
APPLICATIONS OF BIOBASED COMPOSITES: CURRENT DEVELOPMENTS AND FUTURE OPPORTUNITIES -A REVIEW

Mani vannan M¹, Akash Kumar A², Hariharan A³

^{1,2,3}Alpha College of Engineering, Chennai, India.

ABSTRACT

The growing awareness of the environment has encouraged efforts to configure biobased composite materials for various end uses and as a novel substitute for traditional non-renewable synthetic fibers like glass and carbon reinforced composites.

However, biocomposite materials are not a perfect replacement; they have certain disadvantages as well, including low moisture resistance, low thermal stability, flammability, poor electrical properties, difficulties related to extraction, processing, machining, manufacturing, and characterization, and highly anisotropic properties. Many studies have been conducted recently to address issues related to characteristics, sustainable production, long-term durability, dependability, and serviceability.

We look over the general characteristics of the most widely used biofibers that are used to create biocomposites, such as their extraction methods, chemical makeup, and mechanical and physical attributes.

The methods and developments for improving the characteristics of biocomposites such as the treatment and modification of fibers, fiber hybridization, filler integration, sophisticated manufacturing processes, and the search for new sources of biofiber are also examined.

Keywords: Biobased composites, Biofibers, Sustainability , applications

1. INTRODUCTION

Considerable progress has been made in biocomposites with regard to the utilization of different raw materials, processing, characterization, applications, etc. Hemp, wood, basalt, rice husk, coir, sisal, ramie, flax, kenaf, jute, and other biofibers are attracting a lot of attention as possible substitutes for synthetic fibers like carbon and glass. [1, 2]. The extraction of biofibers is a crucial step that affects the properties of the reinforcements. By gathering, transporting, and processing new materials, biofibers can create jobs in rural areas and improve living conditions because they have been shown to be effective reinforcing materials in a variety of matrices and are now more widely used in commercial products. [3].

Compared to their conventional counterparts, biocomposites exhibit a number of significant properties, including relatively high specific mechanical properties, thermal insulation, CO neutrality, good damping properties, high fatigue and health safety, availability, high abrasive and corrosion resistance, low density, less production energy, and light weight. The use of biocomposites in automobile components has grown significantly in recent years, especially among European automakers. According to EU standards known as EURO 6, which went into effect in 2020, cars that emit 95 g/km of CO₂ are subject to significant taxes. [4]

According to a recent survey, the worldwide biocomposites market is expected to develop at a compound annual growth rate (CAGR) of 11.8% between 2016 and 2024. The biocomposite market was estimated to be worth USD 4.46 billion in 2016. The construction industry accounted for the majority of the market's utilization (56.0%). According to the biocomposites market prediction research, the industry is expected to grow from \$4.46 billion in 2016 to \$10.89 billion by 2024. Stated in various ways, the percentage of materials made from biobased feedstock is projected to increase from 5% in 2004 to 12% in 2010, approximately 18% in 2020, and over 25% in 2030. [5] However, biocomposite materials are not a perfect replacement; they have a number of shortcomings, including low moisture resistance, incompatibility with fiber/matrix, logistical problems with supply, flammability, challenging processability, and highly anisotropic characteristics (fiber variability). [6].

Furthermore, the characteristics of a biofiber naturally differ depending on where it comes from, which causes a big difference in the characteristics and longevity of biocomposites. [7]. To achieve long-term durability and characteristics, various issues related to materials and production must be solved. Because biofibers contain large amounts of cellulose, hemicelluloses, pectin, lignin, and other very hydrophilic materials, when they are implanted into hydrophobic polymers, the interfacial bonding is poor. [6]. These characteristics may cause the finished composite to lose its mechanical and thermal stability, which would eventually prevent it from being used in load-bearing applications across a range of industries. [8].

2. BIOFIBERS

Biofibers are made from a variety of biological sources, including minerals, plants, and animals. They are used as reinforcements in composite materials. Considerable attention has also been drawn to the use of biofibers, especially jute, flax, hemp, and kenaf, for structural applications because of their remarkably specialized mechanical qualities to cost ratio. [9].

2.1. Classification of biofibers

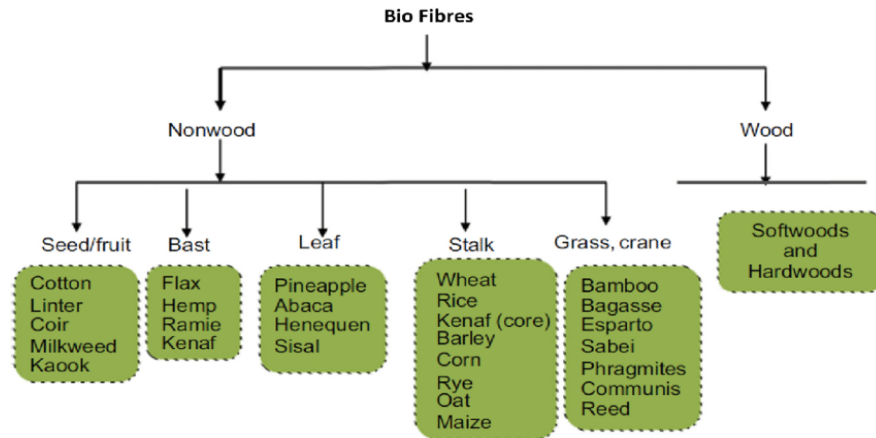


Fig .1 Classification of biofibres

3. BIOFIBERS FROM PLANTS

Plant fibers are divided into primary and secondary fiber categories based on their intended use. While secondary fibers (pineapple, oil palm, banana, coir, etc.) are byproducts of primary fiber cultivation, primary fibers (cotton, sisal, hemp, kenaf, jute, etc.) are grown for their fibers [10]. Plant fibers are classified according to their origin within the plant, such as the leaf, bast, seed, grass, fruit, wood, etc. [11].

The biocomposites produced from date palm can be used as an ecologically friendly and cost-effective replacement for high-performance lightweight applications in the automotive and marine sectors. One of the most widely available biofibers in the Middle East and North Africa is date palm leaves. Sixty-two percent of the world's 100 million date palm trees are found in North Africa and the Middle East. The leaves of date palm trees have a lot of potential uses, including enriching soil, producing energy, producing paper, and absorbing heavy and hazardous metals. Unfortunately, the a significant portion of date palm remains as waste in landfills with no intended use..

Dhawal et al. studied the impact behavior at low velocities and tensile strength of biocomposites based on date palm fiber and polycaprolactone (PCL) that are produced through extrusion. The tensile strength increased by approximately 28 weight percent (from 19 MPa to 25 MPa) and 101.42 MPa (from 140 MPa to 282 MPa) when date palm fibers were used to reinforce the PCL. In a similar vein, the specimens demonstrated improved impact resistance. [12]

4. PROCESSING TECHNIQUES OF BIOFIBERS

The primary step in processing biofibers is the fiber extraction process. Plant fiber extraction and processing involve a variety of techniques. The method that is used the most frequently is water retting. To prevent fiber breakdown during this retting procedure, the evaluation period needs to be continuously observed. [13]. To reduce the processing time, other mechanical, enzymatic, chemical, and microbiological techniques are also used. [14]. During the water retting process, additional water enters into the center section of the stem, breaking off the outer layer (bast fibers). This technique is used in ponds, lakes, and

5. FACTORS AFFECTING FABRICATION OF BIOCOMPOSITES

5.1 Thermal stability

The degradation of many biofibers occurs when the processing temperature rises. The deterioration of fibers is caused by changes in their physical and chemical properties during heating, such as oxidation, decarboxylation, dehydration, recrystallization, hydrolysis, and depolymerization. [15]. These situations may negatively impact the mechanical and functional qualities of biocomposites due to the high temperature. [15]. A biocomposite's thermal stability is influenced by both the moisture content and the chemical makeup of the constituent elements. Hemicellulose- and extractive-rich biofibers are particularly susceptible to heat deterioration. larger crystallite size and crystallinity index indicate larger levels of crystalline cellulose in the fibers, which also indicate stronger thermal stability.

5.2. Distribution of fibers

In a biocomposite, poorly distributed reinforcements cause fiber-rich (cracking-prone) or fiber-deficient (weak) regions. The distribution of the fibers in the biocomposites can be influenced by process variables, fiber diameters, fiber orientation, and physical and chemical treatments (such as coupling agents, alkali treatment, etc.). [16].

5.3. Machining related challenges

The components made of composites are assembled using machining methods. Because of their unique microstructure, biocomposites require overall highly intricate machining compared to other synthetic or isotropic materials. Damages like peel-up, debonding, matrix cracking, etc. are largely caused by machining, which lowers the material's mechanical performance. [17].

6. CONVENTIONAL FABRICATION METHODS FOR BIOCOMPOSITES

Typically, the same traditional fabrication methods that are used to create synthetic composite materials are also employed to create biocomposites. Extensive research is needed to produce high-performance bio composites that can be used for a variety of novel applications.

- Material extrusion: A hot nozzle is used to extrude melted material against a build plate. Typically, the process is referred to as fused filament fabrication (FFF) or fused deposition modeling (FDM). [18].
- Vat photopolymerization: For fabrication, it uses photopolymers that have been UV-cured (stereolithography, or SLA).

Fused filament fabrication (FFF) is the technique that is most frequently utilized in the literature to produce biocomposites among other approaches. The ability to create complicated geometries for commercial and research purposes, as well as minimal manufacturing costs, time consumption, and waste, are the primary advantages of FFF. [19].

The mechanical performance of the structure is greatly influenced by FFF printing parameters (like layer thickness, infill pattern, print orientation, interbead distance, etc.) and slicing parameters (like nozzle temperature, bed temperature, filament feed rate, bed calibration, nozzle geometry, etc.). [20].

7. ADVANTAGES OF BIOFIBERS

Some of the main benefits of biofibers consist of [21, 22]:

- Reusable, recyclable, eco-friendly, reduced reliance on fossil fuels, and carbon neutral.
- Many sources are readily available, and residues obtained through processing pose no risks.
- Affordable and capable of reducing manufacturing costs.
- The methods used to treat and dispose of biofibers are safe for the environment.
- Have a shorter processing temperature need and less wear and tear on the processing instruments, extending their lifespan.
- Lightweight, which increases fuel efficiency in automobile and aerospace applications
- Offers higher specific mechanical characteristics than glass fibers in comparison. \
- Superior sound, heat, and acoustic absorption capacity. • Using agricultural goods leads to increased job prospects.

Drawbacks of biofibers [23]:

- High water absorption causes swelling, which affects dependability, durability, and performance.
- Weak adhesion and incompatibility between some fiber/matrix systems are caused by poor wettability.
- Significant variations in fiber characteristics/quality severely affect the performance of bio composites.
- Easily damaged by high temperature, easy flammability, and low thermal conductivity; • Open to fungal and microbial attacks.
- Depending on the growing environment, a same category of fiber has different properties and costs.
- Crop output has a significant impact on supply fluctuations.

Future trends and challenges in biocomposites

Large-scale AM (high deposition rate and build volume) with six degrees of freedom of movement was developed by Zhao et al. for biocomposites, allowing for the quicker and less expensive printing of complicated geometries. [24] These skills could potentially open up novel opportunities for the production of high-performing biocomposites. But there are additional costs associated with its implementation. The creation of methods for producing lightweight biocomposites that are 4D printed could offer a novel way to combine self-sensing and actuation (autonomous and shape-morphing) properties in materials made of locally accessible resources. With this feature, a structure's

component count, material requirements, assembly time, and fabrication energy usage would all be decreased—all of which are already common in electromechanical systems. Applications for these structures exist in the field of maritime engineering. [25], health care (architectural skin systems) [26], aerospace, automobile, construction (solar tracking and shading) [27], etc. Biofibers with hygroscopic qualities, such as coir, jute, flax, or kenaf, cause swelling that makes them operate as actuators. [25]. Therefore, it is necessary to create hygro-morph biocomposites with the ideal fiber volume content, especially when using a polymer that is extremely sensitive to moisture. Better extrusion without blocking is possible with an ideal design.

Summary

The processes for creating thermoset and thermoplastic-based biocomposites have improved recently. So far, the most widely utilized techniques for producing biocomposites are injection molding, compression molding, SMC, and RTM. Additionally configured are new auxiliary kits for feeding, drying, cooling, heating, venting, and ventilation specifically. Furthermore, special hybrid manufacturing devices like extrusion-compression molding and extrusion-injection machines have been created. Although the aforementioned technologies now account for the majority of biocomposite material fabrication, producers are exploring the possibilities of utilizing alternative processes including pultrusion, AM, etc.

Characterization

Important characterisation methods for biocomposite materials are covered in this section. These methods are essential for selecting biomaterials that work well as biocomposites' component parts.

Basic characterization

Density, diameter, chemical, and fiber fineness measures are among the fundamental characteristics of biofibers. These are often measured with a pycnometer, digital micrometer or microscope, Kurshner and Hoffer method, and fiber fineness test, respectively. [28].

Thermal analysis

Thermal characteristics and the occurrence of chemical processes that affect the properties of the biocomposites are assessed using thermal analysis. [29]. Additionally, it's important to confirm that the biomaterials used in the biocomposite are able to withstand the heat required for production and retain their properties after being exposed to heat. Thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), differential thermal analysis (DTA), dynamic mechanical analysis (DMA), and thermomechanical analysis (TMA) are among the widely used thermal analysis techniques now in use. [30].

Thermomechanical analysis (TMA)

TMA evaluates changes in the specimen's length or volume in relation to time, temperature, and either constant or variable mechanical stress at atmospheric pressure. This method allows for the measurement of a material's glass transition temperature (T), coefficient of linear thermal expansion (CLTE, α), stress relaxation, tensile, flexural, and creep properties, dimensional stability, volume dilatometry, and parallel plate rheometry. Polymer materials are viscoelastic, in contrast to metals. The mechanical performance of a polymer is influenced by its elastic and viscous constituents in relation to temperature and time. The TMA readings are affected by variables including temperature, heating rate, kind of loading, processing conditions, etc. Thermo-Dilatometry (TD) is the term for thermomechanical analysis carried out under negligible load. Hybrid biocomposites have extremely little TMA. Chemical processing combined with hybridization increases the thermal stability of biocomposites. [31, 32].

Fire resistance

Given the possibility of fire incidents, flame retardancy testing is crucial for examining the flammability properties of biocomposites. There is not much information in the scientific literature about biocomposites' ability to withstand fire. At the moment, scientists are working to create biocomposites that are highly fire-resistant and pose no environmental risks. The Federal Aviation Regulation (FAR) states that a vertical Bunsen burner is typically used to conduct flame retardancy tests. Measurements are made of criteria like the drip flame period, flame spreading rates, burn length, etc. based on the test results. [33].

High temperatures can cause biocomposites to lose their mechanical characteristics. greater cellulose content biofibers burn more easily than greater hemicellulose content biofibers, and higher lignin content biofibers typically experience more charring. [34]. Increased silica or ash content in biofiber has also been shown to improve fire resistance. Additionally, the fire resistance of the biofibers is influenced by their microstructure profile, which includes polymerization, crystallinity, and others. [34] Phenolic-based composites provide low maximum heat dispersion rate, high oxygen index, high delay in ignition, low smoke, low flammability, and blowout of flames.

Summary

The mechanical reactions of biocomposites that are primarily studied are tensile, bending, and impact behavior. Impact behavior is one of the weaker aspects of biocomposites in terms of mechanical reaction. Thermal, dynamic, and morphological qualities are being investigated for biocomposites in addition to the previously listed ones. More research is needed to improve biocomposites' performance to the intended level while taking interfacial bonding, fibers, processing techniques, and other factors into account.

8. ENVIRONMENTAL EFFECTS

8.1 Effect of temperature

Temperature is a characteristic that detracts from environmental service conditions and is crucial in the breakdown of biocomposites. [35]. The impact of ambient temperature on the mechanical characteristics of biocomposites that are still present has only been briefly examined in a few number of publications. According to research by Suresh Kumar et al., damage from impact loads on hemp, basalt, and epoxy is negatively impacted by temperature increases. [36]. They also observed that the hemp/epoxy and hemp/basalt/epoxy hybrid composites showed better impact resistance than the basalt/epoxy composites at 50 °C.

Applications of biobased composites

Biocomposites are rapidly emerging as a promising substitute for metal, traditional reinforcement-based composites, and ceramic-based materials in the fields of biomedical engineering, electronics, packing, automotive, marine, and sports. Biocomposites are also used in coating, packaging, electrical, magnetic, optical, electromagnetic shielding, and other fields. [37].

Automotive applications

When compared to traditional glass fiber reinforced composites, biocomposites are noticeably lighter. As a result, biocomposites have been widely employed in automobiles to increase fuel efficiency and lower CO₂ emissions. Biocomposites are typically used mostly in interior components (door panels, matting, storage cabins, dashboards, etc.) because of their relatively low mechanical performance and inherent weak moisture resistance. [38]. Examples of biocomposites used for exterior components include abaca-based biocomposites for wheel covers, spoilers, fender sections, cabin floors, and flax/polyester biocomposites in the engine and transmission enclosures. Extensive research is required to progress the application of biocomposites to more structural components. [38, 39].

9. CONCLUSION AND FUTURE PERSPECTIVES

The purpose of this review paper is to provide an overview of biomaterials, processing methods, qualities, methods of characterisation, and prospects for biocomposites in the future. The goal of this review paper is to provide readers with a solid grasp of the procedures used in the creation, handling, and evaluation of biocomposites. Biocomposites are the ideal option for a number of applications and to protect the bionetwork from the harmful effects of synthetic materials because of their light weight, energy efficiency, health benefits, biodegradability, sustainability, plentiful availability, and low cost.

The performance of thermoplastic and thermoset-based biocomposites, which have seen significant development in the civil and automotive sectors, has been the subject of various studies conducted recently. A greater understanding of material extraction, alteration, and interfacial treatments is credited with this advancement. The potential to produce high-quality biocomposites suitable for a range of applications involves increasing attention in the field of genetic engineering. [40]

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