their wide range of qualities, composite materials have found applications in the mechanical, construction, aerospace, automotive, biomedical, marine, and many other manufacturing industries. In a wide range of applications, it delivers outstanding results. To assist in the selection of right fiber-reinforced composite material for industrial purposes, an overview of a wide range of fibers, their attributes, functioning, classification, and various fiber composite manufacturing techniques is provided. Due to their outstanding performance in a wide range of applications, fiber-reinforced composite materials have emerged as a viable alternative to single metals or alloys.

1.0. Introduction

Rapid growth in the manufacturing industry has necessitated the development of new materials with enhanced strength, stiffness, density, and cost-effectiveness. Composite materials have been developed as one of the materials with such improved qualities that they may be used in a wide range of applications [1]. Composite materials are made up of two or more constituents, one of which is in the matrix phase and the other in the form of particles or fibers. Natural or synthetic fibers have found important applications in a range of industries, including construction, mechanical, car, aerospace, biomedical, and marine [2]. The structural, mechanical, and tribological properties of fiber-reinforced composite (FRC) material have been significantly improved in research investigations over the last two decades, making composites a viable alternative to many conventional materials [3]. Despite the fact that composite materials have increased the material's endurance, there is currently a major concern about the accumulation of plastic trash in the environment [4]. This issue has prompted scientists all over the world to develop ecologically friendly materials and production procedures [5]. To deal with the thousands of tons of composite trash produced each year, several different composite recycling technologies have been devised. Pulverization is a type of mechanical recycling in which smaller recyclates are employed as filler materials in sheet molding compounds. Thermal recycling involves the pyrolysis of composite trash or the production of a large amount of heat energy by burning composite materials having a high calorific value. Chemical recycling (solvolysis) and high-voltage fragmentation are two more efficient techniques (HVF). Natural fillers, such as natural fibers, cellulose nanocrystals, and nanofibrillated cellulose, have been added to the polymer matrix to construct eco-friendly composites, which has increased material qualities while reducing residue buildup [6]. Cellulosic fibers have a number of advantages, including being abundant in nature, nontoxic, renewable, and cost-effective, as well as providing necessary bonding with the cement-based matrix for significant improvements in material properties such as ductility, toughness, flexural capacity, and impact resistance [7]. Fly ash, limestone powder, brick powder, and a variety of other mineral additives are utilized to strengthen composite buildings in current procedures. The addition of fly ash to a concrete composite for structural applications boosted the material's fracture toughness, resulting in a longer lifespan [8]. Plant-based, animal-based, and mineral-based fibers are the most common types of natural fibers. Mineral-based fibers are not well-explored fibers in terms of research into fiber-reinforced composite materials because the asbestos content is hazardous to human health, whereas plant-based fibers offer promising characteristics such as lower cost, biodegradability, availability, and good physical and mechanical properties [9]. Leaf fibers (sisal and abaca), bast fibers (flax, jute, hemp, ramie, and kenaf), grass and reed fibers (rice husk), core fibers (hemp, jute, and kenaf), seed fibers (cotton, kapok, and coir), and all other varieties (including wood and roots) are all examples of plant fibers. Polymer matrices are further separated into a natural matrix and a synthetic matrix, which includes polyester, polypropylene (PP), polyethylene (PE), and epoxy and is based on petrochemicals [10]. The most recent research is helping to build hybrid composites that combine natural and synthetic fibers. Hybrid composites are composite structures that consist of more than one type of fiber. Stacking layers of fibers, intermingling fibers, mixing two types of fibers in the same layer to create an interplay hybrid, selective positioning of fiber where it is needed for improved force, and arranging each fiber according to certain orientation are all strategies for combining these fibers [11]. Stacking fibers is the simplest approach, while others create challenges in achieving a positive hybridization effect. Many researchers have found success by altering fiber composition, orientation, size, or manufacturing procedures to create optimal composite materials for efficient use in certain applications. For FRCs to be used effectively, it is vital to understand their physical, mechanical, electrical, and thermal properties. Due to its strong mechanical qualities, FRCs are being used in a wide range of applications. Some faults, such as manufacturing defects, cause these composite materials to diverge from their designed specifications, resulting in a reduction in mechanical performance. Misalignment, waviness, and sometimes breakage of fibers, fiber/matrix debonding, delamination, and the production of voids in the matrix of a composite material are all examples of manufacturing defects. In composites, a 1% increase in vacancy content reduces tensile strength (10–20%), flexural strength (10%), and interlaminar shear strength (5–10%), respectively. Manipulation of manufacturing process production parameters can be used to eliminate it [12]. As a result, it is necessary to comprehend and research many forms of composite manufacturing

procedures in order to adopt optimum techniques that will eliminate faults and produce a suitable self-sustaining, durable composite material that is effective in the chosen field of application. Many traditional composite material fabrication procedures have been in use for decades, and some of the more recently developed automated composite manufacturing techniques include robot assistance for processing, resulting in complete automation and a significant increase in productivity [13].
Therefore, this study focused on the review of the industrial applications and properties of fiber reinforced and other polymeric composites

2. Classification of Composite Materials

The content of composite materials is divided into two categories: base material and filler material. The filler material is present in the form of sheets, pieces, particles, fibers, or whiskers of natural or synthetic material, and the matrix or binder material binds or holds the filler material in structures. Composites are categorized into three primary groups based on their structure, as shown in Figure 1 [14].

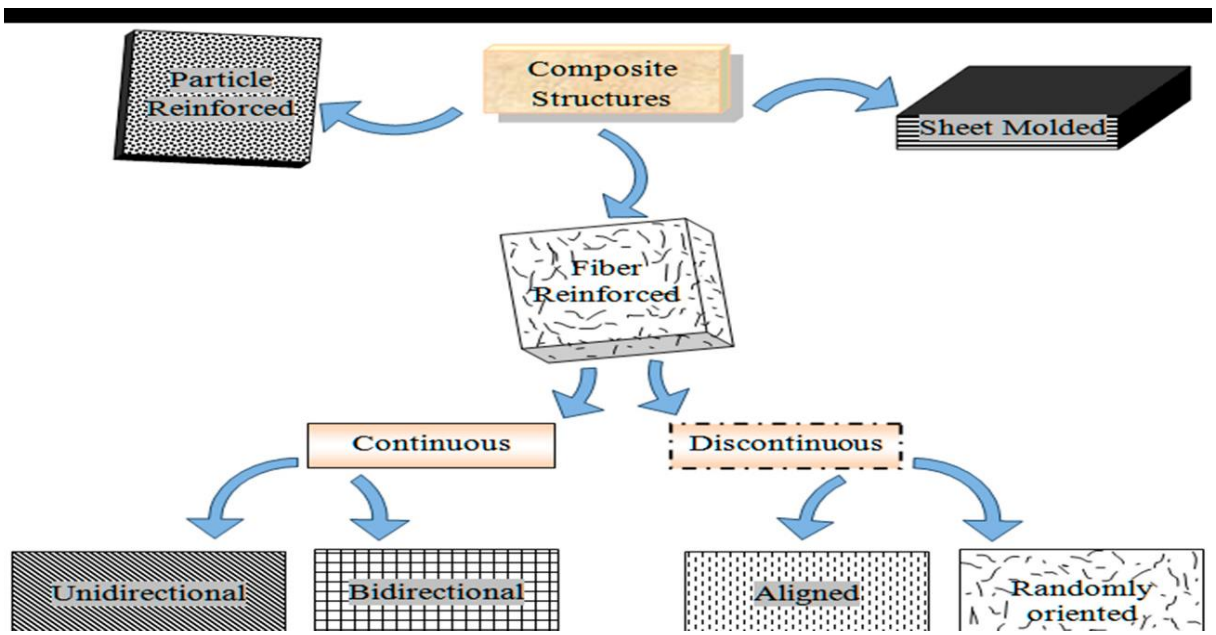

Figure 1: Classification of Composites

2.1. Fiber-Reinforced Composites

Composites are made up of fibers in a matrix structure and are classed based on the length of the fibers. Continuous fiber reinforcement composites are those with long fiber reinforcements, and discontinuous fiber reinforcement composites are those with short fiber reinforcements. Two or more types of fibers are reinforced in a single matrix structure in hybrid fiber-reinforced composites [15]. Continuous fiber composites have fibers that can be put unidirectionally or bidirectionally in the matrix structure, and they easily and effectively transfer loads from the matrix to the fiber. In the case of brittle matrices, discontinuous fibers must have adequate length for successful load transfer and to prevent crack propagation from causing material failure. The characteristics and structural behavior of composite materials are determined by the arrangement and orientation of fibers [16]. The use of chemically treated natural fibers can improve qualities like as impact toughness and fatigue strength. In the matrix structure of fiber-reinforced polymer (FRP) composite materials, glass, carbon, basalt, and aramid fibers in the dispersion phase were traditionally utilized [17]. Natural fiber polymer composites (NFPCs) exhibit significant features that have potential applications in modern industry, according to researchers. Fibers for composite materials come in a variety of types, with natural and synthetic fibers being the most common. Furthermore, when these two fibers are joined with a matrix material to produce a hybrid composite, recent research have revealed extraordinary material characteristics. Figure 2 depicts some of the natural fibers.

Figure 2: Some of the Natural Fibers [4]

2.1.1. Synthetic Fibers

Synthetic fibers are human-made fibers that are created by chemical synthesis and are further categorised as organic or inorganic according on their composition [18]. Fiber materials have a substantially higher strength and stiffness than matrix materials, making them a load-bearing element in the composite structure [19]. Glass fibers (GFs) are the most extensively used synthetic fibers because they have exceptional strength and durability, thermal stability, impact resistance, chemical resistance, friction resistance, and wear resistance. However, when using traditional machining equipment, cutting glass fiber-reinforced polymers (GFRPs) is slow, difficult, and results in lower tool life [20]. GFs also have the drawback of being disposed of at the end of their useful life [4]. Carbon fibers (CFs) are used instead of GFs in some situations where additional stiffness is required. Other synthetic fibers, such as aramid, basalt, polyacrylonitrile (PAN-F), polyethylene terephthalate (PET-F), or polypropylene fibers (PP-F), have some advantages, but they are rarely used in thermoplastic short-fiber-reinforced polymers (SFRP); they have been used for specific applications where their desired properties are applicable [6]. Carbon fiber-reinforced polymer (CFRP) composites have a wide range of uses in aerospace, automotive, sports, and a

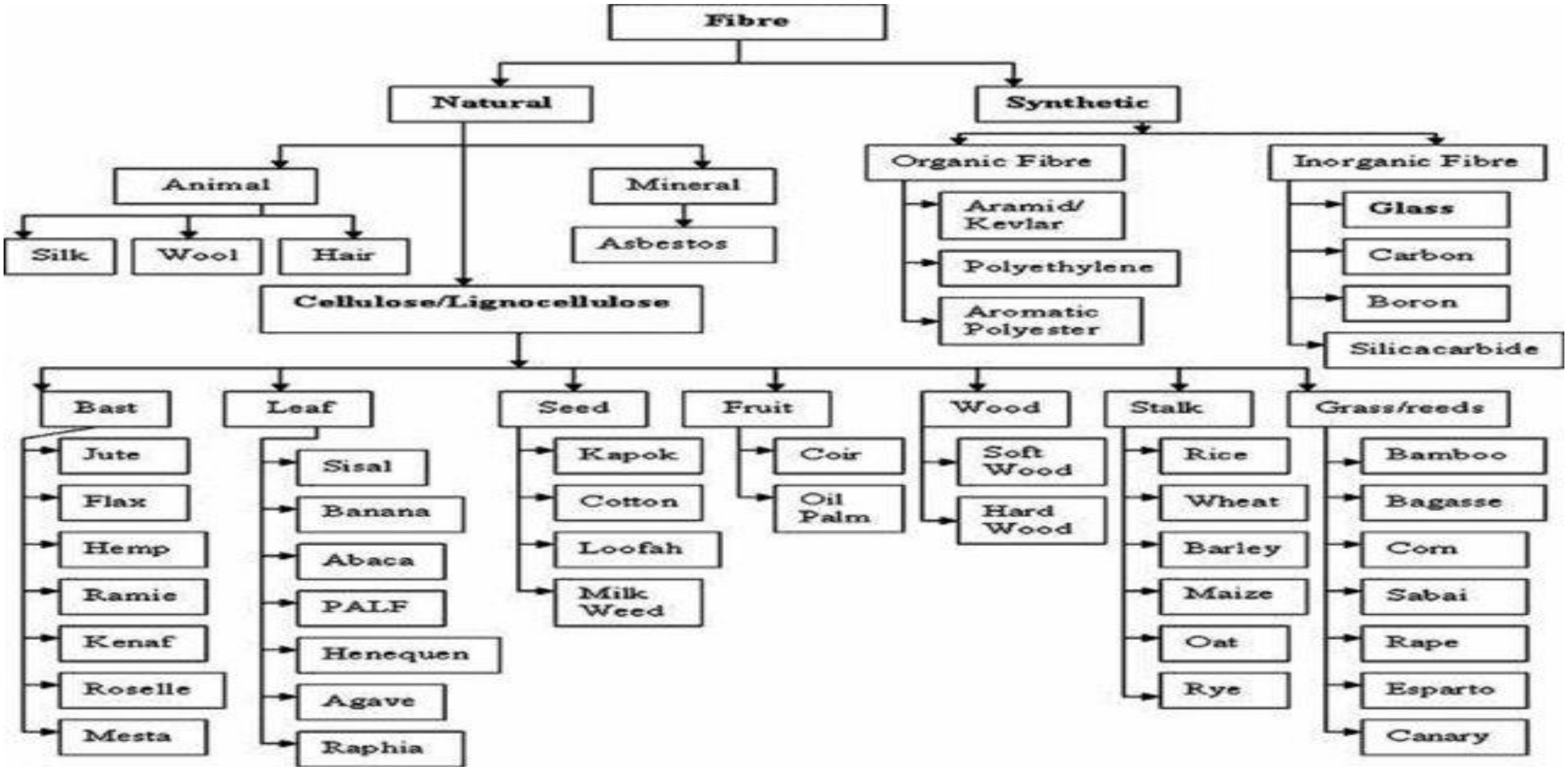

Figure 3: Classification of Natural and Synthetic Fiber

variety of other fields [8]. When the weight percentage of carbon fibers was increased from 10% to 30%, the Young's modulus of solids and foams increased by 78 percent and 113 percent, respectively. When carbon fiber/polypropylene (CF/PP) was utilized to manufacture composite foams made by microcellular injection molding, the cellular structure improved by 35 percent, resulting in a 35 percent increase in Young's modulus. [9]. When compared to carbon fibers, graphene fibers are a novel type of high-performance carbonaceous fiber that exhibits great tensile strength and improved electrical conductivity. Graphene fibers have a number of increased features that reveal their potential in a variety of applications, including lightweight conductive cables and wires, knittable supercapacitors, micromotors, solar cell textiles, actuators, and more [3]. The Young's modulus, shear modulus, and hardness of polymer composites reinforced with graphene increased by 150 percent, 27.6%, and 35%, respectively, in a molecular dynamics simulation. Furthermore, a decrease in the coefficient of friction and the rate of abrasion by 35% and 48% was achieved [4]. Basalt fiber (BF) outperforms fiberglass in terms of physical and mechanical qualities. Furthermore, BF is much less expensive than carbon fibers. The effect of temperature on basalt fiber-reinforced polymer (BFRP) composites has been studied, with a drop in temperatures leading to an increase in static strength and fatigue life at a specific maximum stress [12]. Hybridizing Kevlar fibers (KFs) with glass or carbon fibers improves the thermal properties of Kevlar fiber-reinforced composites (KFRCs), while there is less study on hybridizing Kevlar fibers (KFs) with natural fibers. KFRCs have strong impact strength and tensile qualities, however they have low compression strength compared to glass and carbon fiber equivalents due to their anisotropic nature [15].

2.1.2. Natural Fibers

Natural fibers (NFs) are a widely available and easy-to-find substance in nature. They show biodegradability, low cost per unit volume, high strength, and particular stiffness as excellent material qualities. Composites composed using NF reinforcements appear to have a number of advantages to synthetic fibers, including lower weight, cost, toxicity, pollution, and recyclability. For modern applications, NF composites outperform synthetic fiber-reinforced composites in terms of cost and environmental impact [16]. Natural fibers contain comparable structures with varied contents depending on the type. The use of long and short natural fibers in thermoset matrices has resulted in high-performance results [17]. Because of their excellent tribological qualities, sisal fiber (SF)-based composites are often utilized for automotive interiors and furniture upholstery. Tensile strength increased with fiber volume when SFs were reinforced with polyester composites, and tensile strength of 12.5 MPa was observed in 6 mm long sisal fibers when reinforced with polyethylene (PE) composites [18]. When compared to GF-reinforced composite with a propylene matrix, hemp composite demonstrated a 52 percent increase in specific flexural strength of a material [19]. The flexural and tensile strength of a composite material made up of 5 percent maleic anhydride-grafted polypropylene (MAPP) by weight mixed with a polypropylene (PP) matrix reinforced with 15 percent alkaline-treated hemp fibers by weight increased by 37 percent and 68 percent, respectively [15]. The tensile and flexural strength of polylactic acid (PLA) thermoplastic composites with kenaf fiber reinforcement are 223 MPa and 254 MPa, respectively [19]. Also, eliminating absorbed water from the fibers before laminating improves the flexural and tensile properties of kenaf fiber laminates [16]. Previously, polyester samples with no reinforcements had flexural strengths and moduli of 42.24 MPa and 3.61 GPa, respectively, whereas composite material with 11.1 percent alkali-treated virgin kenaf fibers in unsaturated polyester matrix had flexural strengths and moduli of 69.5 MPa and 7.11 GPa [8]. A sound transmission loss (STL) test was used to study the sound and vibration characteristics of flax fiber-reinforced polypropylene composites

(FF/PPs). Because the material has strong sound absorption capabilities, the results demonstrated an increase in stiffness, damping ratio, and mass per unit area of the material due to increased transmission loss [15]. A material's tensile characteristics were improved by using short flax fiber (FF) laminates. Also, with 45% fiber orientation, material strength and shear modulus improved by 15% and 46%, respectively [17]. Higher fiber content in a polymer matrix causes slippage between the fiber and the matrix, which leads to an increase in the damping ratio during flexural vibration, according to a study on the free vibration properties of ramie fiber-reinforced polypropylene composites (RF/PPs). This suggests that increasing the fiber content improves the damping qualities of the RF/PP composite [19]. A natural coat formed around a rice grain during its growth, known as a rice husk (RH), which is classified as agricultural waste but is used as reinforcement in composite materials to research material properties enhancement [9]. 5 percent RH in polyurethane (PU) foam provided the best sound absorption performance for improving the material's acoustic qualities [20]. Following an impact test, a composite material using 5% chicken feathers as reinforcement fibers and epoxy resin as the matrix material produced the best results. Furthermore, these chicken feathers combined with 1% carbon residuum (CR) fused with epoxy resin to generate a hybrid composite that significantly improved the material's tensile, flexural, and impact strength [9]. Tensile strength and bundle strength of raw jute reeds decrease with length from root to tip, with the root section-based composite having 44 percent and 35 percent stronger tensile and flexural strength, respectively, than the composites derived from the raw jute reed tip portion [3]. Coir fiber-reinforced polypropylene composites with random orientation have better damping capabilities than synthetic fiber-reinforced composites. Low fiber loading leads to more energy absorption due to the higher damping qualities of high resin concentration. At 10% fiber concentration in the coir–PP composite, the highest damping ratio of 0.4736 was obtained, while increasing fiber content to 30% enhanced the natural frequency of the material to 20.92 Hz [1]. The fiber-matrix interfacial contact in palm fibers (PFs) was exceptional. In addition, adding palm fibers to low-density polyethylene (LDPE) increased the Young's modulus when compared to homopolymers [11]. Abaca fiber (AF) reinforcement is used to make friction composites, which has an excellent wear resistance property with a wear rate of 2.864107cm3/Nm at 3% fiber content. In addition, when the amount of abaca fiber in the mixture increased, the density decreased [12]. The use of luffa fibers (LFs) as a reinforcing ingredient of composite material improved the mechanical properties of the material, such as tensile, compressive, flexural, impact strength, and water absorption characteristics [9]. When 9.6 wt percent LFs were added to an epoxy matrix, the density of the material decreased by 3.12 percent, resulting in a reduction in material weight [15]. Cotton fiber epoxy composite has been used to improve the energy absorption and load-carrying characteristics of a tube material [10]. Table 1 shows the manufacturing procedures and applications of various fibers with their matrix materials.

Table 1: Matrix Material Used for Some Fibers with Their Applications and Manufacturing Techniques

References	Materials Used		Application	Manufacturing Techniques
	Fiber Reinforcement	**Matrix/Binder Material**		
[5, 6]	Carbon	PP, metals, ceramics, epoxy resin, Polyether ether ketone (PEEK)	Lightweight automotive products, fuel cells, satellite components, armor, sports	Injection molding, filament winding, resin transfer molding (RTM)

[6, 8]	Graphene	Polystyrene (PS), epoxy, Polyaniline (PANI)	Wind turbines, Gas tanks, aircraft/automotive parts.	CVD, pultrusion, hand/spray up method
[4, 5]	Sisal	PP, PS, epoxy resin	Automobile body parts, roofing sheets	Hand lay-up, compression molding
[6, 7]	Hemp	PE, PP, PU	Furniture, automotive.	RTM, compression molding
[10, 20]	Kenaf	PLA, PP, epoxy resin	Tooling, bearings, automotive parts.	Compression molding, pultrusion
[9, 11]	Flax	PP, polyester, epoxy	Structural, textile.	RTM, spray/hand lay-up, vacuum infusion
[14, 16]	Ramie	PP, Polyolefin, PLA	Bulletproof vests, socket prosthesis, civil.	Extrusion with injection molding
[17, 18]	Rice Husk	PU, PE	Window/door frames, automotive structure.	Compression/injection molding
[14, 15]	Jute	Polyester, PP	Ropes, roofing, door panels	Hand lay-up, compression/ injection molding
[9, 13]	Coir	PP, epoxy resin, PE	components, building boards, roofing sheets, insulation boards	Extrusion, injection molding

2.1.3. Hybrid Fibers

When compared to thermoset composites, thermoplastic composites reinforced with natural fiber demonstrate poor strength performance. As a result, these natural fiber composites are hybridized with small amounts of synthetic fibers to improve design flexibility and recycling possibilities, making them more desirable for technological applications. When a filler content of 25% hemp and 15% glass was included in a composite construction by weight, flexural strength was 101 MPa and flexural modulus was 5.5 GPa. The material's impact strength and water absorption capabilities were also perceived to be improved [10]. SEM analysis of an oil palm/kenaf fiber-reinforced epoxy hybrid composite demonstrated strong interfacial bonding between the fiber and the matrix, indicating that the material's tensile and flexural properties had improved. Furthermore, as compared to other composites, the oil palm/kenaf fiber hybrid composite absorbs more energy during impact loading, making it a viable competitor in the automobile industry [2]. The average weight of a hybrid composite made up of carbon and flax fibers reinforced in an epoxy resin matrix was reduced by 17.98%, and the material had a maximum interlaminar shear strength (ILSS) of 4.9 MPa and a hardness of 77.66 HRC [3]. Fiber hybridization is a potential method in which two or more types of fibers are blended in a matrix of composite material to reduce the disadvantages of one type of fiber while maintaining the benefits of the others. The synergetic actions of both fibers contribute to the composite material's enhancement of qualities that none of the parts possessed [10,15]. The tensile strength of a hybrid composite comprised of epoxy resin as the matrix material and reinforcement of 27 percent banana and 9 percent jute fibers was 29.467 MPa. The compressive strength of another composite with the same matrix material and reinforcement of 21.5 percent coconut sheath and 15.5 percent jute fibers was 33.87 MPa. The tensile strength of the composite material improved as the number of banana fiber reinforcements increased [16].

2.2. Particle-Reinforced Composite

In terms of material strength and fracture resistance, particle-reinforced composite (PRC) is less effective than FRC. Ceramic, metal, or inorganic particles, on the other hand, limit deformation and improve material stiffness. PRCs have gotten a lot of interest recently because of their isotropic features and cost-effectiveness. Furthermore, these composites are made utilizing processes comparable to those used to make monolithic materials [7, 8]. PRCs are used in civil applications such as highways and concrete constructions that require a high level of wear resistance. Cement is used as a binder in concrete, and coarse rock or gravel is used as a filler to give it hardness and stiffness [19].

2.3. Sheet-Molded Composites

Sheet-molded composites (SMCs) are made by using a compression molding method to connect homogeneous layers of materials into nonhomogeneous composite laminates. The laminate is made up of layers, and the buckling stability of FRP composites constructed of fiber sheets improves as the number of layers in the laminate increases [11]. SMC is used in large structural components with a high strength-to-weight ratio, such as automotive body pieces [13]. Natural fibers' tensile characteristics are determined by their chemical composition. Tensile strength rises as the cellulose content of the fibers rises, but it falls as the lignin content rises. Some of the qualities of commonly used fibers were studied in relation to the matrix material's properties. Aside from composite ingredients and manufacturing procedures, a number of other factors influence FRP composite performance. The region around the fiber in a matrix phase of a FRP composite construction is known as the interphase. At loading conditions, matrix to fiber transfer occurs at the interphase stress. As a result, not only the qualities of the constituent materials, but also the behavior of the inter-phase must be considered when evaluating the performance of a composite [13]. Pretreatments: Preheating, alkalization, acetylation, and the use of a silane coupling agent on fibers to change the fiber surface and internal structure improves adhesion at the interface and allows the matrix resin to amalgamate into the fibers [18]. Size effect: For FRP-confined cylindrical concrete columns, size effect is dependent on the mechanism of failure; if failure is dominated by plasticity, there is no size impact. Shear banding is the cause of fracture-dominated failure. Small cylinders break in massive columns because to FRP rupture caused by plastic deformation in the concrete [19]. Methods of confinement include: When adequately restricted, FRP-confined high strength concrete (HSC) and ultra-high-strength concrete (UHSC) exhibit very ductile compression behavior. Inadequately confined HSC or UHSC, on the other hand, degrades the axial compressive performance of the FRP tube-encased or FRP-wrapped specimen. The strain reduction factor (k'') is unaffected by FRP thickness or confinement method, whereas for concrete structures, k'' declines as concrete compressive strength increases [20]. The behavior of concrete-filled fiber-reinforced polymer tubes (CFFT) under concentric compression is determined by the amount and kind of tube material employed, concrete strength, cross-sectional shape, specimen size, and manufacturing procedure. When comparing newly produced rectangular and square CFFTs to conventional CFFTs, newly developed rectangular and square CFFTs demonstrate extremely ductile behavior as a considerable improvement with internal FRP reinforcement [12]. Further research has revealed that the compressive behavior of CFFTs is unaffected by specimen size. Despite the fact that there is a substantial relationship between fiber elastic modulus and strain reduction factor, fibers with a higher modulus of elasticity result in a drop in the strain factor, which resembles concrete brittleness when producing CFFTs [2]. Volume of fiber: To increase adhesion between bamboo fiber and the polypropylene matrix composite material, maleic anhydride-grafted polypropylene (MA-g-PP) was utilized as a compatibilizer. Impact strength increased by 37%, flexural strength increased by 81 percent, flexural modulus climbed by 150 percent, tensile strength increased by 105 percent, and tensile modulus increased by 191% in a composite with 5% MA-g-PP concentration and 50% fiber volume. When the fiber volume of a chemically treated composite with MA-g-PP compatibilizer was increased from 30% to 50%, the heat deflection temperature (HDT) increased by 23 degrees Celsius to 38 degrees Celsius when compared to virgin PP. As a result, the recommended optimized composition for bamboo fiber-reinforced polypropylene composites is a 50 percent fraction fiber volume, 1–6 mm fiber length, and 90–125 _m fiber diameters, combined with MA-g-PP compatibilizer, which results in a maximum enhancement in mechanical properties and a higher thermal stability [13].

Table 2: Some Significant Properties of Frequently used Fiber Materials [11–17].

S/N	Fiber	Density (g/cm3)	Elongation (%)	Tensile Strength (MPa)	Young's Modulus (GPa)
1	Aramid	1.4	3.3–3.7	3000–3150	63–67
2	E-glass	2.5	2.5–3	2000–3500	70
3	S-glass	2.5	2.8	4570	86
4	Cotton	1.5–1.6	3–10	287–597	5.5–12.6
5	Hemp	1.48	1.6	550–900	70
6	Jute	1.3–1.46	1.5–1.8	393–800	10–30
7	Flax	1.4–1.5	1.2–3.2	345–1500	27.6–80
8	Ramie	1.5	2–3.8	220–938	44–128
9	Sisal	1.33–1.5	2–14	400–700	9–38
10	Coir	1.2	15–30	175–220	4–6
11	Kenaf	0.6–1.5	1.6–4.3	223–1191	11–60
12	Bamboo	1.2–1.5	1.9–3.2	500–575	27–40
13	Oil palm	0.7–1.6	4–8	50–400	0.6–9
14	Betel nut	0.2–0.4	22–24	120–166	1.3–2.6
15	Sugarcane bagasse	1.1–1.6	6.3–7.9	170–350	5.1–6.2

2.4. Manufacturing Techniques

Manufacturing FRP composites begins with the creation of fiber preforms, which are then reinforced with the matrix material using a variety of processes. Fiber preforms are made by weaving, knitting, braiding, and sewing fibers together in long sheets or mats [12, 17]. Preforms are utilized in conjunction with robotics to create a high level of automation, allowing control over the fiber angle and content on every zone of the molded object [18].

2.4.1. Conventional Manufacturing Processes

Prepregs are a mix of fibers and uncured resin that has been pre-impregnated with thermoplastic or thermoset resin and just has to be activated by temperature. These prepregs are ready-to-use materials that are cut and placed down into an open mold [18]. Dow Automotive Systems has developed VORAFUSE, a prepreg technology that blends epoxy resin and carbon fiber to increase material handling and cycle time in composite structure compression molding. They have achieved significant weight reduction in partnership with a range of automobile businesses, resulting in efficient CFRP composite structure manufacturing [19]. Figure 3 depicts hand lay-up, the most frequent and commonly used open mold composite production method. Fiber preforms are first placed in a mold with a small coating of antiadhesive finish added to make extraction easier. On a reinforcing material, the resin substance is poured or applied with a brush. The roller is used to drive the resin into the fabrics, ensuring better contact between the reinforcing layers and the matrix components [12]. The spray-up method is identical to the hand-lay-up method. It, on the other hand, employs a pistol to spray glue and chopped fibers onto a mold. A roller is used to fuse these fibers into the matrix material at the same time.

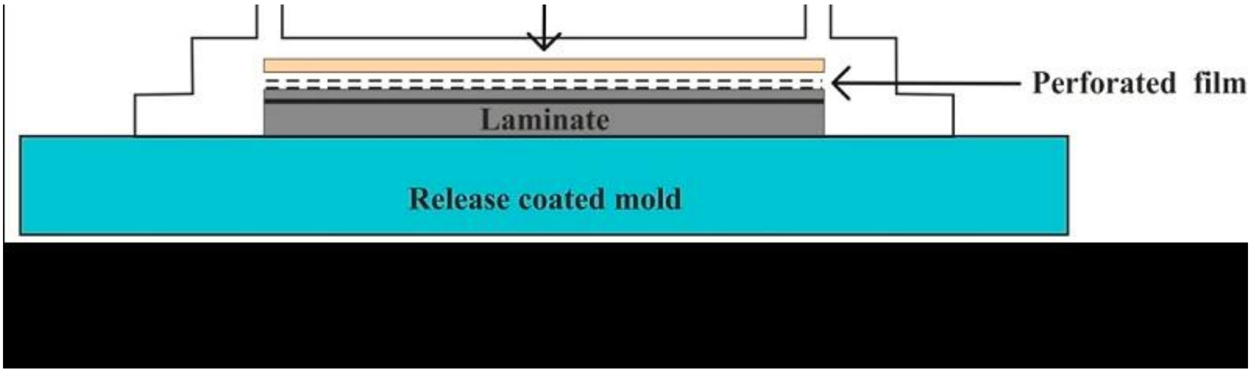

Figure 4: Shows the Hand Lay-up polyvinyl alcohol (PVA) to enclose and seal the part from the outside air.

The vacuum bag molding technique is frequently used in conjunction with the hand lay-up technique. The hand lay-up process is used to create the laminate, which is then sandwiched between the vacuum bag and the mold to ensure even infusion of fibers into the matrix material [15]. A vacuum pump is used to remove the air between the mold and the vacuum bag, while atmospheric pressure compresses the part. Figure 5 illustrates the procedure clearly. The use of a vacuum bagging process to prepare hierarchical composites with multiscale carbon fiber reinforcements eliminated the possibility of detectable porosity and improper impregnation of dual reinforcements, resulting in increases in flexural and interlaminar shear properties of 15% and 18%, respectively [17].
Preheated resin is poured under pressure by an injector into the preform fiber reinforcement mat or woven roving positioned at the bottom half of the mold [13]. Figure 6 illustrates the mechanics of the resin transfer molding (RTM) process. RTM [18] allows for a wide range of fiber material and orientation combinations, as well as 3D reinforcements. It creates high-quality, high-strength composite structural parts with surface quality that matches the mold's surface [14].

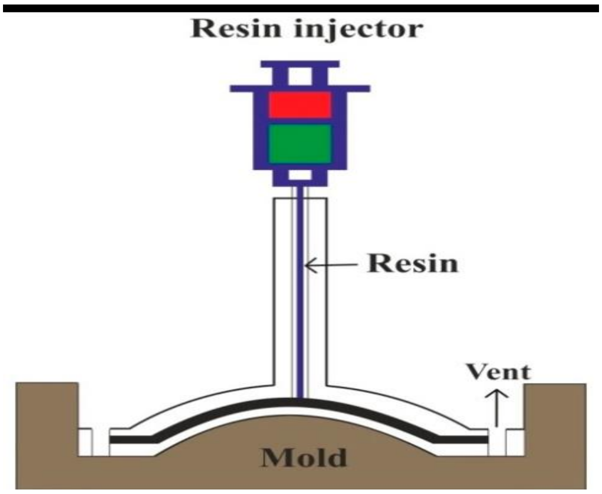

Figure 5: Vacuum Bag Molding Process

2.5 Fiber-Reinforced Composites

The non-continuous phase of composites that receive the most reinforcing is in the form of a fiber. High strength and/or stiffness on a weight basis are frequently design goals for fiber-reinforced composites. Specific strength and specific modulus parameters are used to express these properties, which correspond to the ratios of tensile strength to specific gravity and elastic modulus to specific gravity, respectively. Low density fiber and matrix materials have been used to create fiber reinforced composites with extremely high specific strengths and moduli [11].

2.6 The Fiber Phase

Small diameter fiber is significantly stronger than the bulk material in most materials, especially brittle ones, and the probability of a critical surface fault that leads to fracture lowers with decreasing surface area, and this fracture is employed to some advantage in fiber reinforced composite. In addition, the materials employed for fiber reinforcement have a high tensile strength [6]. Fibers are divided into three categories based on their diameter and character: whiskers, fibers, and wires. Whiskers are single crystals that are incredibly thin and have a very significant length-to-diameter ratio [14]. They have a high degree of crystalline perfection as a result of their small size, which accounts for their very high strengths; they are the strongest known materials. Despite their great strength, whiskers are not widely used as a reinforcement medium because they are exceedingly expensive and do not make strong interfacial connections with many popular matrix materials; also, incorporating whiskers into a matrix is complex and often impracticable. Graphite, silicon, carbide, Silicon nitride, and aluminum oxide are the materials used in whiskers. According to Ardanuy et al., [20], fibers are polycrystalline or amorphous materials with tiny dimensions that are classed as fibers; fibrous materials are typically polymers or ceramics (e.g nylon, the new polymer aramids, glass, graphite, boron, aluminium oxide, and asbestos).

2.6.1 Influence of Fiber Length

The overall strength of a fiber-reinforced composite, according to Ardanuy et al., [20], is determined not only by the tensile strength of the fibers, but also by the degree to which an applied load is maintained on the fibers. The amount of the fiber-matrix interfacial connection, as well as fiber length determines the extent of this load transmittance. This fiber-matrix link breaks at the fiber extremities when a stress is applied, resulting in a matrix deformation pattern; in other words, there is no load transmission from the matrix at the fiber endpoint. The load that a fiber can support is determined by its position. Except at the terminal regions, where the load tapers off to zero, the load is constant. As a result, the fiber phase's reinforcing of the matrix becomes more effective as fiber length grows. Because the end effect spans the full fiber length, there is very little reinforcing for extremely short fibers. The critical fiber length required for successful composite material strengthening is determined by fiber diameter, ultimate strength, and interfacial fiber-matrix bond strength. For many fiber-matrix combinations, the critical length is between 20 and 100 times the fiber diameter. In a fiber-reinforced composite exposed to applied tensile stress, the load was dispersed over the length of a fiber [18]. Continuous fibers are those that are much greater than this crucial length; discontinuous fibers are those that are on the order of, or shorter than this critical length. The matrix deforms around discontinuous fibers with lengths much less than the critical, resulting in essentially negligible stress transference and no reinforcing by the fiber.

2.6.2 Influence of Fiber Orientation and Concentration

Both the arrangement and orientation of the fibers relative to one another and fiber concentration have a significantly influence on the strength and other properties of fiber-reinforced composite [13]. With respect to orientation, two extremes are possible:

(1) As a parallel alignment of the longitudinal axis of the fibers in a single direction.

(2) As a totally random alignment. Often, continuous fibers are aligned and discontinuous ones are randomly oriented.

2.6.3 Continuous and Aligned Fiber Composite

Longitudinal loading: The properties of a composite having its fibers aligned are highly anisotropic, that is, dependent on the direction in which they are measured. Let us first consider the deformation of this type of composite in which a stress is applied along the longitudinal direction. Assume, also that the fiber matrix interfacial bond is very good, such that deformation of both matrix and fibers is the same (an isostrain situation). Under these conditions, the total load sustain by the composite F_c, is equal to the load carried by the matrix phase F_m and the fiber phase Ff [15].

$$Fc=F_m+F_f \quad (1)$$

From the definition of stress (ϬϬ): F=ϬA, and thus, an expression for F_c, F_m and F_f in terms of their respective stresses ($Ϭ_c$, $Ϭ_m$ and Ϭf) and cross-sectional area (A_c, A_m and A_p) are substituted into equation 1 to obtain the equation below (that is equation 2 and 3).

$$Ϭ_cA_c= Ϭ_mA_m+ Ϭ_fA_f \quad (2)$$

Dividing through by the total cross-sectional area of the composite, Ac, we have;

$$Ϭc= Ϭ_mA_m/A_c + Ϭ_fA_f/A_c \quad (3)$$

where A_m/A_c and $A_f/(A_c)$ are the area fractions of the composite, matrix and fiber phases lengths are all equal, A_m/A_c is equivalent to the volume fraction of the matrix V_m and likewise for the fibers $V_f=A_f/A_c$ equation 4 becomes

$$Ϭ_c =Ϭ_mA_m+ Ϭ_fA_f \quad (4)$$

The previous assumption of an isostrain state means that

$$\varepsilon_c =\varepsilon_m=\varepsilon_f \quad (5)$$

and when each term in equation 4 is divided by its respective strain.

$$\frac{Ϭc}{\varepsilon c} = \frac{ϬmVm}{\varepsilon m}+\frac{ϬfVf}{\varepsilon f} \quad (6)$$

Furthermore, if composite, matrix, and fiber deformations are all elastic, then

$\frac{ɓc}{εc} =$ E_c, $\frac{ɓm}{εm} = E_m$, and $\frac{ɓf}{εf} = E_f$

The E's being the elastic moduli for the respective phases, substituting into equation 7 yields;

$$E_c = E_m V_m + E_f V_f \quad (7a)$$

$$E_c = E_m (V - V_f) + E_f V_f \quad (7b)$$

Since the composite consist of only matrix and fiber phases, that is $V_m + V_f = E$.

Thus, the elastic modulus of a continuous and aligned fiber-reinforced composite in the direction of alignment is equal to the volume-fraction weighted average of the elastic moduli of the fiber and matrix phases. Other properties, including tensile strength, also have this dependence on volume fractions.

It can also be shown, for longitudinal loading, which the ratio of the load carried by the fibers to that carried by the matrix is

$$\frac{F_f}{F_m} = \frac{E_f}{E_m} \frac{V_f}{V_m} \quad (8)$$

Transverse Loading: A continuous and oriented fiber composite may be loaded in the transverse direction; that is, the load is applied at an angle of 900 to the direction of fiber alignment [16]. For this situation, the stress ɓ to which the composite as well as both phases are expressed as the same;

$$ɓc = ɓm = ɓf = ɓ \quad (9)$$

This is termed an isostress state. Also, the strain of deformation of the entire composite εc is

$$εc = ε_m V_m + εf V_f \quad (10)$$

Since ε= ɓ/E, then

$$\frac{ɓ}{Ec} = \frac{ɓVm}{Ec} + \frac{ɓVf}{Ef} \quad (11)$$

Dividing through by ɓ

$$\frac{1}{Ec} = \frac{Vm}{Ec} + \frac{Vf}{Ef} \quad (12)$$

$$E_c = \frac{EmEf}{VmEf + VfEm} = \frac{EmEf}{(1 - Vf)Ef + VfEm} \quad (13)$$

2.6.4 Randomly Oriented Fiber Composites

Normally, when the fiber orientation is random, short and discontinuous fibers are used, reinforcement of this type is schematically shown in figure 14

$$E_c = kE_f V_f + E_m V_m \quad (14)$$

In this expression, k is a fiber efficiency parameter, which depends on V_f and the E_f/E_m ratio of course, its magnitude will be less than unity, usually in the range 0.1 to 0.6. Thus, for random fiber reinforcement (as with oriented), the modulus increases in some proportion of the volume fraction of fiber. By summary, aligned fiber composite are inherently anisotropic such that the maximum strength and reinforcement are achieved along the alignment (longitudinal) direction. In the transverse direction, fiber reinforcement is virtually nonexistent; fracture usually occurs at very low tensile stresses, which may be less than the strength of the matrix material. For other stress, orientations, composite strength lies between these extremes. The efficiency of fiber reinforcement for several situations is presented in Table 2; this efficiency is taken to be unity for an oriented fiber composite in the alignment direction, and zero perpendicular to it [16]. An aligned fiber composite is ordinarily utilized when an applied stress is uniaxial, and, of course, the orientation is with the fibers in the stress direction, where multidirectional stresses are imposed within a single plane, aligned layers that are fastened together one on top of another at different orientations.

Table 2: Reinforcement Efficiency of Fiber-Reinforced Composites for Several Fiber Orientations and at Various Directions of Stress Application

Fiber Orientation	Stress Direction	Reinforcement Efficiency
All fibers parallel	Parallel to fibers Perpendicular to fibers	1 0
Fibers in two directions, in proportions a_1 and a_2.	Parallel to direction of a_1 fiber Parallel to direction of fiber a_2	a_1 a_2
Fibers randomly and uniformly distributed within a specific plane	Any direction in the plane of the fibers	3/8
Fibers randomly and uniformly distributed within three dimension is space	Any direction	1/5

Source: Adopted from Materials Selection textbook

2.7 Benefits of Composites

1. Different materials are suitable for different applications. Why composites are selected over traditional materials such as metal alloys or woods, is because of one or more of the following advantages:
2. Relatively low Cost: This is as a result of prototypes, mass production, part consolidation, maintenance, long term durability, production time and maturity of technology.
3. Weight: Light weight and excellent weight distribution is obtainable.
4. Strength and Stiffness: Composites have high strength-to-weight ratio and directional strength and/or stiffness.
5. Dimension: Large parts and special geometry can be produced.
6. Surface Properties: Corrosion resistance, weather resistance and tailored surface finish can be obtained.

7. Thermal Properties: Low thermal conductivity and low coefficient of thermal expansion is obtainable.
8. Electric Property: High dielectric strength, non-magnetic and radar transparency exist in composite material [5].

Note that there is no single material that fits all solution in the engineering world. Also, the above factors may not always be positive in all applications. An engineer has to weigh all the factors and make the best decision in selecting the most suitable material(s) for the project at hand.

2.8 Classification of Composite by Its Uses

Composite can be classified by their uses. Eight different classes based on their use are as follow: (1) geotextiles, (2) filters, (3) sorbents, (4) structural composites, (5) non-structural composites, (6) moulded products, (7) packaging, and (8) combinations with other materials. In some cases one type of composite can be used for more than one use. For example, once a fiber web has been made, it can be directly applied as a geotextile, filter, or sorbent, or can be further processed into a structural or nonstructural composite moulded product, used in packaging, or combined with other resources.

2.9 Structural Composites

A structural composite is defined as one that is required to carry a load in use. In the housing industry, for example, these represent load bearing walls, roof systems, subflooring, stairs, framing components, furniture, etc. In most, if not all cases, performance requirements of these composites are spelt out in codes and/or in specifications set forth by local or national organizations [4]. Structural composites can range widely in performance from high performance materials used in the aerospace industry down to wood-based composites which have lower performance requirements. Within the wood- based composites, performance varies from multi-layered plywood and laminated lumber to low cost particleboard. Structural wood based composites, intended for indoor use, are usually made with a low cost adhesive which is not stable to moisture, while exterior grade composites use a thermosetting resin that is higher in cost but stable to moisture. Performance can be improved in wood-based as well as agro-based composites by using chemical modification techniques to modify fiber properties such as dimensional stability, biological and ultraviolet resistance and stability to acids and bases, or treated with conventional fire retardant and/or, decay control chemicals [18].

2.10 Non-Structural Composites

As the name implies, non-structural composites are not intended to carry a load in use. These can be made from a variety of materials such as thermoplastics, textiles, and wood particles and they are used for products like doors, windows, furniture, gaskets, ceiling tiles, automotive interior parts, moulding, etc. These are generally lower in cost than structural composites and have fewer codes and specifications associated with them. These can be produced by a variety of processes including extrusion, thermo pressing, pulltrusion, sheet moulding, and injection moulding [14].

3. Mechanical Properties

To finalize the material for an engineering product or application, is it important to understand the mechanical properties of the material. The mechanical properties of a material are those which affect the mechanical strength and ability of a material to be molded in suitable shape. Some of the typical mechanical properties of a material include: Strength, Toughness, Hardness, Hardenability,

Brittleness, Malleability, Ductility, Creep and Slip, Resilience, Fatigue Strength**.** It is the property of a material which opposes the deformation or breakdown of material in presence of external forces or load. Materials which we finalize for our engineering products, must have suitable mechanical strength to be capable to work under different mechanical forces or loads.
The formula is: s = P/a Where, s is the tensile strength P is the force required to break a is the cross-sectional area

$$\text{Tensile strength} = \frac{\text{Maximum Load}}{\text{Original Cross – Sectional Area}} \qquad (15)$$

a.Toughness

It is the ability of a material to absorb the energy and gets plastically deformed without fracturing. Its numerical value is determined by the amount of energy per unit volume. Its unit is Joule/ m^3. Value of toughness of a material can be determined by stress-strain characteristics of a material. For good toughness, materials should have good strength as well as ductility. For example: brittle materials, having good strength but limited ductility are not tough enough. Conversely, materials having good ductility but low strength are also not tough enough. Therefore, to be tough, a material should be capable to withstand both high stress and strain.

b.Hardness

It is the ability of a material to resist to permanent shape change due to external stress. There are various measure of hardness – Scratch Hardness, Indentation Hardness and Rebound Hardness.

1. Scratch Hardness
   Scratch Hardness is the ability of materials to the oppose the scratches to outer surface layer due to external force.
2. Indentation Hardness
   It is the ability of materials to oppose the dent due to punch of external hard and sharp objects.
3. Rebound Hardness
4. Rebound hardness is also called as dynamic hardness. It is determined by the height of “bounce” of a diamond tipped hammer dropped from a fixed height on the material.

c. Hardenability

It is the ability of a material to attain the hardness by heat treatment processing. It is determined by the depth up to which the material becomes hard. The SI unit of hardenability is meter (similar to length). Hardenability of material is inversely proportional to the weld-ability of material.

d. Brittleness

Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain. Brittleness is converse to ductility of material. Brittleness of material is temperature dependent. Some metals which are ductile at normal temperature become brittle at low temperature.

e. Malleability

Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress. Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling. This mechanical

property is an aspect of plasticity of material. Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

f. Ductility

Ductility is a property of a solid material which indicates that how easily a material gets deformed under tensile stress. Ductility is often categorized by the ability of material to get stretched into a wire by pulling or drawing. This mechanical property is also an aspect of plasticity of material and is temperature dependent. With rise in temperature, the ductility of material increases.

g. Creep and Slip

Creep is the property of a material which indicates the tendency of material to move slowly and deform permanently under the influence of external mechanical stress. It results due to long time exposure to large external mechanical stress with in limit of yielding. Creep is more severe in material that are subjected to heat for long time. Slip in material is a plane with high density of atoms.

h. Resilience

Resilience is the ability of material to absorb the energy when it is deformed elastically by applying stress and release the energy when stress is removed. Proof resilience is defined as the maximum energy that can be absorbed without permanent deformation. The modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without permanent deformation. It can be determined by integrating the stress-strain cure from zero to elastic limit. Its unit is joule/m^3.

i.Fatigue

Fatigue is the weakening of material caused by the repeated loading of the material. When a material is subjected to cyclic loading, and loading greater than certain threshold value but much below the strength of material (ultimate tensile strength limit or yield stress limit), microscopic cracks begin to form at grain boundaries and interfaces. Eventually the crack reaches to a critical size. This crack propagates suddenly and the structure gets fractured.

4.Conclusion

Fiber-reinforced composite material was found to be one of the most promising and effective types of composites, this acclaims to the dominance over the majority of applications from topmost fields. There are numerous types of fibers available for fabrication of fiber-reinforced composites; those are categorized as natural and synthetic fibers. Synthetic fiber provides more stiffness, while natural fibers are cheap and biodegradable, making them environmentally friendly. Though both types of fibers have their efficacy in significant applications, latest research has revealed the exceptional performance of hybrid fiber-reinforced composite materials, as they gain the advantageous properties of both. Composite materials are fabricated with a number of different techniques, among which every technique is applicable for certain material. Effectiveness of manufacturing technique is dependent on the combination of type and volume of matrix or fiber material used, as each material possesses different physical properties, such as melting point, stiffness, tensile strength, etc. Therefore, manufacturing techniques are defined as per the choice of material. For distinct applications in a variety of fields, certain solitary materials might be replaced with composite materials, depending on the enhancement in its required property. Composite structures have shown improvement in strength and sti_ness of material, while the reduction in weight is magnificent. Composites have also revealed some remarkable features such as resistance to impact, wear, corrosion, and chemicals, but these properties are dependent upon the composition of the material, type of fiber, and type of manufacturing technique employed to create it. In accordance with the properties required, composite materials find their applications in many desired fields. More future research is intended to discover new composite structures with a combination of different variants and adopting new manufacturing techniques.

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