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Mechanical Behavior of Bamboo Fiber Reinforced PLA Composites: A Review

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ABSTRACT

This research paper reviews the mechanical characteristic of Bamboo Fiber reinforced Polymer/PLA Composites (BFRP/PLA composites). Fibers that are advantageous to the environment and a replacement to the conventional fibers such as glass and carbon are bamboo fibers through its good mechanical properties and suitable environment factors compared with other natural fibers (banana, jute, husk, sisal, hemp, flax, etc.). Better extraction methods and its pretreatment of bamboo fiber extraction results with good and benefitable characters in processing and manufacturing of bamboo fiber reinforced polymer and bamboo fiber-reinforced PLA composites either by conventional methods or by fused deposition modeling through filament production.

Keywords: Bamboo fiber, Bamboo fiber reinforced composites, PLA composites

1. Introduction

The scientific literatures provided by various researchers over the past four decades have defined the use of composites in industrial and household application and from past 2 decades the use of natural fibers in manufacturing of composites have determined its importance in developing ecological environmental friendly materials. A composite material, referred as a material consisting of two or more constituents with different features, having unique and outstanding properties. Matrix that acts as binder and reinforcements that provide shape and internal structures, matrix and reinforcements are the two basic constituents of a composite material [1, 2]. Based on the type of matrix, classification of composite are presented as polymer, metal and ceramic matrix composites, and based on length of fiber reinforced to produce composites, they are classified as continuous fiber reinforcement composites having long fiber reinforcements, discontinuous fiber reinforcement composites having short fiber reinforcements, and hybrid fiber-reinforcement composites having many types of fibers reinforced in a matrix structure.

The significant enhancement and improvement in mechanical, structural and tribological properties of fiber reinforced materials (composites), though they have increase in durability, but concern in degradability is of greater importance, therefore researchers are presenting their ideas in producing natural fiber based composite, due to their availability, resourceful, ecological, environmental friendly, biodegradability factors and they are compelled in developing environmental friendly materials with cleaner manufacturing processes [3, 4]. Natural fibers comes from plants and they consists coir, banana, flax, sisal, jute, hemp, kenaf, bamboo and other types like wood and roots, among these fibers the most promising substitute to synthetic fiber is bamboo fiber. Natural fibers and even bamboo fibers are ecological, eco-friendly, light-weight, strong, renewable, biodegradable and cheap, and have good physical and mechanical properties. They are attractive due to their low density and are acknowledged because of its mechanical and physical properties depending upon how they are processed. They are gaining importance due to their bio-degradable nature [5, 6, 7, 8].

A composite produced from natural fiber reinforcements implies the diverse properties such as reduced weight, toxicity, cost, and recyclability. Bamboo, a fast growing plant, resourceful in countries (Asia, Africa, South America), used as main material for structural applications in bridges, decorative application. It is gained as a green material, is considered as extremely resilient and durable material and also used as additive in biopolymers [9, 10, 11]. Bamboo belongs to more than 10 genera and has more than thousand species ranges from small annuals to large/giant timer bamboo, is used as an oldest building material of the mankind [12].

Many researchers have studied and presented the advantages of natural fiber composites as well as natural fiber reinforced composites, reinforced with polymers, predominantly polylactic acid (PLA), polypropylene (PP), and other polymers. Their reinforcement addition concept also plays an important role in strengthening the produced fiber-reinforced polymer composites, even the matrix material with it pretreatment factors followed through the composite product fabrication. Hence for these facts, the usage of natural fiber-reinforced polymer composites are rapidly growing in the development of bio-composite, in terms of both industrial and household applications and fundamental research. Bamboo fiber composites are stronger when compared to glass fibers and are proved by various researchers. Numerous methods of extraction of bamboo fibers are presented by their properties that employed its role in fabrication and end product implication. Bamboo fiber considered as a natural fiber has different methods of extraction and pretreatment stages, and also has different methods of bamboo based product fabrication, that implies directly obtaining bamboo products through compressed moulds added with reinforcements and treated bamboo particles/fibers used in filament production followed by additive manufacturing or advanced technologies. This paper gives a quite simplicit review of bamboo fiber-reinforced polymer composite materials.

Nomenclature

PLA – PolyLactic Acid

BFRP – Bamboo Fiber Reinforced Polymer

2. Bamboo Fiber

Worldwide, there are more than a thousand different species of bamboo, which come in both herbaceous and tropical woody types and have rhizomes that are both monopodial and sympodial [13]. According to a number of reports, bamboo may grow up to 2 inches every hour, or 11 to 21 cm per day, or roughly 122 cm per day [14]. Bamboo can reach maturity in 3 years, although it takes most of them between 4 and 6 years, these facts particularly depend on different species [15]. In bamboo-sited and rural areas, bamboo has been the primary material for structural applications such as long homes, suspension bridges and scaffoldings. Typically, bamboo has more favourable mechanical qualities than wood [16]. Bamboo, on the other hand, is now grown in 21 nations, making it a widely available commodity. It is frequently utilised in local construction and to make home items. Despite being a worldwide plant, bamboo is particularly prevalent throughout Asia and South America. The lack of knowledge regarding bamboo's strength and industrial potential, particularly in Asian nations, has prevented it from being properly utilised [17, 15]. Bamboo is a sustainable choice for upcoming material sectors due to its capacity to grow quickly and strength that is equivalent to that of traditional materials [18].

2.1 Bamboo Treatment

The chemical constituents such as lignin which decreases adhesion is a reason to which bamboo is highly hydrophilic in nature, the pretreatments that are defined by the researchers are as follows; Alkaline Treatment, Silane Treatment, Acetylation of Natural Fibers, Benzoylation Treatment, Permanganate Treatment, and Peroxide & Isocyanate Treatment [19, 20].

The most common chemical treatment for natural fibres is the *alkaline process*, which involves using NaOH to ionise the hydroxyl group in order to remove excess lignin, wax, and oils from the fibre cell's outer surface. The *silane treatment* is most noticeable when there is moisture present, and it may also lessen the number of hydroxyl groups in the cellulose. Following *acetylation*, which is the insertion of an acetyl functional group into to the molecule, the natural fibre loses some of its hygroscopic properties. Due to the inclusion of benzoyl in benzoyl chloride, *benzoylation* treatment has the advantage of reducing the fiber's hydrophilic character. The majority of the time, *potassium permanganate*, is the solution used for the permanganate treatment. After receiving an alkali pretreatment, the fibre is given a *peroxide and isocyanate* treatment, followed by an exterior coating of benzoyl peroxide or dichloroperoxide in an acetone solution [19].

2.2 Bamboo Extraction

All Different forms of bamboo fibers are extracted by the type of extraction methods used. Bamboo fibers are extracted main through mechanical methods or chemical methods; they are listed in the figure-1 [21].

Because multiple fibre bundles are still bound together in the lignin's natural matrix, bamboo strip is a sturdy sort of fibre. The construction of composites is made simpler by the bamboo strip’s fibres unidirectional orientation [22]. High-quality fibres are obtained by steam explosion because more lignin removed from the fibre surface, improving the interfacial adhesion between the fibres and matrix. The bamboo culm can simply be processed into bamboo powder using a number of different techniques. To ensure that the powders are spread properly, considerable attention must be taken while fabricating composites with bamboo powder, particularly during the addition of the matrix. Despite having a very low strength, its incorporation into the matrix could improve the mechanical properties when compared to the sample made entirely of the matrix [23]. As per ASTM D3379 (1989), single bamboo fibre tensile testing shows that steam explosion is the preferred extraction technique for creating high-strength bamboo fibre. The steam explosion technique used a vessel to violently boil water into steam and there by break up the wood into small pieces & fibers [24]. Fiber extraction techniques involve using compression techniques, rolling mill technique, retting, crushing steam explosion method and grinding are mechanical extraction techniques, degumming, alkali or acid retting, and chemical retting are chemical extraction techniques. The mechanical methods are eco-friendly but economically less compared with chemical methods [19].

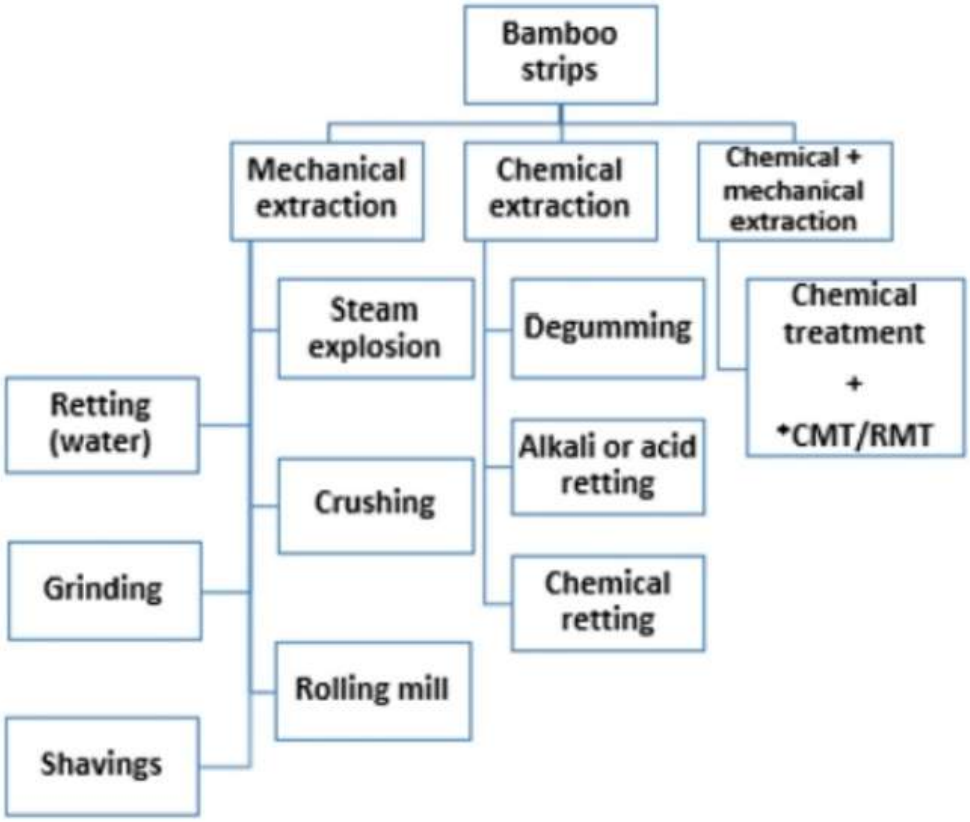

Fig. 1 - bamboo fiber extraction methods [21].

Bamboo Fiber-Reinforced Polymer Composites

Equations Bamboo Fiber reinforced Polymer (BFRP) composite is also an eco-composite that is environmentally responsible, lightweight & comparable in strength to traditional materials [25]. The fabrication method, type of matrices, and type of fibres are the three primary elements that are to be addressed in detail in order to distinguish bamboo composites because they all have an impact on the qualities of the finished products. These three elements work together to produce bamboo composites with good characteristics [23]. Composite materials can be reinforced using various bamboo fibre kinds. The processes used to fabricate composites are based on the types of fibres. The choice of manufacturing is also influenced by the various matrices [23].

Natural fibres are widely available in nature and are surprisingly simple to produce. These materials also exhibit amazing material characteristics, such as low cost/volume, specific stiffness, high strength & biodegradability [26]. Natural and synthetic fibres can be used to create fiber-reinforced composites; natural fibres are less expensive, biodegradable, and environmentally friendly than synthetic fibres [27], synthetic fibres provide higher stiffness. Composites produced by natural fiber that are reinforced to an entity is said to carry some diverse properties over synthetic fibers, such as reduced cost, toxicity, weight, environmental pollution and recyclability [26]. NFRPC are available in abundant and are affordable easily as natural material alternative candidate to wood having potential application in the structural components, construction field, furniture, automobile & industrial applications [28], and researches are been conducted to determine their properties based on their resistance to impact, wear, and corrosion.

This [29] study or research was aimed to synthesize bamboo particle reinforced polymer composites as a substitute for particle board products. Variables in the composite synthesis process included powder sizes (50, 100 & 250 mesh), volume fractions (10, 20 & 30%), and reinforcing matrix types (polypropylene, polyester, Tali Bamboo & Haur Bamboo) and were examined with regard to tensile and flexural strength. Bamboo fibre reinforcement in polymer composites was created using hand layup and extrusion techniques. The tensile and bending test results showed that their composite's tensile and bending strength was enhanced by 28 to 165% and 27 to 197%, respectively, even though the matrix's strength value was lower than the composite's.

The tensile properties of BFRP are studied in this research work [30] and review was made describing various works undergone in development of bamboo fiber reinforced polymer composite materials. Various extraction methods of bamboo fiber were classified and its mechanical and physical properties were redefined, and tensile properties with its graph representation were described and compared it to various other bamboo composite works. Bamboo's usage in composite materials offers practical answers for new developments in the material sectors. Composites made from bamboo have been widely used in furniture and wall panels for homes.

3.1 Bamboo Fiber-Reinforced PLA (3D Printed) Composites

A 3D printed bio composite removable clipping connection system for raw bamboo space structures was introduced in the paper [31]. The suggested connection mechanism made it simple to create bamboo buildings by joining many bamboo culms together with this system. FDM was used to produce

filament by adding fibers as reinforcement (continuous and chopped) with two specimen configuration with 50% infill. The resulted products could withstand 7 KN (weight in compression) having diameter 30mm and 4mm thickness.

In this work [32], describes the study of natural bamboo fibres; with various shape depositions, layer thicknesses & fill densities, specimens were created using FDM. NaOH treated bamboo fibres with PLA were utilized in manufacturing of the filament for additive manufacturing. The specimens contained 20% (recycled) bamboo fibre and 80% PLA. The strength of the PLA and bamboo fibre separately was determined to be superior to the values derived from the analysed composite by 96% and 43%, respectively.

In this research work [33], a review is made on the challenges and opportunities associated with FDM of Continuous Fiber Reinforced Polymer Composites (CFRPCs), here various choices of continuous fibers and matrix polymers with the effects on their performance is discussed. Latest equipment and methods for fabrication of CFRPCs with their key parameters that affects its properties are analyzed and summarized. Fiber-reinforced polymers are in high demand in industrial sectors in consideration based on weigh-to-strength ratio and used FDM method to fabricate components are presented in the work [34], the mechanical behavior is studied on the 3d printed parts for the future prospects.

The effort to improve the Natural Fiber Reinforced composites (NFRCs) in the use of AM techniques is explained in the work [35], the fiber treatment, composite preparation methods and compatibilizer agents added was analyzed & discussed here. The agents were used to improve the adhesion of fibers despite having effective surface properties in previous researches, the natural fibers that are explored, they are; rice husk, hemp, wheat, cotton & bamboo. Mechanical properties were evaluated through their printing parameters that effect its temperature, layer height, & infill, and a review for future challenges was made.

4. Conclusion

Bamboo's usage in composite materials offers practical answers for new developments in the material sectors. Bamboo trees are a renewable resource that mature very quickly and grow quickly. As a result, bamboo fibres have a proven steady supply and a lower production cost than other types of traditional fibres. To maximise the removal of lignin from the surface of bamboo fibres, which can enhance the interfacial adhesion between fibres and matrices, an appropriate process of fibre extraction must be used. This bonding is improved by the use of coupling agents and fibre preparation. Composite materials made of bamboo are highly efficient and can compete with conventional materials. Use of 3D printing (additive manufacturing) technologies have provided greater advances in composite production followed through its filament fabrication, this has led the bamboo polymer/PLA in higher complexity products. Eco-friendly products are created when bamboo fibres are used instead of synthetic fibres, especially when it comes to energy use and the disposal of solid waste. Composites made from bamboo have been widely used in furniture and wall panels for homes. To better understand bamboo and explore its possibilities in cutting-edge technology, however, more research must be done.

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