**Biocomposites as Alternatives to Synthetic Fiber Composites: Types, Production Methods, and Mechanical Properties**

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**Abstract**

Global issues such as the depletion of resource reserves, environmental pollution, and economic concerns have shifted the focus of research across various disciplines. The concepts of recycling and sustainability have become ubiquitous across all sectors, leading to significant advancements in various economic aspects. In recent years, advances in nanotechnology and composite materials have led to major developments in the material sector. Composite materials have replaced metals to a certain extent in our daily lives. However, the desire for a cleaner world has spurred the idea of replacing the synthetic products used in these materials with natural ones. In recent years, researchers have examined natural fibers or polymers and investigated their usability. Researchers widely examine biocomposites based on their fiber matrix content, production methods, and application areas. This review presents an overview of existing natural fibers, categorization of biocomposites, mechanical properties, and production methods.

***Keywords:*** *Biofiber, biopolymer, recycling, sustainability*

1. **Introduction**

A composite material is a novel substance that possesses unique properties, combining two or more physically distinct phases that bear no resemblance to each other [1]. The matrix is one of the phases, while the reinforcement material, known as the fiber, serves to fortify it. The purpose of the matrix is to hold the fibers together and transfer the applied load to the fibers. It is also to protect the fibers from environmental and mechanical damage [2].

Due to concerns about recycling, the environment, and the economy, many sectors that previously favored composite materials over metals are now focusing on biocomposites. Biocomposites are materials consisting of biodegradable polymers (matrix) and biodegradable reinforcements. Biodegradable materials are substances that can be degraded by living organisms [3]. The fillers used in biocomposites are usually biofibers. Biocomposites made from natural biofibers are renewable, lightweight, biodegradable, and environmentally friendly. Biocomposites produced from renewable resources have gained universal importance due to their biodegradable nature. Although matrices provided from completely recyclable sources are preferred in obtaining biocomposites, biochemical technology is also in the works that enable the usability of synthetic thermoplastic and thermoset materials. For example, polyethylene and polypropylene are polymers used in commercial biocomposite production [4].

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Biocomposites made from natural biofibers are composites with very wide application areas in biomedical, agricultural, packaging, and other related engineering fields [5]. For example, important industrial applications of PLA matrix biocomposites include the automobile industry, textile products, and foam materials [6]. As environmentally friendly materials, they have been extensively researched for use in various fields. Natural polymers and biofibers cannot be used as much as they should because they do not work well with the hydrophobic polymer matrix, get too hot, or can catch fire [6]. Solution proposals and studies to eliminate these negativities are ongoing.

1. **Classification of Biocomposites**

Biocomposites are generally classified according to matrix and reinforcement elements. Classification according to reinforcement is examined as short fiber, continuous fiber, and particulate composites. In the classification according to matrix, agropolymer and biopolyester matrix composites are examined. In addition, biocomposites are evaluated according to whether the matrix is petroleum-based plastic or bioplastic, with biofiber as the basis. When biofiber and bioplastic are used, they are called green composites.

**2.1 Classification by matrix element**

Agropolymer matrix biocomposites are an important class of biocomposites. They are obtained from biomass products. They mainly focus on starchy materials. The biggest disadvantage of starch is its sensitivity to water and its poor mechanical properties. This situation can be overcome by reinforcing the starch with natural fibers and coating both sides of the produced foam material with a biodegradable, low-hydrophilic polyester film such as polycaprolactone [7].

Biotechnological methods (e.g., PLA), microorganisms (e.g., PHB), and petroleum products (e.g., PCL) provide biomatrices for biopolyester matrix biocomposites. Polymerization of lactic acid monomers, produced by fermentation from natural sources, yields PLA, a biodegradable polymer. Microorganisms produce PHA as a carbon and energy reserve. Polyhydroxybutyrate (PHB), which is in this group, contains 3-hydroxybutyric acid amphoteric units. Caprolactone polymerization yields PCL, a petroleum-based biopolymer [8].

**2.2 Classification by fiber element**

Various methods (such as weaving, knitting, ribboning, felting, twisting, and netting) can draw fiber into yarn or transform it into fabric and other products. For thousands of years, the production of synthetic fibers limited the use of fiber to natural fibers like silk, wool, linen, and cotton.

Plant fibers contain millions of microfibrils arranged in lamellae within the cell walls. There are basically three types of cell wall polymers: cellulose, lignin, and polysaccharides (pectin and hemicellulose).

Biofibers are being investigated as cellulose (bast, leaf, and seed) and protein-based fibers (silk, wool).

**2.2.1 Cellulose-based fibers**

Bast fibers are formed in the bark or bark tube of some plants. The textile industry, which produces rope, string, paper, and sacking, heavily utilizes bast fibers. This group includes jute, flax, hemp, kenaf, and ramie fibers. Jute fiber is the cheapest and weakest natural fiber. Jute fibers are generally used in home textiles, some technical materials, sugar and coffee bags, carpet underlay, rope, twine, and rope production. Flax fiber is the oldest textile fiber. It is soluble in strong acids, resistant to alkalis, organic solvents, and high temperatures. Areas of use include various garments, technical products (such as luggage, bags, wallets, sewing thread), beds, tables, bathroom items, and linen fabrics with different textures. Hemp fiber bears a resemblance to linen, albeit with a coarser and tighter texture and greater strength. Kenaf fiber is shorter and coarser than jute fiber. It has many areas of use, such as textiles, paper products, composites, building materials, and absorbents. Ramie fiber is rigid and prone to breakage. Ramie's traditional uses are in heavy-duty products such as canvas or tent cloth, packaging materials, and upholstery fabrics [9].

Leaf fibers are hard and have a tighter, coarser structure than bast fibers, so their commercial value is limited.  Typical examples are sisal, abaca, and henequen fibers. Sisal fiber is coarse and strong, has a high elongation under tension, but is less flexible than abaca fiber. Also, this fiber is resistant to salt water. Marine applications use abaca fibers as rope and cable materials due to their exceptional resistance to water, especially salt water. They are a preferred material in tea bags due to their water resistance, cleanliness, and easy extraction. Other uses include rope, mats, felt, tablecloths, and various garments. Henequen fiber is from the agave family of plants, very similar to sisal [10].

Seed fibers are called coir, cotton, and kapok fibers. Coir fibers are long, hard, and strong, but their softening and water absorption capacities are poor.  Cotton fiber is a widely used natural fiber. Cotton is hydrophilic, its fibers swell significantly in water. Cotton is flexible, highly absorbent, and resistant to alkalis. Generally, people use kapok fiber as a fiber filling and insulation material. It is eight times lighter than cotton, non-allergenic and non-toxic, and resistant to odor and rot [11]*.*

**2.2.2 Protein-based fibers**

Fibrous proteins are a class of proteins that are fibrous, strong, threadlike, and generally insoluble in water. Important protein fibers are silk, wool, fur, and some special hair fibers. Generally, alkalis, dry heat, and chlorine bleach degrade them, causing them to burn easily. Silk is the strongest natural fiber, it is light and has moderate abrasion resistance. Spider silk is elastic and the strongest known natural fiber. Sheep naturally produce wool, a hair-like protein fiber. Wool has moderate abrasion resistance, excellent flexibility, dimensional stability, and poor electrical conductivity [12].

1. **Mechanical Properties of Biocomposites**

Mechanical properties generally vary with the type of resin, its origin, the type, orientation, amount, and form of fiber, mixing, and the plasticizer used.

**Tensile Strength-Tensile Modulus:** Biopolymer matrix composites reinforced with biofibers exhibit significantly improved tensile properties. The tensile strength of fully biodegradable composites varies between 20 and 73 MPa. The hemp-reinforced PLA biopolymer composite (PLAHF: 73 MPa) exhibits the highest tensile strength, while the flax-reinforced polycaprolactone composite (PLCFF: 20-25 MPa) displays the lowest. The highest tensile modulus is 20 GPa for PLA/Sisal (PLASF) and the lowest for PCL/Flax (PLCFF) (0.8-0.9 GPa) [13].

**Flexural Strength-Flexural Modulus:** Flexural strength varies depending on the biofiber, biopolymer, and fabrication techniques in the biodegradable composite. The highest flexural strength belongs to hemp-reinforced PLA (PLAHF: 102 ± 2 MPa), while the lowest value belongs to flax-reinforced PCL (PLCFF: 30-35 MPa) biocomposites. The highest and lowest flexural modulus values are for sisal fiber-reinforced PLA (PLASF: 19 GPa) and flax fiber-reinforced PCL (PLCFF: 1.8-1.9 GPa), respectively [14].

**Percentage Elongation-Impact Force:** According to the tensile tests of sample biodegradable composites, the highest and lowest elongation values were determined as PLA/Jute (PLAJF: 1.5-4.71%) and PLA/Flax (PLAFF: 1.0%). In the impact tests showing the durability of the material, the biocomposites with the highest and lowest values were PLA/Jute (PLAJF: 15-80 kJ/m2) and PLA/Sisal (PLASF: 3-3.5 kJ/m2) [15].

1. **Manufacturing of Biocomposites**

Natural fibers have similar behaviors to fiberglass. Natural fibers require preparation for processing before use and necessary surface modifications to achieve these properties. This ensures good adhesion between the matrix and the fiber, achieves the appropriate degree of polymerization, and yields homogeneous physical properties [16].

The manufacturing techniques for biocomposites are mostly based on manufacturing processes for plastics or composites, such as press molding, hand lay-up, filament winding, pultrusion, extrusion, injection molding, compression molding, resin transfer molding, and sheet molding [17].

The compounding stage plays a crucial role in the production of biocomposites through various processes. The purpose of compounding is to prepare materials (such as pellets) with suitable properties for subsequent injection, molding, extrusion, or other processes. In compounding, polymers, fillers, fibers, and additives are generally mixed, a good dispersion is provided, and the aim is to obtain granules in suitable form and with processable properties [17].

1. **Conclusion And Future Trends**

Researchers are extensively studying composite materials, which have important application areas such as automotive, marine, and aviation. Numerous factors, including nanoscale developments, global innovations, economic challenges, and environmental factors, are driving these studies. Natural products are evaluated with the factors of being abundant in resources, clean, and recyclable. Researchers are exploring biofiber-reinforced composites in a variety of ways within this context. Researchers aim to tackle the challenges of obtaining and preparing biofibers for use, eliminating matrix and biofiber incompatibility, enhancing interface adhesion, and ultimately boosting strength. In the future, it is expected that these composites will reach the strength values of synthetic fiber-reinforced composites such as glass, carbon, and aramid and will find a very wide application area in all sectors.

**References**

[1] Mortensen, A. (Ed.). (2006). *Concise Encyclopedia of Composite Materials*. Elsevier.

[2] Rajak, D.K., Pagar, D.D., Menezes, P.L., & Linul, E. (2019). Fiber-reinforced polymer composites: Manufacturing, properties, and applications. *Polymers*, *11*(10), 1667.

[3] Karthika, M., Shaji, N., Johnson, A., Neelakandan, M.S., A. Gopakumar, D., & Thomas, S. (2019). Biodegradation of green polymeric composites materials. *Bio Monomers for Green Polymeric Composite Materials*, 141-159.

[4] Manu, T., Nazmi, A.R., Shahri, B., Emerson, N., & Huber, T. (2022). Biocomposites: A review of materials and perception. *Materials Today Communications*, *31*, 103308.

[5] Akter, M., Uddin, M.H., & Tania, I.S. (2022). Biocomposites based on natural fibers and polymers: A review on properties and potential applications. *Journal of Reinforced Plastics and Composites*, *41*(17-18), 705-742.

[6] Akampumuza, O., Wambua, P.M., Ahmed, A., Li, W., & Qin, X.H. (2017). Review of the applications of biocomposites in the automotive industry. *Polymer Composites*, *38*(11), 2553-2569.

[7] Bhat, A.H., Dasan, Y.K., Khan, I., & Jawaid, M. (2017). Cellulosic biocomposites: Potential materials for future. *Green Biocomposites: Design and Applications*, 69-100.

[8] Shanks, R.A., Hodzic, A., & Wong, S. (2004). Thermoplastic biopolyester natural fiber composites. *Journal of Applied Polymer Science*, *91*(4), 2114-2121.

[9] Eyupoglu, S. (2020). Sustainable plant-based natural fibers. *Sustainability in the Textile and Apparel Industries: Sourcing Natural Raw Materials*, 27-48.

[10] Thomas, S., Paul, S.A., Pothan, L.A., & Deepa, B. (2011). Natural fibres: Structure, properties and applications. *Cellulose Fibers: Bio-and Nano-Polymer Composites: Green Chemistry and Technology*, 3-42.

[11] Lee, J.A. (2019). Plant fibers. In *CRC Handbook of Plant Science in Agriculture* (pp. 173-182). CRC press.

[12] Boy, R., Narayanan, G., & Kotek, R. (2018). Formation of cellulose and protein blend biofibers. *Polysaccharide-Based Fibers and Composites: Chemical and Engineering Fundamentals and Industrial Applications*, 77-117.

[13] Li, X., Chu, C.L., Liu, L., Liu, X.K., Bai, J., Guo, C., ... & Chu, P.K. (2015). Biodegradable poly-lactic acid based-composite reinforced unidirectionally with high-strength magnesium alloy wires. *Biomaterials*, *49*, 135-144.

[14] Chaitanya, S., Singh, I., & Song, J.I. (2019). Recyclability analysis of PLA/Sisal fiber biocomposites. *Composites Part B: Engineering*, *173*, 106895.

[15] Gunti, R., Ratna Prasad, A.V., & Gupta, A.V.S.S.K.S. (2018). Mechanical and degradation properties of natural fiber‐reinforced PLA composites: Jute, sisal, and elephant grass. *Polymer Composites*, *39*(4), 1125-1136.

[16] Gholampour, A., & Ozbakkaloglu, T. (2020). A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications. *Journal of Materials Science*, *55*(3), 829-892.

[17] Hasan, K.F., Horváth, P.G., Zsolt, K., & Alpár, T. (2021). Design and fabrication technology in biocomposite manufacturing. In *Value-Added Biocomposites* (pp. 157-188). CRC Press.