A Review on Fabrication and Physico-Mechanical Characterizations of Fiber Reinforced Biocomposites

SM Surid, M. A. Sayed Patwary, MA Gafur

Abstract: Over the last century and a half, human have learned how to make synthetic polymers into plastic products. As awareness of environmental issues spread, the persistence of plastic waste began to trouble observers. Researchers and innovators are looking for a way to place more environmentally friendly biodegradable materials on the market than conventional plastics. Subsequently, biodegradable biocomposites have entered the market for use in agriculture, medicine, packaging, civil engineering and other sectors. Recently, natural or lignocellulosic fiber-based biocomposites have received a great deal of popularity for various industrial uses and applications owing to their low density and renewability and the major advantages of natural fibres. The physically and mechanically acceptable characteristics of these fibre-reinforced biocomposites (e.g. tensile properties, flexural stress-strain behavior, fracture strength, impact strength), make them more sustainable and attractive than other composites with a remarkable environmental degradability characteristic. This paper depicted a comprehensive review on conventional, advanced and automated fabrication techniques along with related scientific data in an organized way. The aim of this review is to include a thorough overview on biocomposites, natural fiber-reinforced biocomposites, lignocellulosic fiber-based biocomposites, various fiber-reinforced biocomposite production processes, major physical and mechanical properties of fiber-reinforced biocomposites, biocomposite materials and their potential growth.

Index Terms: Biocomposites, Fiber reinforced biocomposites, Fabrication, Physical characterization, Mechanical characterization

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1 Introduction

Human civilization has always researched and investigated to obtain materials with better quality for use at low prices, but sometimes these causes are hazardous to the environment. For the increasing consumption of fossil products, the loss of natural supplies, and the entanglement of plastics growing at an unprecedented pace in the world. Pollution issues, which are growing day by day responsible for plastics use and fossil fuel combustion, impact our everyday lives, and endanger human rights to live. Availability, cheap rate, and easy to use of plastic products, though every class of people can use it an increased amount of plastic waste that causes a negative impact on Bangladesh and also affects Global environment. European Union as a whole and many European governments, in particular, are recently changing conventional policies and revising the policy options to minimize the plastic waste problems [1]. The scientists and researchers are still trying to decrease the use of traditional plastic products and have discovered numerous new approaches that have already eaten up more plastics space and are also developing innovative methods that can help replace plastics in the near future [1].

Composite materials are becoming more common because of their unique characteristics than traditional plastics, and in such materials, a homogeneous matrix is reinforced by a stiffer, tougher, typically fibrous component. For example, fiber-reinforced plastics (FRPs) or fiber-reinforced polymers are materials formed by incorporating Fibers such as glass, carbon, wood, etc. into a polymer matrix based on epoxy, vinyl, etc. FRPs replace traditional stainless steel, premium alloys, carbon steels, and so on. It is very difficult to substitute traditional plastics with biodegradable materials, while the architecture of the materials demonstrates structural and functional stability during storage and use, and these biodegradable materials are efficient for microbial and environmental degradation only when disposed of and with environmentally friendly features. Naturally, these composite materials can't be used as fibers alone, typically fiber is impregnated by a matrix material that works to transfer the load to the fibers. Matrix also restrains the fibers from abrasion and environmental impact. Glass and metal are used as matrix materials, but for these high prices and restriction of using to R&D laboratories, polymers are much more commonly used having the majority of low-to-medium performance applications and epoxy or more sophisticated thermosets having the higher demand in the market. Several important attempts have been made in recent years to put some of the biodegradable composites using natural materials rather than conventional composites. Fiber acts as reinforcement by giving strength and stiffness to the structure of the material while the plastic matrix serves as the adhesive for holding the fibers in place so that suitable structural components can be made in the plastic composites reinforced by fiber. Biocomposites are possible solutions when it comes to balancing costs and acquiring appropriate properties for various purposes and applications. Biocomposites are defined as a special class of composite materials obtained by blending natural fibers or bio fibers or lignocellulosic fibers with bio-based polymers. These materials represent an environmentally friendly and low-cost alternative to conventional petroleum-based materials. For these reasons, the final use of these materials is gradually increasing. These several articles present some of the reviews of different natural fiber-reinforced biocomposites [3-8]. Biocomposites produced using the reinforcement of renewable resources and the reinforcement biopolymer matrix are now an extensive area of research and development due to the promising mechanical properties, recyclability after service,

- ***SM Surid,*** *Research Assistant, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh. Email: Sakibmsurid@gmail.com*
- ***M.A. Sayed Patwary,*** *Research Assistant, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh. Email: Sayedtex97@gmail.com*
- ***MA Gafur,*** *Principle Scientific Officer, PP&PDC, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh. Email: dr.abdul.gafur999@gmail.com*

biocompatibility, and biodegradability of these materials. Various potential applications of such composites in various fields, such as automotive, packaging, and household goods. Natural Fiber-reinforced biocomposites can be used at the same time as low-cost materials with different structural properties [9-12].

This paper focuses on the review of biocomposites and natural fiber-based reinforced biocomposites. This study focused on composites, biocomposites, natural fiber-based reinforced biocomposites, lignocellulosic fiber-reinforced biocomposites, various manufacturing processes of fiber-reinforced biocomposites, physico-mechanical properties of fiber-reinforced biocomposites, selection of materials for biocomposites and also addresses future developments of fiber-reinforced biocomposites.

2 COMPOSITES

A composite material consists primarily of two distinct materials, a fiber acting as a reinforcement and a matrix tend to act as a binder each having its mechanical properties such as stiffness and strength. When the reinforcement and matrix are combined to form a composite, the mechanical properties depend not only on those of the two materials being mixed or blended but also on the relative quantity of each material, the size and shape of the reinforcement and its direction concerning the loads to be added to the composite.

Fibers; natural or, synthetic, offers strength and rigidity and serve as reinforcement in fiber-reinforced composite materials; essentially, the intrinsic properties of these fibers control composite material properties. The matrix material can be described as a continuous process that includes composites of polymer matrix materials, composite of metal matrix materials, and the composite of the inorganic non-metallic matrix by the various matrix materials. A structure contains a mixture of polymers, metals, and ceramics. In short, composite material is a multi-phase system that consists of material and matrix material being reinforced. The reinforcement, for the most part, is harder, stronger, and more rigid than the matrix. The mechanical properties of composite materials are an important function of reinforcement shape and dimensions [13-16].

Natural fibers like wood and some synthetic composites have been used by humans for thousands of years, but in recent times the major developments have occurred. Both vegetable fibers, whether of wood or non-wood origin, consist of three primary cell wall polymers: cellulose, lignin, and polysaccharides matrix (such as pectins and hemicelluloses) connected with cellulose and lignin in the cell wall. Several non-structural components, such as waxes, nitrogenous substances, and inorganic salts, are also present as extractives. In the structure of fibers, vegetable fibers are seen as miniature composites made up of millions of fibrous units known as microfibrils [17-21]. The selection parameters of suitable fibers are the necessary values of the stiffness and tensile strength of a composite. Failure elongation, adhesion of fibers and matrix, thermal resilience, dynamic and long-term behavior, quality, and manufacturing costs are the additional requirements for selecting an acceptable composite material reinforcing fiber. When it comes to contrasting the tensile strength, elasticity, and elongation at breakage of natural fiber with synthetic fibers, it is very clear that hemp and flax fibers will theoretically compare with E-glass fibers, which are used as a comparison because of their significant positions in composite manufacturing [22].

Industrial composite materials are primarily based on thermosets, thermoplastics and polymer matrices. Typically, such fabrics are filled with ceramic bonded fibers such as carbon or glass. Commonly exhibit marked anisotropy, as the matrix is much weaker and less rigid than the fibers. Recent years have seen increased interest in metal matrix composites (MMCs), such as a luminium reinforced with short fibers or ceramic particles and titanium containing long, large-diameter fibers [23-24].

3 BIOCOMPOSITES

This century has seen tremendous developments in the field of polymer science due to environmental considerations and sustainability concerns through the development of biocomposites in green materials. The main and important benefit of these biocomposites can be conveniently disposed of or composted at the end of their life cycle without threatening the atmosphere that is not possible for conventional fiber-based polymer composites. Statistical statistics on Municipal Solid Waste (MSW) landfills are the prevailing choice for waste disposal in many areas of the world, with 70 percent of MSW in Australia being sent to landfills without pre-treatment in 2002 [7,25-26].

Biocomposites are fully degradable composites consisting of natural fibers as a reinforcing process with a biopolymer matrix. Material is described as a biocomposite composed of two or more distinct components (one of which is naturally derived) that are combined to create a new material with improved performance over individual constituent materials. The constituent materials are the matrix and the reinforcing component. The primary load-bearing factor of the reinforcement portion, which may be in the form of fibers, particles, whiskers, and flakes. The matrix used to tie the reinforcement components together and provide mechanical support [27-28].

Not only were these biocomposite materials produced by combining natural fibers and polymers, but there are also several examples where two natural polymers were combined to form a biocomposite with improved mechanical and gas barrier properties. Rice proteins, wheat gluten, egg albumin, and starch were mixed to enhance the composite's functional properties. An hourly biocomposite study is a natural, fiber-reinforced biopolymer composite. This reinforcement part is a natural extract of fibers or cellulose combined with the matrix of a bioplastic. Since natural fiber has good tensile strength, the elongation percentage adds additional strength to the weaker biopolymer matrix and makes it possible to use the biocomposite material in more applications [29-34].

Researchers and scientists have recently focused on the incorporation of nanoparticles or particulate matter such as silicate layers, hydroxyapatite, carbon nanotubes, cellulose, and talc into bioplastics. PLA bioplastics (most often used) is layered silicate clay, as the material properties such as improved traction and bending properties, improved barrier characteristics, high heat distortion temperature and accelerated biodegradation have been dramatically enhanced. These nano-biocomposites are distributed and dispersed by the reinforcement within the biopolymer [35].

3.1 Fiber Reinforced Biocomposites

Biocomposites reinforced by fibers produce reinforcements with lengths greater than cross-section. Fibrous reinforcement is more physical than a chemical way of modifying a substance to suit specific technological applications [36].

3.2 Natural Fiber Reinforced Biocomposites

Natural fibers such as jute, kenaf, hemp, oil palm, pineapple, flax, sugarcane, and leaf are inexpensive, environmentally sustainable, organic, partially and fully biodegradable, and can be used to produce modern high-performance polymer materials. Natural fiber composite materials have significant characteristics that are eco-friendly, lightweight, strong, renewable, cheap, biodegradable, and sustainable. Compared to synthetic fiber it has relatively stronger properties. Recently, due to their advantages over conventional synthetic materials, many researchers and scientists have used natural fibers as an alternative reinforcement in polymer composites. Such natural fibers include jute, hemp, banana, bamboo, sisal, kenaf, coir, flax, sugar cane and many others that have strong mechanical properties compared to man-made fibers and are cost-efficient and sustainable, recyclable and reusable, minimize energy consumption, lower health risk, non-irritation of the skin and non-abrasive of the machinery [8,36-38].

Due to its thermoplastic and thermosetting properties, natural fibers can be used as reinforced material. Thermosetting resins such as epoxy, polyester, unsaturated polyester resin, polyurethane, and phenolic are widely used in the manufacture of composite material and offer a greater output in different applications. They have adequate mechanical properties and the price is fair for such products. Due to their good mechanical properties such as high strength, low density, and ecological advantages, academics, researchers, students, and also Research and Development (R&D) sectors of industries pay more attention to natural fiber-based composites than conventional synthetic fiber-based composites. Since of their biodegradable, non-carcinogenic properties, and the use of natural composites is growing day by day. In 2010, U$2.1 billion natural fiber reinforced polymer composites (NFPCs) were used in numerous manufacturing sectors around the world and after that industry held a major interest in the NFPC and after five years (2011-2016), the NFPCs industry increased the use of natural fiber by about 10% [39].

Along with its cost-effectiveness behavior, it can be used in various sectors such as automotive, building, aerospace, packaging and construction, storage devices, railway coach interiors and is also used as a replacement for high-cost Fiber glass. While natural fiber has many benefits (i.e. low cost, low density, biodegradability, etc.), it also has some drawbacks, such as high absorption of moisture. Chemical treatments are thus essential for controlling the high absorption of moisture. Many factors such as fiber length, fiber-matrix adhesion, fiber aspect ratio, etc. after chemical treatment adversely affect the mechanical properties of the natural fibers. A variety of research work has already been conducted using natural fiber. Besides, these fibers can be used to form light composites which lead to weight reductions and fuel savings, especially in the automotive sector [40-42].

Efficient benefits of being biodegradable and made from renewable materials, natural fibers are often less abrasive to manufacturing equipment than synthetic fibers such as acrylic or ceramic fibers and conventional fillers such as mica and stone and have a lower density, which makes biocomposites lightweight, economical and environmentally safe [43].

3.3 Natural Fibers used for Biocomposites

As natural fibers come from plant, animal, and mineral sources, natural fibers can be divided and classified into three main classes according to their resources. They are plant fibers, mineral fibers, and animal fibers. Lignocellulosic natural fibers are widely used among natural fibers as reinforcements for the production of biocomposites.

3.3.1 Lignocellulosic Natural Fibers

Lignocellulosic fibers (LCFs) are those fibers indicate the predominance of cellulose and lignin in natural plant fibers and these fibers can reach tensile strength values near close to the glass fiber [3].

Between natural fibers, lignocellulosic fibers are explored in polymeric composites as potential replacements of synthetic fibers, and several studies have analyzed the disadvantages and benefits of the most important lignocellulosic fibers and their associated polymeric composites. As described before, it is understood that all forms of plant fibers are made up of cellulose and animal fibers contain protein. There are three main chemical components of lignocellulosic fibers, namely cellulose (α-cellulose), hemicellulose, and lignin. Often, lignocellulosic fibers contain small quantities of pectin, waxes, and water-soluble substances. Bledzki and Gassan also suggested that a single plant fiber is a dynamic natural material made up of many cells. These cells are composed of microfibrils of cellulose linked by lignin and hemicelluloses. Lignin is an amorphous binder with both aliphatic and aromatic polymeric constituents, whereas hemicellulose consists of polysaccharides which remain associated with cellulose even after lignin is removed. The ratio of cellulose to lignin / hemicellulose as well as the longitudinal angle of the microfibrils ranges from one natural fiber to another. Since these structural parameters define the mechanical properties, every form of LCF has distinct properties [3-4, 44-46].

Lignocellulose fibers compositions and structures vary greatly, depending on plant species, age, climate, and soil conditions. The information on the chemical composition of lignocellulosic fillers and fibers is important because it determines their properties and thus their applications [12].

Table 1: Chemical composition and structural parameters of common lignocellulosic fiber [7-8, 47-51]

Fiber	Cellulose (wt %)	Hemicellulose (wt %)	Lignin (wt %)	Pectin (wt %)	Wax (wt %)	Water soluble (wt %)	Microfibrillar angle (deg)
Flax	71–78	18.6–20.6	2.2	2.3	1.7	3.9–10.5	5–10
Hemp	70.2–74.4	17.9–22.4	3.7–5.7	0.9	0.8	2.10	2–6.2
Jute	61–71.5	13.6–20.4	12–13	0.2	0.5	1.2	8
Kenaf	45–57	21.5	8–13	3–5	N.S.	N.S.	N.S.
Ramie	68.6–76.2	13.1–16.7	0.6–0.7	1.9	0.3	6.1	7.5
Banana	63–64	10	5	N.S.	N.S.	N.S.	11
Sisal	67–78	10-14	8-11	10	2	13	10–22
Pineapple	80–83	15–20	8–12	2–4	4-7	1-3	8–15
Abaca	56–63	21.7	12–13	1.0	0.2	1.6	N.S.
Henequen	77.6	4–8	13.1	N.S.	N.S.	N.S.	N.S.
Cotton	85–90	5.70	0.7–1.6	0–1	0.6	1.0	20–30
Coir	36–43	0.15–0.25	41–45	3–4	5.2–16.0	N.S.	30–49
Oil Palm	65	0–22	19	N.S.	N.S.	N.S.	46
Hardwood	43–47	25–35	16–24	N.S.	N.S.	N.S.	N.S.
Softwood	40-44	25-29	25-31	N.S.	N.S.	N.S.	N.S.

N.S. = Not Specified.

4 FABRICATION OF FIBER REINFORCED BIOCOMPOSITES

Diverse processing approaches for bio-composites have been studied. Which are divided into two groups depending on the reinforcing forms used: (i) particle or small fibers and (ii) continuous fibers. Woven fabric has been developed from natural fibers as substitutes for the continuous bio-composites reinforced by fibers [52].

Fabrication process of laminated composite with four layers of jute woven fabrics has been introduced and done. By saturating in the resin matrix, the jute fabrics were treated with alkali in the biaxial tensile stress state. Therefore, the mechanical stiffness of the composite with the fibers treated with alkali has been improved under applied stress. From research results, it was found that leaf fiber (Pineapple leaf fiber or PALF, Henequen) based biocomposites show very high impact strength while bast fiber (Kenaf, Hemp, etc.) based bio-composites exhibit superior flexural and tensile properties. Proper pre-treatment of bio-fibers like alkali treatment (AT) and/or silane treatment (ST), the water absorption of the resulting bio-composites could be reduced [53-54].

For fabricating continuous or discontinuous fiber reinforced composites, a commingled technique was developed for the preparation of thermoplastic composites such as PP. To prepare the continuous fiber composites, both the reinforcement and matrix fibers are mingled into yarns or fabrics, while both fibers are entangled into nonwoven mats for the preparation of chopped fiber composites. Heat and pressure are applied to the commingled perform only the resin fibers within them melt and flow, forming a continuous matrix phase between the reinforced fibers for converting them into solid composites. This fabrication method is exploited to manufacture bio-composite material using a carding process, which is used to make uniform blends of discontinuous natural fibers such as jute or kenaf with synthetic fibers for use as the matrix.

The mixed manufacturing method using the carding process can be an effective means of processing bio-composites using long and discontinuous natural fibers, as it can avoid the process of converting them into continuous yarns, which allows cost reduction and uniform distribution of the fibers in the composites. Long fibers here apply to fibers with a median length of a hundred millimeters relative to short fibers [55].

Typical processing techniques include Hand Lay-up, Spray-up, Pultrusion, Compression molding, Injection molding, Vacuum bug molding, Vacuum infusion molding, Resin transfer molding, Hot compression technique, sheet molding compounding, Solvent casting method, Electrospinning process, Additive manufacturing, Filament winding process.

Typical processing techniques include extrusion, injection molding, compression molding, pultrusion and filament winding, direct long-fiber thermoplastic (D-LFT) is suitable and investigated for natural fiber reinforced thermoplastic biocomposites [8, 56]. On the other side, resin transfer molding (RTM) and sheet molding compound (SMC) is implemented with thermosets matrices. Processing methods and suitable processing conditions have a significant influence on the parameters (moderate temperatures (below 200°C), dispersion, orientation, and aspect ratio) that determine the mechanical properties of a natural fiber-reinforced biocomposites [57].

Therefore, to choose a suitable process to fabricate natural fiber-reinforced biocomposites, design, and manufacturing engineers would mainly focus on several criteria including desired properties, size, and shape of resultant composites, the production rate, processing qualities of raw materials and the manufacturing cost [58].

Table 2: Various fabrication techniques of Lignocellulosic Fibers.

Fiber	Matrix	Processing Methods	Reference
Jute	PBS	HAAKE Mixer	59
Kenaf	PLA	Compression molding	60
Cotton	Wheat flour-based plastic	Extrusion	61
Jute	PLA/P(3HB-co-4HB)	Injection Molding	62
Flax	Starch	Hot pressing	63
Ramie	PLA	Two-roll milling	64
Bamboo	PLA	Extrusion	65

4.1 Conventional Manufacturing Techniques

Conventional processing techniques are used for making composite materials, Fiber-reinforced plastics(FRP), Natural Fiber-reinforced composites(NFRC) and biocomposites include Hand Lay-up, Spray-up, Pultrusion, Compression molding, Injection molding, Vacuum bug molding, Vacuum infusion molding, Resin transfer molding, Hot compression technique, sheet molding compounding, Solvent casting method.

Hand Lay-up: The simplest and oldest open molding method of the composite fabrication process is the hand lay-up method. By this process, low-volume, labor-intensive methods suited especially for large components, such as boat hulls. Fiber or other reinforcing mat or woven fabric or roving is positioned manually in the open mold, and resin is poured, brushed, or sprayed over and into the chopped fiber where the secondary spray-up layer embedded the core between the laminates, resulting in the composite. To complete the laminate structure the entrapped air is removed manually with squeegees or rollers. Room temperature curing polyesters and epoxies are the most commonly used matrix resins. Curing is a process that is initiated by a catalyst in the resin system that hardens the fiber-reinforced resin composite without external heat. A pigmented gel coat is first applied to the mold surface for a high-quality part surface. A mold release agent is applied onto the mold surface for ease of removing of finished composite products.

- The laying-up of a component begins with applying a gel coat to the mold surface.
- It is a resin-rich layer and the purpose is to prevent the fibers from appearing on the mold surface.
- The composites are then prepared by placing a fiber reinforcement and by adding polymer resin onto it.
- A roller is used to consolidate the composites and the composites are made layer by layer.
- The process is repeated with more layers until the desired thickness is obtained.
- Then the composites are cured at room temperature or in an oven.
- Thermosetting resins like unsaturated polyester, vinyl ester, and epoxy are among the most commonly used resins [66].

Spray-up process: The spray-up technique is a similar process of hand lay-up. A handgun is used that sprays resin and chopped fibers on a mold. Simultaneously, a roller is also used to fuse these fibers into the matrix material. This technique is an open mold type of technique, where chopped fibers provide good conformability and quite faster than the hand lay-up method [67-68].

Pultrusion: Pultrusion is a combination of two words, pull and extrusion. It is a production process to produce continuous lengths with constant cross-sectional reinforced polymer structural shapes. The raw materials are a liquid combination of resin and the lightweight woven fibers reinforced (containing glue, fillers, and advanced additives). The method involves dragging these raw materials into a hot steel shaping die using a continuous pushing unit (rather than squeezing, as occurs in extrusion). While pultrusion machine design varies with part geometry, the basic pultrusion process concept is described in the schematic shown below:

- The process is similar to the extrusion process, but in pultrusion, the product is developed by pulling the materials rather than pushing the materials through the die as in the case of extrusion.
- Continuous fiber rovings or tapes are pulled using a puller through a resin bath of a thermosetting polymer.
- Examples of thermosetting polymers that can be used in this process include epoxy and unsaturated polyester.
- The resulting impregnated fiber composites leave the resin bath and are being pulled and passed through a series of forming dies.
- The shape of the final product follows the shape of the cross of the dies and the shape can be circular, rectangular, square, and I-shaped and H-shaped sections.
- The composite is also cured in one of the dies. The end products are normally in the form of rods and bars. At the end of the pultrusion process, the products are cut to the required lengths.

Compression molding: Compression molding is a common process used for both thermoplastic and thermoset stock shape materials.

- Compression molding is accomplished by placing the plastic material (can be a granular or pelletized form) in a mold cavity to be formed by heat and pressure. The process is someone similar to making waffles.

- The heat and pressure force the materials into all areas of the mold. The heat and pressure cycle of the process will harden the material and then it can be removed.
- Typically, thermosetting compounds like polyesters, phenolics, melamines and other resin systems are compression molded using alternating layers of different reinforcement materials to create a final product.
- However, various thermoplastics are commercially compression molded as well.
- Compression molding offers a high degree of automation, short cycle times, good reproducibility and excellent dimensional stability for both thermoplastics and thermoset which is the reason for diverse applications in various industrial sectors including the automotive industry.

Injection molding: Injection molding is a manufacturing technique widely used for the manufacture of products from plastic trinkets and toys to car components, mobile phone covers, water bottles and containers. Injection molding may also be used to produce composite polymer products, but the fibers used in the composites are short particle or powder fibers.

- In a typical injection molding process, fiber composites in the form of pellets are fed through a hopper, and then they are conveyed by a screw with a heated barrel.
- Once the required amount of material is melted in a barrel, the screw injects the material through a nozzle into the mold where it is cooled and acquires the desired shape.
- Injection molding is found to be very effective for thermoplastic encapsulations of electronic products required in medical industries.
- Improvement in fiber-matrix compatibility and uniformity in the dispersion of fibers in the matrix material is achieved during the surface treatments of biocomposites [69-70].

Resin Transfer molding: Resin Transfer Molding (RTM) is an established manufacturing process of composites normally used to manufacture automotive and aircraft components. During this process, fiber reinforcement is initially cut using a template and a knife or scissors, either long or woven fibers. Such reinforcements called performs are bound by means of thermoplastic binder and then put in the closed mold cycle within the mold cavity. Resin is transferred through a variety of equipment, such as pressure or vacuum, into the mold cavity. Resins commonly used in this process include polyester, epoxy, phenolic and vinyl ester.

Salim et al. (2011) used RTM to build composite experiments for epoxy composites reinforced by nonwoven kenaf fiber mat. After a series of processing such as opening, carding, cross lapping, and needle punching procedures, Kenaf fiber mats were prepared. Stitching density was designed to test their effects on the composite's mechanical properties. Therefore, the effects of fiber loading on the mechanical properties were also observed. Compared with unstitched kenaf mat composites, the mechanical properties increased when the kenaf mat was sewn in composites.

A variety of combinations of fiber material with its orientation, including 3D reinforcements, can be achieved by RTM. It produces high-quality, high-strength composite structural parts with surface quality matching to the surface of the mold.

4.2 Advance Manufacturing Process

Emerging nanotechnology has inspired researchers to figure out new methods for the production of composite materials on the nano scale fiber. A process called electrostatic fiber processing uses electrospinning forces to produce two nano-meter to multiple micrometers of continuous fibres. The spinneret-shaped polymer solution forms a continuous fiber collected at the collector. It has enhanced physical and mechanical properties, stability over process parameters, high surface-to-volume ratio and lower porosity; thus, it has promise in numerous fields of biomedical applications such as wound healing, tissue engineering scaffolds, drug delivery, biosensor membrane, enzyme immobilization, cosmetics, etc. [71-72].

4.3 Automated Manufacturing Techniques

Filament winding: It is a continuous process that leads to self-automation to reduce cost. Filament winding is useful to create axisymmetric, as well as some non-axisymmetric, composite parts, such as pipe bends. Driven by several pulleys, continuous prepreg sheets, rovings, and monofilament are made to pass through a resin bath and collected over a rotating mandrel. Then, after applying sufficient layers, mandrel, which has the desired shape of the product, is set for curing at the room temperature. Recently developed robotic filament winding (RFW) technique is provided with an industrial robot equipped with a feed and deposition system. It yields advantages over process control, repeatability, and manufacturing time by replacing a human operator [73-76].

5 CHARACTERIZATIONS OF FIBER REINFORCED BIOCOMPOSITES

Fibers provide strength and stiffness and act as reinforcement in fiber-reinforced composite materials; ultimately the properties of a composite are governed by the inherent properties of these fibers. Careful selection of the reinforcing fibers and matrix polymers, in light of the intended application, is the first step in obtaining a composite with the desired properties. Natural fibers are of basic interest since they can be functionalized and also have advantages from weight and fiber-matrix adhesion, specifically with polar matrix materials. They have good potential for use in waste management due to their biodegradability and their much lower production of ash during incineration. Nevertheless, the properties of a biocomposite may be controlled and indeed enhanced by altering those factors that control composite properties, namely fiber architecture and the fiber–matrix interface. The natural fiber reinforced polymer composites performance depends on several factors, including fibers chemical composition, cell dimensions, microfibrillar angle, defects, structure, physical properties, and mechanical properties, and also the interaction of a fiber with the polymer. To expand the use of natural fibers for composites and improved their performance, it is essential to know the fiber characteristics [23, 77].

5.1 Physical Characterizations

Each natural fiber's physical properties are critical, including the dimensions, defects, strength and structure of the fiber. For through natural fiber, several other physical properties are necessary to learn about before fiber can be used to achieve its full potential. Taking into account the fiber dimensions, defects, strength, variability, crystallinity, and structure.

Knowledge of fiber length and width is important to compare natural fibers of different types. For cellulose-based fiber composites, a high aspect ratio (length/width) is very important because it indicates potential strength properties. In a given application, the fiber quality may be a significant consideration when choosing a particular natural fiber. Differences in fiber morphology can be caused by variations in physical properties. Major structural differences such as density, thickness of the cell wall, length, and diameter result in differences in physical properties. It is also interesting to note that the morphology of fibers ground plant is very different from that of fibers water plant. The cellulose content and the angle of the spiral between the fiber qualities are different from fiber to fiber and also in a single fiber design.

Natural fibers crystallinity values vary across various parts of the plant. As the plant matures, the crystallinity tends to decrease, but the difference between bast and core fibers is inconsistent [77].

5.2 Mechanical properties

It is important to be knowledgeable of certain mechanical properties of each natural fiber to be able to exploit the highest potential of it. Among these properties are the tensile, flexural, impacts, dynamic mechanical and creep properties.

Drying of the fiber before processing is necessary because moisture on the fiber surface acts as a debonding agent at the fiber–matrix interface. Additionally, because of water evaporation during the reaction, voids appear in the matrix (thermosets have a reaction temperature above 100°C). Both the aspects lead to a decrease in the mechanical properties of biocomposites [78].

Tensile properties: The tensile properties are among the most widely tested properties of natural fiber reinforced composites. The fiber strength can be an important factor regarding the selection of a specific natural fiber for a specific application. A tensile test reflects the average property through the thickness, whereas a flexural test is strongly influenced by the properties of the specimen closest to the top and bottom surfaces. The stresses in a tensile test are uniform throughout the specimen cross-section, whereas the stresses in flexure vary from zero in the middle to maximum in the top and bottom surfaces.

Under tensile load, composites with efficient stress transfer show higher strength, higher stiffness and lower strain at break than those with a weak interface. Rao et al. investigated the tensile properties of bamboo, date palm, abaca, oil palm, sisal, coir and vakka fibers regarding their fiber cross sections, atmospheric moisture content and density. Khan, Ruhul A. et al. showed the value of TS is found to be 59.3MPa for 40% jute-containing composite which gained 77.17% increase in TS, respectively, than those of PVC matrix. TSs of 20% and 60% jute-containing composites are found to be 39.83 MPa and 51.13 MPa, respectively [78-80].

Flexural properties: The flexural stiffness is a criterion of measuring deformability. The flexural stiffness of a structure is a function based upon two essential properties: the first is the elastic modulus (stress per unit strain) of the material that composes it; and the second is the moment of inertia, a function of the cross-sectional geometry.

Biocomposites were fabricated from chopped hemp fiber and cellulose ester biodegradable plastic via two different processes: powder impregnation by compression molding and an extrusion process followed by an injection molding process. Fabricated through process extrusion followed by injection molding process of hemp (30 wt%) fiber reinforced cellulose acetate biocomposite exhibited flexural strength of 78 MPa and modulus of elasticity of 5.6 GPa as contrast to 55 MPa and 3.7 GPa for the corresponding hemp fiber/PP based composite. The corresponding biocomposites showed superior flexural strength and modulus values during the extrusion and ensuing injection molding processes, as compared to biocomposites powder impregnated through compression molding process [81].

Impact properties: Impact strength is the ability of a material to resist fracture under stress applied at high speed. Biofiber reinforced plastic composites have properties that can compete with the properties of glass fiber thermoplastic composites, especially concerning specific properties. However, one property, namely the impact strength is often listed among the major disadvantages of biofiber reinforced composites. In recent years, the development of new fiber manufacturing techniques and improved composite processing methods along with enhancement of fiber/matrix adhesion has improved the current situation somewhat.

The impact strength of the bamboo fiber/PLA composites decreased after addition of bamboo fiber. The impact strength of treated fiber reinforced composites improved after the addition of treated fibers. Good fiber/matrix adhesion provides an effective resistance to crack propagation during impact tests. The impact strength increased significantly (33%) for silane treated bamboo fiber/PLA composites compared to untreated bamboo fiber/PLA composites with 30 wt% fiber content [82].

Table 3: Mechanical properties of different natural fibers and traditional fibers [3-4, 83-88].

Fiber type	Modulus (GPa)	Density (g/cm3)	Specific strength (modulus/density)
E-Glass	70–73	2.5–2.55	27.5–29.2
Jute	13–26.5	1.35–1.46	8.9–19.6
Flax	27.6–70	1.4–1.5	19.7–50
Hemp	70	1.48	47.3
Cotton	5.5–12.6	1.5–1.6	3.4–8.4
Ramie	61.4–128	1.45	42.3–88.3
Coir	4–6	1.15	3.48–5.2
Sisal	9.4–38	1.33–1.45	6.5–28.6

Table 4: Variation of mechanical properties of various natural Fiber-reinforced polymer composites [89-91].

Type of composite	Tensile strength (MPa)	Young's modulus (GPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength	Hardness (R L)
Jute-PP	23–29	1.6–2.4	45–54	1.7–2.8	30–51 J/m	76–91
Coir-PP	25–28	1.7–2.7	47–49	1.6–2.8	41–54 J/m	85–87
Abaca-PP	23–27	1.6–2.6	46–48	1.4–2.6	39–46 J/m	79–86
Bagasse-PP	17–22	1.2–1.4	21–34	0.8–1.6	3.3–6.2 KJ/mm^2	N.S.
Banana-PP	36–41	0.82–0.98	N.S.	N.S.	10.2–12.8 KJ/mm^2	N.S.
Hemp-PP	27–29	1.6–1.8	N.S.	N.S.	N.S.	N.S.
Palm-PP	21-30	1.1-1.6	44-55	1.6-2.6	39-53 J/m	92-96

Tensile, flexural, and impact properties are the most widely studied mechanical properties of natural fiber-reinforced polymer composites. Impact strength in terms of mechanical performance is one of the undesirable weak points of such materials. In addition to these tensile, flexural and impact properties, the long-term performance (creep behavior), dynamic mechanical behavior, and compressive properties of natural fiber composites are also investigated. To improve performance to the desired level, still much work is to be done considering Fiber processing, non-linear behavior, fiber–matrix adhesion, fiber dispersion, composite manufacturing with optimized processing parameters [89-91].

5.3 Chemical properties

The chemical composition varies from plant to plant, and within different parts of the same plant. It also varies within plants from different geographical regions, ages, climate and soil conditions. The chemical properties are influenced by the fiber growth time (days after planting), the botanical classification of the fiber and the stalk height. The chemical composition can also vary within the same part of a plant. Both the root and stalk core have a higher lignin content than that of the fibers.

The chemical composition of the natural fibers, which varies depending on the plant from which they are derived, consists mainly of cellulose (50–70 wt%), hemicellulose (10–20 wt%), lignin (10–30 wt%), and pectin and waxes in smaller amounts [8].

6 MATERIAL SELECTION FOR BIO-COMPOSITES AND ITS IMPORTANCE

Selecting materials is an important procedure for selecting specific material properties from a cluster of defined nominees after the physical design structures have been determined. Or identifying materials after appropriate manufacturing processes, which will hold the dimensions, shapes, and properties desired for the product to perform its required function at the lowest cost. Material selection for a specific purpose is an important task since materials play a significant role during the whole product design process. It requires interdisciplinary efforts with experts from diverse backgrounds, depending on the product field of application. The materials selection process is considered as the main step of engineering design. Materials are responsible for function, shape, and interaction with other components of the product, also the effect on customer selection decision [92-100].

7 FUTURE DEVELOPMENTS

As a result of the enhancement of fiber quality as well as polymer-fiber measurement methodologies, advances, and emerging patterns for biocomposites occurred. In addition to composite processing, this encourages all treatment and interfacial engineering. Therefore, considering bio-materials, it is necessary to find practical motivations concerning environmental performance. This would allow designers to make informed judgments without exhaustive experimental work and without wasting time and effort. Such proposed methods may include elaborating more desired characteristics of bio-composites' constituents that designers have to take into consideration for sustainable designs to enhance achieving better performance for the future [77].

8 CONCLUSIVE REMARK

Researchers and investigators found many problems associated with the utilization of plastic-based products such as increasing costs and most importantly its negative impact on the environment. Therefore, researchers have recently discovered and focused their attention on biocomposites. Petroleum-based materials are replacing day by day by the development of biocomposites and also an alternative solution of synthetic fibers based plastic composite products and generating more economic opportunities for the civil engineering sector. Further multidisciplinary research in the fields of engineering, agriculture, biology, and economy along with government support through education, multiple training programs, and giving tax reduction and breaks. Most importantly, eco-friendly or, environmentally friendly biocomposites from plant-derived fibers would be the blessing materials of this century as a solution to the increased environmental threats. Most research works have been carried out to study the potential uses of natural fibers for various technical applications. Among the most popular natural fibers; jute, hemp, flax, sisal, ramie, and kenaf fibers were extensively researched and employed in different applications. But in recent days, abaca, pineapple leaf, coir, oil palm, bagasse, and rice husk fibers are gaining interest and importance in both research and applications due to their specific properties and availability. A multidisciplinary step for the manufacturing process is required in order to produce high-quality natural fibers that contributes to the cost of high-performance natural fibers as well as the improved mechanical properties of the composites. Natural fibers or, biofibers or, lignocellulosic fibers surface modifications, development of bio-plastic as a suitable matrix for composite material processing, and fabrication techniques play vital roles in designing and engineering biocomposites of commercial interest. Biocomposites reinforced with natural fibers and/or biopolymers are predestined to find more and more applications in the near future, especially in Europe, where pressure from both legislation and the public is rising. Biocomposites in building materials offer several significant advantages such as they are cheap, lightweight, biodegradable, environmentally friendly, bio-renewable, and more durable. Several studies are examined, reviewed, and highlighted in this review paper regarding the importance of fiber-reinforced biocomposites as well as fabrication methods, physical and mechanical properties of biocomposites with future developments. Further research is required to overcome some obstacles such as inadequate toughness, moisture absorption, and reduced long-term stability for outdoor applications. Efforts to develop fiber-reinforced biocomposite materials with improved performance for global applications is an ongoing process. To get a large market share and profits, the need to manufacture fiber-reinforced biocomposites to the industries in a wide range.

Acknowledgement

None.

Conflict of Interest

There is no conflict of interest in this work.

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