© AUG 2017 | IRE Journals | Volume 1 Issue 2 | ISSN: 2456-8880

A Review on Bamboo Fiber Composites

Talekar Vikrant Popat[1], Ashwini Yeshwant Patil[2]
[12] Bansilal Ramnath Agarwal Charitable Trust's Vishwakarma Institute of Technology, Pune, Maharashtra, India

Abstract-From the last thirty to thirty five years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. Bamboo plants are giant, fast-growing grasses that have woody stems. The characteristics of each vary in size, growth habit, sun tolerance, soil moisture needs and heat/ cold temperature tolerance. Bamboo fibers are often known as natural glass fiber due to its high strength with respect to its weight derives from fibers longitudinally aligned in its body. The tensile strength of bamboo is relatively high and can reach 370 MPa. This makes bamboo an attractive alternative to steel in tensile loading application. Thus the study of anatomy of bamboo, extraction of bamboo fibers, bamboo fiber composites with different matrix materials becomes necessary.

Index Terms- Natural fibers, Bamboo Fibers, Anatomy Extraction, Testing, Bamboo Fiber composites.

I. INTRODUCTION

Over the last thirty to thirty five years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. Recently, for manufacturing of the composite materials the most commonly used synthetic fibers are the glass fibers carbon fibers and so many types of fibers are used. All the ordinary synthetic fibers used such as glass fibers Natural fiber composites excel in most parameters except strength; strength of glass fiber composites is higher compared to natural fibers [01]. The adverse effect of composite materials on the environment is detailed explained in the paper [12]. Since the properties of the natural fibers as compared to the synthetic fiber are favorable according to the social and economic aspects the use of natural fibers in many applications is increased in many types of industry.

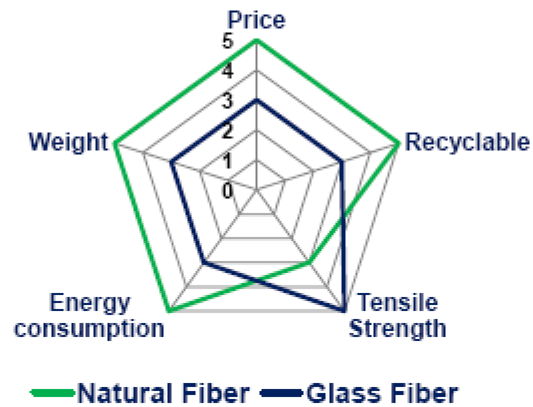

Fig. 1: Comparative study of natural fibers and glass fibers [01]

Natural fiber composites include coir, jute, bagasse, cotton, bamboo, hemp. Natural fibers come from plants. These fibers contain lingo cellulose in nature. Natural fibers are eco-friendly; lightweight, strong, renewable, cheap and biodegradable. The natural fibers can be used to reinforce both thermosetting and thermoplastic matrices. Thermosetting resins such as epoxy, polyester, polyurethane, phenolic are commonly used composites requiring higher performance applications. They provide sufficient mechanical properties in particular stiffness and strength at acceptably low price levels. Recent advances in natural fiber development are genetic engineering. The composites science offer significant opportunities for improved materials from renewable resources with enhanced support for global sustainability. Natural fiber composites are attractive to industry because of their low density and ecological advantages over conventional composites. These composites are gaining importance due to their noncarcinogenic and bio-degradable nature [2]. Recent developments in natural fibers composite field and applications are summarized in presentation [11].

II. WHY BAMBOO FIBERS?

The detailed classification of the natural fibers and their sources collectively available according to different aspects [02] [03] [04].The characteristics and properties of the Calcutta Bamboo are summarized in paper [20]. Bamboo fibers have been extensively used in composite industries for socio-economic empowerment of peoples. The fabrication of bamboo fiber based composites using different matrices has developed cost effective and eco-friendly bio composites which directly affecting the market values of bamboo. The sustainable future of bamboo based composite industry would help in utilizing the bamboo in a way other than usual traditional mode. The effective characterization of bamboo fiber as well as bamboo fiber based composites should be more advance in terms of analysis and testing [05].

Bamboo plants are giant, fast-growing grasses that have woody stems. The characteristics of each vary in size, growth habit, sun tolerance, soil moisture needs and heat/ cold temperature tolerance. Several investigators have examined bamboo as a source of best fiber and as a source of cellulose from pulping the bamboo. One of benefits using bamboo fibers is that the bamboo is an abundant natural resource in Asia and Middle & South America. Bamboo fibers are often known as natural glass fiber due to its high strength with respect to its weight derives from fibers longitudinally aligned in its body. The tensile strength of bamboo is relatively high and can reach 370 MPa. This makes bamboo an attractive alternative to steel in tensile loading application [6].

Thus bamboo is selected as fibers for the use of bio composite with matrix material PLA (Poly Lactic Acid). Better development of processing technologies and improvements in natural fiber treatments will facilitate the production of with optimum mechanical and physical performance but also generate high cost competiveness and greater acceptance of these materials in the market place [14].

Features of Bamboo

Bamboo (Bambusa Shreb.) is a perennial plant, which grows up to 40 m in height in monsoon climates. Generally, it is used in construction, carpentry, weaving and plaiting etc. Curtains made of bamboo fiber can absorb ultraviolet radiation in various wavelengths, making it less harmful to human body. The development of composites for ecological purposes (eco-composites) using bamboo fibers and their basic mechanical properties were evaluated. The steam explosion technique was applied to extract bamboo fibers from raw bamboo trees. The experimental results showed that the bamboo fibers (bundles) had a sufficient specific strength, equivalent to that of conventional glass fibers. The tensile strength and modulus of PP based composites increased about 15 and 30% when using steam-exploded fibers. This increase was due to good impregnation and a reduction of the number of voids, in comparison to composites using fibers that were mechanically extracted [15].

III. GLOBAL DISTRIBUTION OF BAMBOO

The bamboo is grown in various continents of the world; it has been divided accordingly; Asia–Pacific bamboo region, American bamboo region, African bamboo region and European and North American region (Table 1). The Asia–Pacific bamboo region is the largest bamboo growing area in the world. In Asian countries, bamboo is known by different names, In China it is known as ‘‘friend of people’’, ‘‘wood of the poor’’ in India, ‘‘the brother’’ in Vietnam. FAO provided the data of bamboo production at global level as shown in Table 1. In Asia, large area of bamboo is occupied by six countries viz. India, China, Indonesia, Philippines, Myanmar, Vietnam and others. Globally among sympodial and monopodial, sympodial type of bamboo dominates major part. The extensive awareness of bamboo plantation in China has led to an increase in monopodial bamboo by about 30% [05].

Bamboo fibers were chosen over other natural fibers because bamboo is abundant and not widely used. Bamboo is plentiful in Asia and South America and it grows naturally without the need for cultivation [18]. The countries where there is scarcity of forest resources, agricultural crops have been utilized for developments and research on polymer composites. Bamboo is one of the agricultural crops which can be exploited for the design and development of polymer composites [6]. Bamboo is found in abundance in Asia and South America. In many Asian countries bamboo has not been explored fully to its extent although it is considered as natural engineering material. This sustainable material has evolved as backbone for socio-economic status of society as it takes several months to grow up [05].

TABLE 1. Bamboo regions along with country

Bamboo region	Countries	Percentage
1. Asia–Pacific	China, India, Burma, Thailand, Bangladesh, Cambodia, Vietnam, Japan, Indonesia, Malaysia, Philippines, Korea and Sri Lanka	65%
2. American bamboo region (Latin America, South America and North America)	Mexico, Guatemala, Costa Rica, Nicaragua, Honduras, Columbia, Venezuela and Brazil and some European countries	28%
3. African bamboo region	Mozambique, Eastern Sudan	7%

A bamboo plant tends to reach its mature size in six to eight months with some variation between species [18]. Not only is it a renewable resource, it is often considered a weed because it grows and spreads quickly. Bamboo is used on a small scale for construction and home décor, but it remains a niche market. Some claim that bamboo is the last sustainable plant resource that has not been vastly used [18].

IV. ANATOMICAL STRUCTURE OF BAMBOO

The structure of bamboo culm is a hollow cylinder, and the inner side of every culm is divided by several diaphragms that appear to be rings from the outside. The space between two rings is called the ‘‘internode’’, and branches grow from this space. The distance between each node varies among species. The culm wall of bamboo consists of many vascular bundles, providing strength to the culm. The number of internodes can be defined by the height of the culm. Consequently, the average size, density and number of vascular bundles are important parameters to characterize bamboo species. The anatomy of bamboo culms determines their physical properties, which reflect their usability. The bamboo fiber density increases with decreasing upper diameter of the bamboo culm. Therefore, the base section has a lower strength but a greater capacity to withstand force than the top section [08].

The microstructure of bamboo culm consists of many vascular bundles embedded in parenchyma tissue and distributed across the wall thickness. Vascular bundles and bundle sheaths are the main parts of this plant, reinforcing the bamboo culm and connecting the nodes to the culm. Vascular bundles, which are surrounded by fibrils (sclerenchyma cells), are heavily distributed near the outer side of the culm wall, and are less abundant on the inner side. The size and density of vascular bundles vary from the base to the top of the bamboo culm. Every vascular bundle is separated into two parts, namely xylem and phloem.

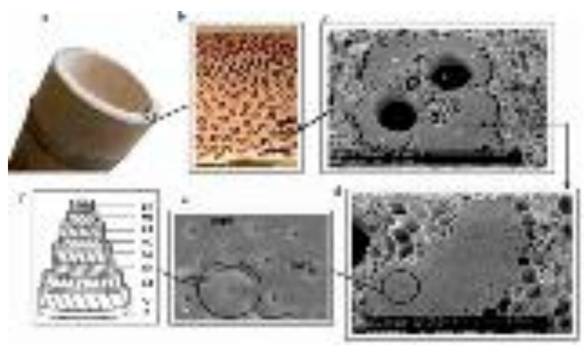

Fig.2. (a) Bamboo culm, (b) cross-section of bamboo culm, (c) vascular bundle, (d) fiber strand, (e) elementary fibers (f) model of poly lamellae structure of bamboo [08].

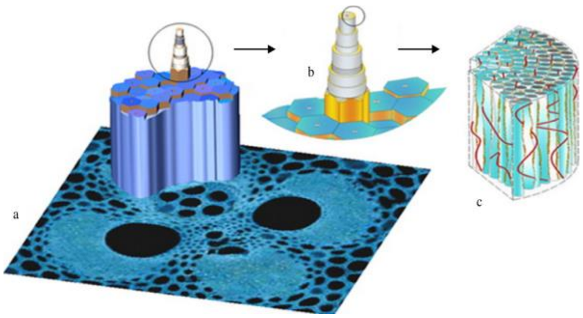

Fig.3. (a) Vascular bundle of bamboo, (b) elementary fiber 10–20 lm, (c) Nano fibril 1–10 lm involves lignin and hemicellulose [08].

The function of xylem is to transfer water, and phloem carries nutrients and sugars to all parts of the plant. Generally, each vascular bundle consists of a fiber strand, sclerenchyma cells, vessels, and sieve tubes with companion cells. The fiber strand involves many elementary fibers with hexagonal and pentagonal shapes, where Nano-fibrils are aligned and bound together with lignin and hemi-cellulose. The structure of a bamboo culm and a diagram of bamboo fiber structures are shown in Figs. 2 and 3.

Microstructure of the bamboo is studied in so many papers [07] [08] [09] [10] [11]. The bamboo has 60% cellulose and a considerably high percentage of lignin (about 32%). In this study, fiber bundles of 125–210 mm in diameter [10].Anatomical structure of bamboo is detailed explained in the paper [08] covers all the points. Detailed anatomical structure of bamboo is also covered in paper [20].

Chemical Composition of Bamboo

The percentage composition of the bamboo fibers may vary according to the bamboo age, environmental conditions, and the region from where it belongs. Various researchers studied the bamboo fibers but the percentage composition of the cellulose, lignin, ash, hemicellulose etc. varies.

The chemical composition of bamboo fiber constitutes mainly cellulose, hemicelluloses and lignin. These components are actually same high-glycans, and make about 90% of total weight of bamboo fiber. The other constituents are protein, fat, pectin, tannins, pigments and ash. These constituents play important role in physiological activity of bamboo and they are found in cell cavity or special organelles. The chemical composition of the bamboo fiber is given in Fig. 4 [05] [18]. Usually the chemical content of bamboo changes with age of the bamboo, particularly cellulose content keeps on decreasing while age of bamboo is increased so directly it directly affects the chemical composition of bamboo fiber [06]. The lignin is considered to provide stiffness and yellow color to bamboo fibers [10]. Different treatments cannot remove all the lignin content of the bamboo fibers, as lignin has been found quite resistant to various alkalis. Non cellulosic components have enough contribution to fiber properties such as strength, flexibility, moisture, and even density [05].

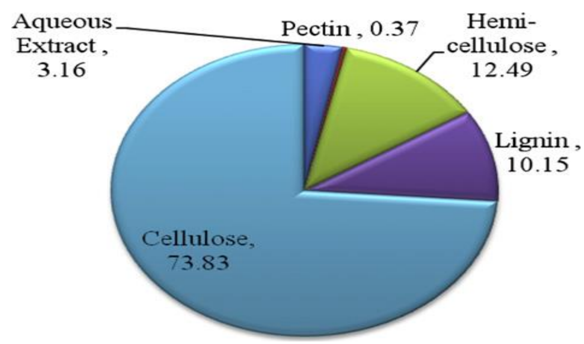

Fig. 4: Chemical constituents of Bamboo fiber [05].

The percentage composition of bamboo fibers with the various bamboo fibers is also compared with other natural fibers; alternately the mechanical properties of the fibers are also compared because the fibril source from all natural fibers is same that is cellulose and lignin

V. BAMBOO FIBERS EXTRACTION

The bamboo fiber is obtained from bamboo tree and it is divided into two kinds of fiber according to different process flow and method: Natural original bamboo fiber and bamboo pulp fiber (namely bamboo viscose fiber or regenerated cellulose bamboo fiber). Original bamboo fiber is directly picked up from natural bamboo without any chemical additive, using physical and mechanical method. In order to differentiate from bamboo pulp fiber (bamboo viscose fiber), we call it as original bamboo fiber or pure natural bamboo fiber. But bamboo pulp (viscose) fiber belongs to regenerated cellulose fiber as chemical fiber. Broadly there are two types of processing to obtain bamboo fibers viz. mechanical processing and chemical processing. Both processes initially include splitting of bamboo strips, which is followed by either mechanical processing or chemical processing depending upon the further use of bamboo fibers. Chemical processing includes initial alkali hydrolysis (NaOH) to yield cellulose fibers. Alkali treated cellulose fibers are then passed through carbon disulphide via multi-phase bleaching. Most of the manufactures use this process as it is least time consuming procedure to yield the bamboo fibers [05].

A. *Mechanical extraction*

This method can take the form of different procedures such as steam explosion or heat steaming, retting, crushing, grinding and rolling in a mill. All of these methods have been used to extract fiber for the application of bamboo fiber in reinforced composites in various industries. The main advantage of mechanical fiber extraction over chemical processes is its better environmental characteristics.

a) *Steam explosion method*

This method was invented in 1962 as a low energy consumption method to separate the cell walls of a plant to produce pulp. Although the steam explosion procedure is an appropriate method to separate lignin from the plant surface, especially for the pulp industry, the resulting fibers are rigid and dark [16]. In a research study extracting fibers using a steam explosion process, the bundles were not effectively separated into single fibers. Fiber bundles with diameters of 125–210 lm were produced by a sifter machine with mesh filtering. Then, the fibers were dried for 2 h at 120 _C. This method was not able to completely remove lignin from the fibers, as the main function of this technique is to remove lignin from woody materials. Thus, a mixing machine was used to eliminate the remaining lignin from the fibers and produce Bamboo Fiber cotton (BFc). The tensile strength of a reinforced maleic anhydride modified polypropylene composite containing BFc was greater at higher weight percentages compared with those containing Bamboo Fiber (BF). The same process was performed by cutting raw bamboo and overheating it in an autoclave at 175 _C and 0.7–0.8 MPa for 60 min. Subsequently, the steam was immediately released for 5 min, and this process was repeated nine times to ensure that the cell walls were fractured. At the end, the ash was removed by washing the fibers in hot water at 90–95 _C with the addition of soap and then drying in an oven at 105 _C for 24 h. Most of the lignin was condensed on the surface of the fibers, which reduced the adhesion between the extracted fibers and the resin. During the steam explosion process, the cell walls of the fibers are cracked and bamboo fibers become soft, enabling extraction. In this method the crushed soft cell walls stuck onto the bamboo fiber surfaces had low shear resistance. As some lignin partly decomposed on the fibers, the researchers ultrasonically washed the fibers and then treated them with isocyanate silane to remove those unexpended cells from steam exploded fibers. The results indicated that steam exploded bamboo fibers have a higher tensile strength than silane treated fibers. On the other hand, the interfaces between the fibers and soft cells are weak, and these interfaces may reduce the tensile strength of the fiber reinforced thermoplastic. Appropriate surface treatment is required to achieve strong adhesion between the fiber and the matrix [08].

b) Retting

In this procedure, the bamboo bark was removed and the cylindrical part of the culm was peeled to obtain strips. The strips of bundles were kept for three days in water. Then, to separate the fibers, the wetted strips were beaten, scraped with a sharp edged knife and combed. In this method, the process of scraping the fiber surface had a strong effect on the quality of the fibers, and the fibers broke less along the length of fibers. Another study did not involve scrapping or combing, instead simply cutting raw bamboo into several longitudinal parts without removing the bamboo node and epidermis. Before retting, the bamboo strips were cleaned with flowing water. The bamboo culms were fermented in water at room temperature for 2 months. Two different types of retting were used, namely anaerobic and aerobic retting and these techniques were able to separate the bundles from the culm. These authors found that every extracted fiber bundle consisted of a single fiber, and these fibers could be acquired in any length.

c) Crushing

Bamboo fibers were extracted by first cutting the raw bamboo into small pieces by a roller crusher. Then, the small pieces were extracted into coarse fiber by a pin-roller. Before the coarse fibers were put in a dehydrator, they were boiled at 90 _C for 10 h to remove their fat and later dried in the rotary dryer. The problem with this process is that it yields short fibers, which become powdered after mechanical over-processing.

d) Grinding

Bamboo culm without nodes was cut into strips and soaked in water for 24 h. Then, the drenched strips were manually cut into smaller pieces with a knife. The wider strips passed through an extruder, and small bamboo chips were obtained by cutting the longer strips. Next, short bamboo fibers were acquired by grinding bamboo chips with a high speed blender for 30 min. The fibers were separated by size using several sieves with various apertures. Finally, the extracted fibers were dried in an oven for 72 h at 105 _C. Long fibers were able to carry a higher tensile load as a result of their increased transverse length, increasing the tensile modulus of the composite. However, the tensile strength of the longer fibers was decreased. Some researchers have used the same procedure to extract fiber and to study the rheological and morphological behavior of the bamboo fiber composite. They found that bamboo fiber acted as an efficient nucleating agent for the crystallization of the matrix, increasing the rate of crystallization. This method has also been used to make particles from dried bamboo strands in studies working with Nano clay.

e) Rolling mill

Bamboo culm was cut from the nodes into smaller pieces, and these pieces were then cut into strips with a thickness of 1 mm. The strips were soaked in water for 1 h to facilitate the separation of fibers. Then, they were passed through the rolling mill at low speed and under slight pressure. The rolled strips were soaked in water for 30 min and then separated into fibers with a razor blade. The obtained fibers, ranging in length from 220 to 270 mm, were dried in the sun for 2 weeks. In another study, after bamboo strips were cut, they were pressed between two pairs of steel cylinders, and the fibers were extracted without soaking in water. In the rolling technique, the sliced bamboo is steamed and soaked in water to soften lignin, and then the fibers are passed through the roller to reduce their bonding strength. Usually, the fibers extracted from this procedure range from 30 to 60 cm in length.

B. *Chemical extraction*

Chemical extraction procedures use alkali or acid retting, chemical retting, Chemical Assisted Natural (CAN), or degumming to reduce or remove the lignin content of the elementary fibers. This treatment also has effects on other components of the bamboo microstructure including pectin and hemicellulose. The following section reviews the chemical procedures researchers have used to extract fibers.

a) Degumming

Several studies have used the degumming process to extract fiber by eliminating the gummy and pectin content from the decorticated bamboo strips. Controlling the degree of bamboo degumming is essential to producing a long single fiber.

Furthermore, some parts of the plant such as pectin and lignin need to be connected.

b) Alkali or acid retting

In the alkali procedure, bamboo strips were heated in a stainless steel container with 1.5 N NaOH solutions at 70 _C for 5 h. Subsequently, the press machine was used to press the alkali treated bamboo strips, and fibers were separated by a steel nail. Eventually, the extracted fibers were washed with water and dried in an oven. This extraction method caused less fiber damage. In another study, bamboo strips with the size of chips were soaked in NaOH for 2 h at 4% mass per volume to influence the cellulosic and non-cellulosic parts [18]. This method was repeated several times at a certain pressure to extract fiber in pulp form. The problem with this technique is that some large fiber bundles were formed during the extraction. Another research group soaked small bamboo strips in 1 N sodium hydroxide for 72 h to facilitate fiber extraction. As lignin is soluble in both acidic and alkaline conditions, trifluoroacetic acid (TFA) and alkaline solutions were used to extract fibers. These researchers also considered the amount of lignin in the middle lamellae. Their results indicated that in the alkali process, lignin remained in the middle lamellae, while a large portion was removed in the TFA procedure. Overall, alkali treatment improves the interfacial bonding or surface adhesion of composites as compared with other methods [17].

c) Chemical retting

Researchers used the Chemical Assisted Natural retting (CAN) procedure to reduce the lignin and water content in fibers. In this process, bamboo culm was cut into a thin slab in the longitudinal direction with a slicer. The manually separated fibers were immersed in Zn (NO3)2 solutions with concentrations of 1%, 2% and 3% and a material to liquor ratio of 1:20. The fibers were immersed at 40 _C at neutral pH for 116 h and kept in a BOD incubator, and then boiled in water for 1 h. These researchers found that this procedure was able to remove more lignin compared with alkaline and acid retting, but the moisture content of the treated fibers was high. In another study, researchers slit bamboo culm into 2 cm chips and roasted the chips for 30 min at 150 _C. The chips were immersed in water at 60 _C for 24 h and then dried in air prior to further impurity removal by repeated rolling. Subsequently, the fiber bundles were cooked with 0.5% NaOH (w/v), 2% sodium silicate, 2% sodium sulphite and 2% sodium polyphosphate solutions at 100 _C for 60 min at liquor to bamboo ratio of 20:1. After washing with hot water, the fibers were treated with 0.04% xylanase and 0.5% diethylene triamine pentacetic acid for 60 min at 70 _C and pH 6.5. The obtained fibers were cooked again at 100 _C for 60 min following the same procedure, with the exception of using 0.7% NaOH. The fibers were bleached in a polyethylene bag with 0.2% sodium hydroxide, 4% H2O2, and 0.5% sodium silicate for 50 min. The pH was kept at 10.5 and the liquor ratio was 20. Lastly, after treatment with 0.5% sulphuric acid for 10 min and emulsification for 5 days, the refined bamboo fibers were acquired. This study found that the bamboo fiber had a smaller orientation angle for exterior macro fibrils, which is an important factor showing that bamboo fiber is suitable for use as fiber reinforcement in composites in comparison with ramie, flax, and cotton fibers.

C. *Combined mechanical and chemical extraction*

The compression molding technique (CMT) and roller mill technique (RMT) are usually used after alkali and chemical treatment to extract fibers. In one research study, the CMT technique was used to pressurize a bed of alkaline treated bamboo strips between two flat platens under a load of 10 tons. In this method, the starting bed thickness and compression time are important factors to separate high quality fibers. In the RMT technique, the treated bamboo strips were forced between two rollers, with one fixed and the other rotated. In both methods the bamboo strips were flattened, and the combined alkaline and mechanical process enabled the easy separation of strips into individual fibers. In addition, the size of the compression mound and the diameter of the rollers are two factors that limit the ability to extract fibers with smaller strip sizes in both techniques. In another study, only a roller was used to extract fibers. In this procedure the nodes of the bamboo culm were removed and the internodes were sliced in the longitudinal direction by the slicer to make strips. The bamboo strips were immersed in NaOH solution with concentrations of 1%, 2%, and 3% at 70 _C for 10 h. The mechanical properties of fibers immersed in 1% NaOH are higher than the properties of fibers immersed at other concentrations. The alkali-treated strips were rolled by a roller looser to extract fiber, and finally the small fibers acquired in this way were washed with water and dried in an oven at 105 _C for 24 h. The influence of the mechanical, chemical and combined mechanical and chemical extraction methods on the mechanical and physical properties of bamboo fibers are given in Table 2, and fibers extracted using different methods are shown in Fig. 3 paper [8][13].

Procedure for extraction of rough and fine bamboo fiber is detailed explained in paper [05]. According to author the bamboo fiber is obtained from bamboo tree and it is divided into two kinds of fiber according to different process flow and method: Natural original bamboo fiber and bamboo pulp fiber (namely bamboo viscose fiber or regenerated cellulose bamboo fiber). Original bamboo fiber is directly picked up from natural bamboo without any chemical additive, using physical and mechanical method. In order to differentiate from bamboo pulp fiber (bamboo viscose fiber), we call it as original bamboo fiber or pure natural bamboo fiber. But bamboo pulp (viscose) fiber belongs to regenerated cellulose fiber as chemical fiber. Broadly there are two types of processing to obtain bamboo fibers viz. mechanical processing and chemical processing. Both processes initially include splitting of bamboo strips, which is followed by either mechanical processing or chemical processing depending upon the further use of bamboo fibers. Chemical processing includes initial alkali hydrolysis (NaOH) to yield cellulose fibers. Alkali treated cellulose fibers are then passed through carbon disulphide via multi-phase bleaching. Most of the manufactures use this process as it is least time consuming procedure to yield the bamboo fibers. However, in mechanical process, the initially crushed bamboo is treated by enzymes leading to formation of spongy mass and by the help of mechanical comb fiber technology, individual fibers are obtained. This method is environment friendly as compared to chemical process, although it is less economic process. Researchers reported detailed method of fiber extraction and it was divided into rough and fine bamboo preparation [35]. The rough bamboo fibers were obtained by cutting, separation, boiling and fermentation with enzymes of bamboo. While as to obtain fine bamboo, the steps followed are boiling, fermentation with enzyme, wash and bleach, acid treatment, oil soaking and air-drying. The detailed outline is given in Fig. 5.

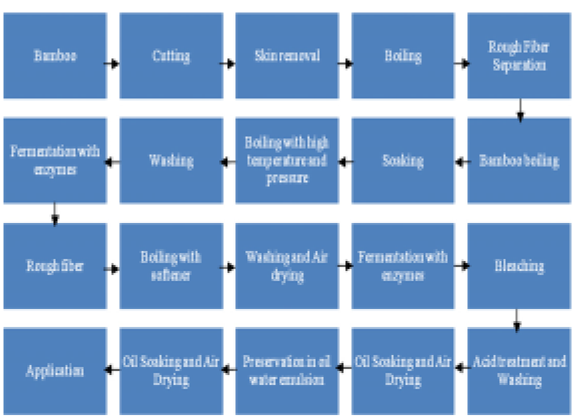

Fig. 5: Extraction of rough and fine bamboo fiber [05].

D. *Preparation of oriented bamboo fiber mat (OBFM)*

The bamboo was sawn into a bamboo tube with the length of 2600 mm, and then was split longitudinally into two semicircular bamboo tubes. Thereafter, the inner nodes were removed, and the semicircular bamboo tube was pushed into the fluffier along the grain direction. The bamboo tubes were fluffed along the longitudinal fiber direction to form a series of dotted and/or linear shaped cracks along the fiber direction; consequently, the natty structural OBFM was formed by the interlaced bamboo bundles fiber consisting of less than 5 vascular bundles and several ground tissues. The OBFMs were dried in the oven to an approximate moisture content of 10% [19].

E. *Extraction of bamboo nano crystals for nano composites*

As we already discussed that Bamboo is large source of the cellulose and cellulose fibers are advantageous in the production of the nano-scale particles and bio-composites because the fibers are made from natural nano scale components. Moreover, cellulose fibers are cheap, environment friendly, and are easily found from plant fibers. For this reasons, natural cellulose fibers are especially suitable to prepare nano-composites. Nano fibers and nanocrystals have been extracted from plants by many scientist and researchers.

There are many methods to obtain nano fibers and nanocrystals from natural materials, but the major approaches to prepare cellulose nano fibers and/or nanocrystals involve mechanical treatment, enzymatic treatment, and/ or chemical modification. However, it is not easy to obtain nano fibers and/or nano crystal, since the cellulose structure is stable, and chemical reagents are blocked from reacting with active groups of fibers.

Mechanical treatments such as ultra-sonication, grinding, and high pressure homogenizer have been utilized to facilitate the chemical process [27].

VI. TESTING OF THE BAMBOO AND BAMBOO FIBERS

Testing of the bamboo and bamboo fibers can be done by the so many researchers with different methods and different specimen sizes. In this paper collectively testing of the bamboo and bamboo fibers is studied with different methods. We will study testing methods for bamboo and bamboo fibers separately. The fiber testing method for finding the modulus of elasticity of fiber according to the ASTM standard is given in the paper [43]. Testing of the bamboo includes testing of the bamboo, bamboo scrimbers and bamboo sheets, and bamboo fibers.

A. *Testing of Bamboo*

Bamboo is a natural functionally graded material whose elastic modulus gradually increases from the inner to the outer surfaces. A hollow cylinder test has been developed to characterize the strength and stiffness of bamboo specimens in the cross sectional plane. A hydraulic jack is used to inflate the rubber hose, which is inserted into a bamboo specimen to apply an inner pressure. The strains on the inner and outer surfaces of the bamboo are measured under an increasing inner pressure until that the bamboo specimen splits. The effective elastic modulus of bamboo varies continuously in the radial direction that is tentatively approximated by a power, exponential or linear function, respectively, each of which includes two parameters to be determined experimentally. In this way bamboo is tested. [36]

The hollow cylinder test is applicable for calculating the elastic modulus in radial and tangential direction. Both the elastic modulus has different values because of anisotropy of the bamboo fibers. The variation of the elastic modulus in radial direction from inner radius to outer radius is exponential. Test is very useful for determination of the strength of the bamboo [36].

Disadvantage of the test is that it is applicable for only hollow bamboos and the dimensions of bamboo specimens are limited; the inner diameter of specimens has to be larger than that of the rubber hose and within the range of tubing inflation. For different applications of bamboo species, different sizes of the test equipment are recommended in future implementation.

Fatigue test is one of the important parameter for the bamboos. Fatigue test can be taken for the axial loading and diametrical compression. Bamboo is subjected to cyclic loading, both in the plant itself and subsequently when the material is used in load-bearing applications in the construction industry. However, there is currently no data in the literature describing fatigue in this material. We found that sections of bamboo culm loaded parallel to the culm axis did not undergo fatigue failure: samples either failed on the first loading cycle, or not at all. By contrast, fatigue was readily apparent in samples loaded in compression across the diameter of the culm. The number of cycles to failure increased as the cyclic load range decreased in a manner similar to that found in many engineering materials: fatigue occurred at applied loads as small as 40% of the ultimate strength [32].

Bamboo culm samples display fatigue failure when loaded in compression across their diameters, simulating a type of deformation which commonly occurs as a result of culm bending. By contrast, no fatigue behavior occurs when samples are loaded in axial compression. Under diametric loading, failure develops in a series of stages during which cracks initiate and grow in different locations around the circumference.

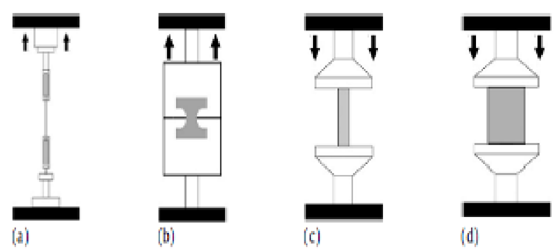

Figure 6: Schematic of tests. [35]

Failure in the first cycle (i.e. static failure) is associated with a tensile stress of 10.4 MPa on the outer surface and 19.1 MPa on the inner surface. High cycle failure at 100,000 cycles requires a stress range of 4.5 MPa on the outer surface and 11 MPa on the inner surface. The effect of stress concentration features such as grooves and holes is complicated owing to the multi-stage failure process. More work is needed to systematically study the effect of feature size, shape and location. [32].

B. *Testing of Bamboo Scrimbers and sheets*

The available bamboo products are bamboo scrimber and laminated bamboo sheets. These bamboo products are used in the furniture applications. The bamboo had become a good replacement for the engineered timber products.

Standard	Test Method	Test Schematic	Direction	Specimen size, mm	Loading Rate, mm/mim
ASTM D143	Tension	a	Parallel to grain	25*25*460	1
		b	Perpendicular to grain	62*50*50	2.5
BS 373	Compression	c	Parallel to grain	20*20*60	0.635
		d	Perpendicular to grain	50*50*50	0.635
BS 373	Shear	e	Parallel to grain	50 _ 50 _ 50	0.635
BS EN 408	4 point bending	f	Bamboo scrimber, Laminated bamboo	40 _ 40 _ 800 40 _ 40 _ 800	10

Table 2: Experimental test methods for bamboo scrimber and laminated bamboo.

Two commercially produced products from China used in the study. The bamboo scrimber product is comprised of Phyllostachys pubescens (Moso) with a phenol formaldehyde resin. The final product is a 140 _ 140 mm section available in varying lengths. The process of manufacturing bamboo scrimber uses the bamboo culm with minimal processing. The resulting commercial product is tested as a final product with no additional modifications. The average density of the bamboo scrimber is 1160 kg/m3 with a moisture content of 7%. The procedure of producing bamboo scrimbers is shown in figure 6. In comparison, Moso as a raw material has a relative density of approximately 0.5–1.0 [35].

Fig. 7: Bamboo scrimber general manufacturing process in China [35].

Laminated bamboo sheets are also manufactured from Moso bamboo strips using a soya-based resin as shown in fig 8 and discussed in the previous section. The structural specimens are built up from a commercial sheet (2440*1220*19 mm). The sheet was Cut and the section laminated into the desired dimensions using polyurethane adhesive (Purbond HB S309). The adhesive was applied manually with a glue proportion of approxy. 180 g/m2 (final product) and the lamina pressed using manual clamps to apply the required pressure of 0.6 MPa for 4 hours.

Fig. 8: Laminated bamboo general manufacturing process in China [35].

The methods for the testing with ASTM standards and different specimen sizes for the tensile, compressive, shear and bending tests are tabulated in table 2. Figure 6 elaborate the specimen sizes.

C. Testing of Bamboo Fibers

Bamboo fibers can be tested as like normal fiber testing procedure. The experimental set up is also same as setup for normal fiber testing. The bamboo fiber includes the physical characterization and mechanical characterization.

The most commonly measure properties in physical characterization are the fiber cross section dimensions and density of the fiber. Fiber (reinforcing material) cross section dimensions can be measured by using vernier caliper or the micrometer screw gauge for the macro size fibers (bamboo strips). The microscopic measurements are also required for the for bamboo fibers. So many times the fiber yarn is used as the reinforcing material in that case the physical characterisation method is same as like for fiber but mechanical characterisation method is different [43]. Density of the fiber is calculated by liquid displacement method mentioned according to the ASTM D3800 [43] [44].

In mechanical testing the most commonly measured properties of fibers are the longitudinal modulus tensile strength, and ultimate tensile strain. A mechanical test method is described in ASTM specification D3379-75 [44]. The method is recommended for fibers with an elastic modulus greater than 21 GPa.

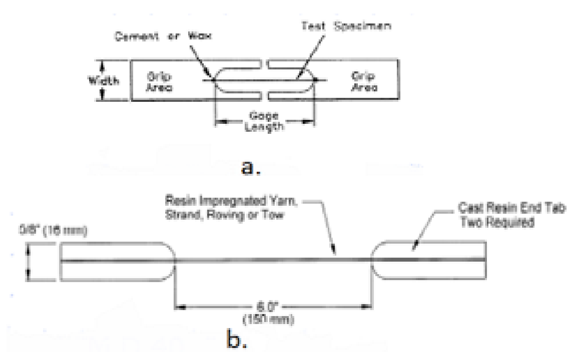

Figure 9: (a) Fiber testing, (b) Tow testing. [43]

The filament is mounted along the centerline of a slotted paper tab and axial alignment is accomplished without damaging the fiber. After the specimen is mounted in the test machine the paper tab is cut to allow for filament elongation. Specimens of various gauge lengths are tested to failure at a constant crosshead rate, and the load displacement curve is obtained. This is the single fiber test shown in figure 9(a) [44] [43]. In so many cases the fibers are tested by using tow test. In the tow test resin impregnated yarn strand also called as the Roving or tow of 150 mm length with both ends casted in resin tab and tensile testing is done [43]. Testing is according to the standard ASTM D4018, shown in figure 9(b).

D. Testing of Bamboo Fiber reinforced composite

Testing of the bamboo reinforced composite is similar to the ordinary composite material. In mechanical testing the most commonly measured properties of fibers are the longitudinal modulus tensile strength, and ultimate tensile strain. All these properties for tensile, compressive or tensile loading are determined for the unidirectional lamina. The mechanical analysis is the study of a material’s behavior when subjected to loads. The mechanical properties mainly provided by the cellulose content, which is influenced by many factors such as fibers volume fraction, fiber length, fiber aspect ratio, fiber-matrix adhesion or fiber orientation. Several papers have been published on the study of bamboo fiber reinforced composites reported that mechanical properties of bamboo vary because of the different testing methods used and the samples tested. Different types of specimen sizes are tested for the different types of materials. All the specifications are according to ASTM standard. All the standards of ASTM are given in the literature [43] and [44].

So many researchers tested bamboo fiber reinforced composite according to the different standards and different specimen sizes. Many researchers compared the results of the tests of bamboo fiber composite for different matrix materials or with same matrix material but different fibers such as the glass fibers, Kenaf fibers, Sisal fibers etc. In this paper we are going to study some of the comparison studies and application oriented studies.

Bamboo and Kenaf fiber composites with biodegradable matrix material CP-300(corn-starch based resin, which was a blend of starch and PCL) are compared and conclusion is made that Fibers Young’s modulus were found to be 22,000 MPa for kenaf and 18,500 MPa for bamboo. In addition, kenaf was found to be more compressible than bamboo due to the porous structure. The compression ratios were 1.6–1.3 for kenaf and 1.1–1.0 for bamboo. However, the flexural modulus in bamboo composites was as same level as that in kenaf composites. This is because the Young’s modulus in the bamboo was measured lower than actual modulus due to the partial breakage behavior during testing. Flexural modulus increases with increase in fiber volume fraction [17].

PLA and bamboo fibers are annually renewable and biodegradable. The effects of fiber content and fiber treatment by mercerization were analyzed. It is possible to create composites of PLA and bamboo fibers by single-screw extrusion and compression molding. These composites can be made with a fiber concentration of up to 40% by weight. Forty percent is a likely limit for the concentration of fibers in composites made by this method. Adding bamboo fibers with this fabrication method caused the PLA to become more brittle. The fibers reduced the bending strength and fracture toughness of PLA while increasing the bending modulus [18].

The dynamic properties of PLA and the composites were highly dependent on temperature in the range of 30 – 150 °C, but they were not very dependent on frequency below 100 Hz. The addition of bamboo fibers did not significantly affect the glass transition temperature of the PLA, but it did reduce the temperature at which PLA begins to degrade. A low degradation temperature can be preferable for disposable materials. Adding high concentrations of treated fibers is a way to increase the flame retardation of PLA. It would be interesting to study the thermal conductivity of these composites in the future to explore their potential as insulation materials [18].

Tensile properties of bamboo fiber, vetiver grass fiber and coconut fiber reinforced PLA composites were prepared by extrusion and injection molding processes. The tensile modulus of untreated natural fiber reinforced PLA composites were increased by the addition of natural fibers. Tensile strength of untreated vetiver grass fiber and coconut fiber composites were lower than neat PLA and decreased with increasing of fiber content. However, the tensile strength of untreated bamboo fiber/PLA composites remained constant and decreased when fiber content reached 40 weight %. The effects of flexible epoxy surface treatment on tensile properties were dependent on the type of natural fiber. Tensile strength of bio composites decreased with the applied of flexible epoxy surface treatment. The flexible epoxy surface treatment improved the tensile strength of bamboo fiber and coconut fiber reinforced PLA composites when compared with untreated composites. Bamboo fiber proved to be the most effective reinforcement for the tensile properties improvement of natural fiber reinforced PLA composite [24].

The mechanical properties of the natural fiber composites (bamboo, sisal) primarily depend upon the fiber/matrix interfacial adhesion. Though the natural fibers are superior in properties, but due to its hydrophilic nature, it possesses poor bonding nature with the hydrophobic polymer matrix. This has resulted in the degradation of its mechanical properties. Many researches works regarding the surface modification of the fibers, both chemically and physically, have been reported for enhancing the

fiber/matrix interfacial interaction. The fiber length, loading and its moisture absorption capacity also influence the mechanical properties of the natural fiber reinforced composites. The optimum fiber length, loading and low moisture absorption nature of the fibers have improved the mechanical properties of the composite. The natural fiber composites are also subjected to weight loss due to thermal degradation at higher temperature. The addition of flame retardants have resulted in the increase of thermal stability of the composite [30].

An innovative GFRP-bamboo-wood sandwich beam was introduced in study. Experiments were conducted to investigate the effects of the thickness of GFRP and bamboo layers on the overall structural performance in bending. Increases of the thickness of the bamboo and GFRP layers could significantly increase the flexural stiffness and ultimate load of the sandwich beams [40].

Beside as an interesting alternative for reducing the inconveniences of polymer utilization, bamboo also give the advantages if we preserving and conserving its. Previous mechanical testing results shows that bamboo fiber can be suggested for capability's mechanical product. Fiber lengths, orientation, concentration, dispersion, aspect ratio, selection of matrix, and chemistry of the matrix need to be investigated thoroughly [06].

Bamboo fiber reinforced epoxy had higher tensile strength; while jute fiber reinforced epoxy composites had higher Young's modulus. Bamboo and jute fiber reinforced epoxy composites had better flexure strength with longitudinal and transverse fiber distribution respectively Fiber distribution was not uniformly for both bamboo and jute fiber reinforced UD composites. It is also revealed that jute fiber reinforced epoxy composites showed better thermal behavior compared to bamboo fiber reinforced epoxy composites [46].

An increase in bamboo fiber content of up to 40 % by mass in bamboo fiber reinforced plastic results in a 60 % increase in tensile modulus. Tensile strength did not show an obvious increase. Replacing bamboo fibers by glass fibers results in improved tensile modulus and tensile strength in Bamboo Glass reinforced plastic. Varying the bamboo fiber length in composite materials does not result in improvement in tensile strength while a slight improvement in tensile modulus is observed [41].

Light-weight PP (Polypropylene) composites reinforced with bamboo strips has considerably higher flexural properties than similar composites reinforced with PP fibers. The bamboo strip (BS)-PP composites have high flexural and acoustical properties even at low composite densities that makes them suitable to replace fiberglass currently used for automotive headliner substrates. BS–PP composites can be manufactured at much lighter weight for the same or higher mechanical properties compared with jute–PP composites. Sound dampening properties of BS–PP composites are also higher compared with jute–PP composites making bamboo an ideal raw material for automotive headliner composites [39].

The mechanical properties of bamboo fiber reinforced composite produced using OBFM (oriented bamboo fiber mat) and phenolic resins are significant enhanced comparing with those of raw bamboo and other bamboo-based composites. This Paper demonstrates that BFRC with good properties are promising and can be achieved with high bamboo utilization [38].

Bamboo Charcoal is used as a reinforcing material in wood plastic composites which increase the capacity of water resistant as the percentage increase in the bamboo charcoal [34].

In one paper the tribological behavior of bamboo/epoxy composite is studied. Bamboo/epoxy shows high specific wear rate at the first stage and then reduced at the steady state due to the smoothening process occurred on both rubbed surface. The bamboo/Epoxy composite has 5.5 to 5.7, mm3/Nm at 2.8 m/s velocity. Coefficient of friction is about 0.57 to 0.64 [33].

Compared with natural cotton fibers, natural bamboo fiber has no antibacterial ability, which is similar to what had been for flax fiber. Ramie fiber, by contrast, exhibits some inhibitory action against all three test bacteria, especially against Staphylococcus aureus, with the bacteriostatic rate as high as 90.2%. In addition, regenerated bamboo fiber has an inhibitory effect on bacterial growth but has no effect on fungi. The linear relationship between the moisture regains and the bacteriostatic rate suggests that the microbial resistance of plant fiber may be related to its hygroscopy. Some extraction methods could improve the performance of natural bamboo fiber against bacteria [28].

The bamboo fiber composites are as stronger as we can use it for the glass fiber composite applications, since bamboo fibers are as stronger as glass fibers is proved by various researchers. Details of the Bamboo fiber composite studied by various researchers are tabulated in table 3.

Table 3: Details of Bamboo fiber composite

Bamboo composite (matrix material)	Type of bamboo composite material and fabrication method	Properties	Applications
Bamboo/Phenol formaldehyde resin[35]	Scrimber, bamboo culm with minimal processing-compression and heat curing	average density is 1160 kg/m3 with a moisture content of 7%, Flexural modulus-13 GPa	Structural applications and furniture applications
Bamboo/Soya-based resin [35]	Laminated bamboo sheets; gluing of the bamboo laminas by polyurethane adhesive	average density is 686 kg/m3, Flexural modulus is around 11-13 GPa	Structural applications and furniture applications, Partition laminates.

Bamboo/CP-300(corn-starch based resin, which was a blend of starch and PCL), Kenaf/CP-300 [17]	Randomly oriented fiber composite sheet, fabricated by press forming Resin transfer molding	Young's modulus is 18,500 MPa for bamboo and 22,000 MPa for kenaf, The flexural modulus increased with increasing fiber volume fraction up to72% for bamboo, and decreased above volume fraction.	Fabrication of automobile parts
Bamboo/PLA Resin[18]	Bamboo fiber reinforced plastics, fabricated by single-screw extrusion and compression molding	Total biodegradable composite, Adding bamboo fibers with this fabrication method caused the PLA to become more brittle. The fibers reduced the bending strength and fracture toughness of PLA while increasing the bending modulus.	Mobile phones and electrical components cases, automobile doors and other structural components. As PLA is biodegradable it has bright future.
Bamboo/PLA, vetiver grass fiber/PLA, coconut fiber/PLA [24]	Fiber reinforced plastics for all three fibers. Fabricated by extrusion and injection molding processes at an injection temperature 200^{o} C.	Tensile strength of untreated vetiver grass fiber and coconut fiber composites were lower than neat PLA and decreased with increasing of fiber content. However, the tensile strength of untreated bamboo fiber/PLA composites remained constant and decreased when fiber content reached 40 weight %	Bamboo fiber proved to be the most effective reinforcement for the tensile properties improvement of natural fiber reinforced PLA composite. PLA composite are suitable for so many industrial applications where brittle material is suited.
Bamboo/ Silane (KH560), Sisal/ Polyethylene [30]	Fiber Reinforced Plastics	Weight loss due to thermal degradation at higher temperature, electrical resistant, The addition of flame retardants has resulted in the increase of thermal stability of the composite.	Used in many engineering applications like sliding panels, bearings, linkages, bushings, also used as the engineering material.
GFRP-bamboo-wood sandwich beam [40], Adhesive used is Purbond HBS 109 polyuretha	The wood core was first adhesively bonded with bamboo layers on both sides. Then the sandwich specimens were manufactured	Increases of the thickness of the bamboo and GFRP layers could significantly increase the flexural stiffness and	Civil engineering applications, Aerospace engineering, Used as thermal insulations and acoustical walls in

ne adhesive, Resin used with glass fiber and bamboo is vinyl ester, paulownia wood is used for sandwiching element [40]	by applying glass fiber sheets and resin on the top surface of the bamboo layer through a vacuum infusion process and cured for 24 h. The outer face layer of the sandwich specimens consisted of four layers of bi-axial E-CR glass with 0_/90_ orientations and the fiber volume content was 65%,	ultimate load of the sandwich beams. high specific bending stiffness, weight efficiency, and good thermal and acoustical insulation, over conventional forms of structural members	recording studios.
Bamboo/Epoxy, Jute/Epoxy [46]	Vacuum assisted resin transfer molding and hot pressing	Young's modulus of Jute and bamboo fiber reinforcement composite is 31 GPa and 29 GPa respectively and tensile strength 216 MPa and 392 MPa respectively.	Automotive applications, Applicable for the replacement of the glass fibers.

Bamboo/Polypropylene resin, Glass/ Polypropylene resin, and Bamboo-Glass/ Polypropylene resin hybrid composite [41]	Short fibers are reinforced in matrix to produce composite, fabricated by the resin transfer molding.	An increase in bamboo fiber content of up to 40 % by mass in bamboo fiber reinforced plastic results in a 60 % increase in tensile modulus. Tensile strength did not show an obvious increase. Replacing bamboo fibers by glass fibers results in improved tensile modulus and tensile strength in Bamboo Glass reinforced plastic.	Mainly utilized in outdoor applications, Industrial applications etc.
Bamboo/Polypropylene resin [39]	Fine bamboo strips (BSs) have been laid on polypropylene (PP) web, stacked, and compression molded to prepare unconsolidated light-weight composites.	Density is 0.312 g/cm^3, Flexural strength, modulus, offset yield load, and Noise Reduction Coefficient (NR) of the BS–PP composites are 5.8 times, 2.9 times, 6.5 times, and 1.4 times higher, respectively,	Sound Engineering applications, automotive applications.

		compared to jute–PP composites, excellent mechanical and sound absorption Properties.	
Bamboo/Phenolic Resins (Phenol Formaldehyde) [38]	Oriented Bamboo Fiber Mat (OBFM) is dipped in resin and after that oven dried. Similar laminas are glued over each other with adhesive as a same resin.	The yield of OBFM reaches to 92.54%.The mechanical properties of bamboo fiber reinforced composite produced using OBFM and phenolic resins are significant enhanced comparing with those of raw bamboo and other bamboo-based composites.	Applications in furniture, flooring, building and civil engineering field.
Bamboo Charcoal + Wood Plastic/ Polyethylene [34]	WPC and BC-WPC pellets were prepared and The pellets were injected into ISO standard specimens by using an injection molding machine.	BC-WPC composites increased water resistance with increasing the content of BC, Flexural Properties is also better.	Buildings and constructions, automotive and gardening and outdoor products, substitutes of wood

VII. CONCLUSION

Bamboo is a fast growing plant that has the potential not only to replace wood for certain applications but also to replace non-environmentally friendly and non-recyclable raw materials, such as fiberglass and polyurethane for composites applications.

The bamboo strip composites have high flexural and acoustical properties even at low composite densities that make them suitable to replace fiberglass currently used for automotive headliner substrates. Bamboo fiber composite can be manufactured at much lighter weight for the same or higher mechanical properties compared with other natural fibers. Sound dampening properties of Bamboo composites are also higher compared with composites making bamboo an ideal raw material for automotive headliner composites. Mats made of fine bamboo strips are already available in the market. Therefore, commercial manufacturing of bamboo strips as reinforcement for composites and subsequent fabrication of composites should not be technically challenging. Bamboo strip mats have good acoustic properties hence we can use the bamboo strip mats furniture in recording studios, multiplex etc. as a noise absorber. Extraction of bamboo fiber is simple and less energy consuming as compared to the glass and carbon fiber extraction processes. One of the limitations of Bamboo fiber is it is compared with natural cotton fibers, natural bamboo fiber has no antibacterial ability. Regenerated bamboo fiber has an inhibitory effect on bacterial growth but has no effect on fungi.

ACKNOWLEDGMENT

I express our sincere thanks to my beloved parents for their invaluable love; moral support and constant encouragement in my life. We owe immense gratitude to my guide Prof.G.N.Kotwal, Vishwakarma Institute of technology, Pune for his moral during the course of my Research work. I sincerely thanks to Prof.Dr.M.V.Walame, Professor, Department of Mechanical Engineering.

REFERENCES

[1] Lucintel Brief. Opportunities in Natural Fiber Composites. Lucintel March 2011.

[2] U.S.Bongarde, V.D.Shinde. Review on natural fiber reinforcement polymer composites. International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 3, Issue 2, March 2014.

[3] Omar Faruk, Andrzej K. Bledzki, Hans-Peter Fink, Mohini Sain. Biocomposites reinforced with natural fibers: 2000–2010. Progress in Polymer Science 37 (2012) 1552– 1596.

[4] D. Chandramohan & .K. Marimuthu. A Review on Natural Fibers. IJRRAS 8 (2)-August 2011

[5] H.P.S. Abdul Khalil, I.U.H. Bhat, M. Jawaid, A. Zaidon, D. Hermawan, Y.S. Hadi. Bamboo fiber reinforced biocomposites: A review. Materials and Design 42 (2012) 353–368.

[6] Kannan Rassiah and M.M. H Megat Ahmad. A Review on Mechanical Properties of Bamboo Fiber Reinforced Polymer Composite. Australian Journal of Basic and Applied Sciences, 7(8): 247-253, 2013.

[7] S. A. H. Roslan, Z. A. Rasid and M. Z. Hassan. The Natural Fiber Composites Based On Bamboo Fibers: A Review. ARPN Journal of Engineering and Applied Sciences-Vol. 10, No. 15, August 2015.

[8] Parnia Zakikhani, R. Zahari, M.T.H. Sultan, D.L. Majid. Extraction and preparation of bamboo fiber-reinforced composites, Materials and Design 63 (2014) 820–828.

[9] Sarah E. Royse. Fabrication and Characterization of Biocomposites from Polylactic Acid and Bamboo Fibers. DigitalCommons@University of Nebraska – Lincoln-8-1-2012.

[10] Kazuya Okubo, Toru Fujii, Yuzo Yamamoto. Development of bamboo-based polymer composites and their mechanical properties. Composites: Part A 35 (2004) 377–383.

[11] Composites: Part A 35 (2004) 377–383. Natural Fiber Composites; Recent developments. Composites: Part A 35 (2004) 377–383.

[12] Shakila Umair. Environmental Impacts of Fiber Composite Materials Study on Life Cycle Assessment of Materials used for Ship Superstructure. SOM-EX 06-40, Stockholm, 2006.

[13] Parnia Zakikhani, R. Zahari, M.T.H. Sultan, D.L. Majid. Extraction and preparation of bamboo fiber-reinforced composites, Materials and Design 63 (2014) 820–828.

[14] Eustathios Petinakis, Long Yu, George Simon, Katherine Dean. Natural Fiber Bio-Composites Incorporating Poly (Lactic Acid).

[15] Omar Faruk, Andrzej K. Bledzki, Hans-Peter Fink, Mohini Sain. Biocomposites reinforced with natural fibers: 2000–2010. Progress in Polymer Science 37 (2012) 1552– 1596.

[16] Kazuya Okubo, Toru Fujii, Erik T. Thostenson. Multi-scale hybrid biocomposite: Processing and mechanical characterization of bamboo fiber reinforced PLA with microfibrillated cellulose. Composites: Part A 40 (2009) 469–475.

[17] Shinichi Shibata, Yong Cao, Isao Fukumoto. Flexural modulus of the unidirectional and random composites made from biodegradable resin and bamboo and kenaf fibers. Composites: Part A 39 (2008) 640–646.

[18] Sarah E. Royse, Fabrication and Characterization of Biocomposites from Polylactic Acid and Bamboo Fibers. University of Nebraska-Lincoln, seroyse@huskers.unl.edu.

[19] Yanglun Yu, Xianai Huang, Wenji Yu. A novel process to improve yield and mechanical performance of bamboo fiber reinforced composite via mechanical treatments. Composites: Part B 56 (2014) 48–53.

[20] Literature Review, author is not mentioned but I have attached the soft copy.

[21] Koichi Goda, Meyyarappallil Sadasivan Sreekala, Sant Kumar Malhotra, Kuruvilla Joseph, and Sabu Thomas. Advances in Polymer Composites: Biocomposites – State of the Art, New Challenges, and Opportunities.

[22] S. Siti Suhaily, H.P.S. Abdul Khalil, W.O. Wan Nadirah and M. Jawaid. Bamboo Based Biocomposites Material, Design and Applications. http://dx.doi.org/10.5772/56057.

[23] S B Roy, Dr. S C Shit, Dr. R A Sengupta, Dr. P R Shukla. A Review on Bio-Composites: Fabrication, Properties and Applications. International Journal of Innovative Research in

Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 3, Issue 10, October 2014.

[24] Wassamon Sujaritjun, Putinun Uawongsuwan, Weraporn Pivsa-Art, Hiroyuki Hamada. Mechanical property of surface modified natural fiber reinforced PLA biocomposites. 10th Eco-Energy and Materials Science and Engineering (EMSES2012).

[25] A.Balaji, B. Karthikeyan, and C. Sundar Raj. Bagasse Fiber – The Future Biocomposite Material: A Review, International Journal of ChemTech Research CODEN (USA): IJCRGG ISSN: 0974-4290 Vol.7, No.01, pp 223-233, 2014-2015.

[26] N. A. Azahari, N. Othman and H. Ismail. Biodegradation Studies of Polyvinyl Alcohol/Corn Starch Blend Films in Solid and Solution Media. Journal of Physical Science, Vol. 22(2), 15–31, 2011.

[27] Yun Qian, Zhongyan Qin, Ngoc-Minh Vu, Guolin Tong, Y. C. Frank Chin. Comparision of Nanocrystals from Tempo Oxidation of Bamboo, Softwood, and Cotton Linear Fibers with Ultrasonic-Assisted Process.

[28] Lixia Xi, Daochun Qin, Xin an, Ge Wang. Resistance of Natural Bamboo Fiber to Microorganisms, and Factors that May Affect Such Resistance. Peer Reviewed Article.

[29] Premraj R and Mukesh Doble. Biodegradation of Polymers. Indian Journal of Biotechnology Vol. 4, April 2005, pp 186-193.

[30] Thingujam Jackson Singh, Sutanu Samanta. Characterization of Natural Fiber Reinforced Composites-Bamboo and Sisal: A Review. IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | PISSN: 2321-7308.

[31] N. Tudorachi, C.N. Cascaval, M. Rusu, M. Pruteanu. Testing of polyvinyl alcohol and starch mixtures as biodegradable polymeric materials. Polymer Testing 19 (2000) 785–799.

[32] Lauren Keogh, Patrick O'Hanlon, Peter O'Reilly, David Taylor. Fatigue in bamboo. International Journal of Fatigue 75 (2015) 51–56.

[33] Shalwan, B.F. Yousif. In State of Art: Mechanical and tribological behaviour of polymeric composites based on natural fibers. Materials and Design 48 (2013) 14–24.

[34] Xiang Li, Bingrong Lei, Zhidan Lin, Langhuan Huang, Shaozao Tan, Xiang CAI. The utilization of bamboo charcoal enhances wood plastic composites with excellent mechanical and thermal properties. Materials and Design 53 (2014) 419–424.

[35] Bhavna Sharma, Ana Gatóo, Maximilian Bock, Michael Ramage. Engineered bamboo for structural applications. Construction and Building Materials 81 (2015) 66–73.

[36] Po-Hua Lee, Marty Odlin, Huiming Yin. Development of a hollow cylinder test for the elastic modulus distribution and the ultimate strength of bamboo. Construction and Building Materials 51 (2014) 235–243.

[37] Lukas Sobczak, Reinhold W. Lang, Andreas Haider. Polypropylene composites with natural fibers and wood – General mechanical property profiles. Composites Science and Technology 72 (2012) 550–557.

[38] Yanglun Yu, Xianai Huang, Wenji Yu. A novel process to improve yield and mechanical performance of bamboo fiber reinforced composite via mechanical treatments. Composites: Part B 56 (2014) 48–53.

[39] Shah Huda, Narendra Reddy, Yiqi Yang. Ultra-light-weight composites from bamboo strips and polypropylene web with exceptional flexural properties. Composites: Part B 43 (2012) 1658–1664.

[40] Hai Fang, Huiming Sun, Weiqing Liu, Lu Wang, Yu Bai, David Hui. Mechanical performance of innovative GFRP-bamboo-wood sandwich beams: Experimental and modelling investigation. Composites Part B 79 (2015) 182e196.

[41] Moe Moe Thwe, Kin Liao. Effects of Environmental Aging on the Mechanical Properties of Bamboo-Glass Fiber Reinforced Polymer Matrix Hybrid Composite. Composite: Part A 33 (2002) 43-52.

[42] Shinichi Shibata, Yong Cao, Isao Fukumoto. Flexural modulus of the unidirectional and random composites made from biodegradable resin and bamboo and kenaf fibers. Composites: Part A 39 (2008) 640–646.

[43] Dr. Dan Adams (Director, Composite Mechanics Laboratory University of Utah Salt Lake City, UT 84112 (801)585-9807 adams@mech.utah.edu. Composite Structure Engineering Safety Awareness Course, Module: Composite Materials Test Methods.

[44] Isaac M. Daniel, Ori Ishai. Engineering Mechanics of Composite Materials. New York Oxford, Oxford University Press, 1994.

[45] Autar K. Kaw. Mechanics of Composite Materials, Second Edition. CRC Press, Taylor and Francis Group, 2006.

[46] Subhankar Biswasa, Sweety Shahinura, Mahbub Hasana and Qumrul Ahsana. Physical, Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites. Procedia Engineering 105 (2015) 933 – 939.

[47] Giuseppe Cristaldi, Alberta Latteri, Giuseppe Recca and Gianluca Cicala. Composites Based on Natural Fiber Fabrics.

[48] Dilip Tambyrajah, NFCDesign. Indulge and Explore, Natural Fiber Composites An invition to product designers.