Chapter 2
Bamboo Fiber Processing, Properties, and Applications

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Contents

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Abstract Bamboo fiber is a cellulosic fiber that is regenerated from bamboo plant. It is a great prospective green fiber with outstanding biodegradable textile material, having strength comparable to conventional glass fibers. Bamboo used for fiber preparation is usually 3–4 years old. Fiber is produced through alkaline hydrolysis and multi-phase bleaching of bamboo stems and leaves followed by chemical treatment of starchy pulp generated during the process. Bamboo fiber has various micro-gaps, which make it softer than cotton and increase its moisture absorption. They are elastic, environment-friendly, and biodegradable. The fiber is bacteriostatic, antifungal, antibacterial, hypoallergenic, hydroscopic, natural deodorizer, and resistant against ultraviolet light. Furthermore, it is highly durable, stable and tough and has substantial tensile strength. Due to its versatile properties, bamboo fibers are used mainly in textile industry for making attires, towels, and bathrobes. Due to its antibacterial nature, it is used for making bandages, masks, nurse wears, and sanitary napkins. UV-proof, antibiotic and bacteriostatic curtains, television covers, and wallpapers and many other things are also prepared from bamboo fibers to lessen the effects of bacteria and harm of ultra violet radiations on human skin. Bamboo fibers are also used for decoration purpose.

Keywords Bamboo • Bamboo fibers • Tensile properties • Mechanical properties • Processing

2.1 Introduction

Bamboo is a common term applied to approximately 1,250 species of large woody grasses, ranging from 10 cm to 40 m in height (Scurlock et al. 2000). Bamboo is considered to be the second largest resource of forestry in the whole world because of its rapid growth potential. Bamboo forests are distributed extensively in tropical and sub-tropical climates in frigid zones. The area covered by bamboo forestry is estimated to be around 20 million hectares. China is considered to be rich in bamboo resources and there are about 40 families and 400 species of bamboo found only in China. This rich resource of bamboo in China covers an area of about 7 million hectare; 35 % of the area covered by bamboo forests in the whole world (Yao and Zhang 2011). Bamboo is called a cash crop because the time required for its cultivation is less, can be grown in deprived regions and has a variety of uses. Furthermore, the plant is harvested after 3–4 years (Erdumlu and Ozipek 2008). Bamboo is observed to produce an adult tree in only 1 year.

Bamboo is supposed to be one of the best functionally gradient composite materials available. It is observed that in a piece of bamboo, 1 mm^2 area near outer periphery contains approximately eight fibers and inner periphery contains two fibers (Ray et al. 2005). Bamboo fiber is a new kind of natural material, which has high potential in textile field due to some of its specific properties (Liu and Hu 2008). Bamboo fibers are also known as breathable fabric as they resemble puffball of light and cotton in untwisted form (Yao and Zhang 2011). These fibers are cellulosic in nature and are obtained from natural, reproducible resource of bamboo plants. Bamboo fibers are made from pulp of the plant, which is extracted from the plant's stems and leaves.

Total culm of bamboo comprises of 60 % parenchyma, 40 % fibers, and 10 % conducting tissues (vessels and sieve tubes). Bamboo culm constitutes 60–70 % of fiber content by weight (Liese 1992). Bamboo fibers consist of cellulose, hemicellulose, and lignin in the ratio 2:1:1 (Tung et al. 2004; Fukushima et al. 2003). Bamboo monofilament has four layers where crystallized cellulose micro-fibrils (MF) are aligned longitudinally with reverence to the axis of the fiber. MFCs are bonded together with lignin and hemi-cellulose (Fukushima et al. 2003). Lignin is hydrophobic and plays an important role in formation of fibers in the form of matrix whilst MFCs play a role in reinforcement. The overall structure appears to have a hydrophilic surface with hydrophobic lignin core (Jain et al. 1992).

Bamboo fibers have good properties of moisture adsorption, moisture desorption, and air permeability (Yao and Zhang 2011). Being natural they are available in abundance, have high strength, are biodegradable and renewable (Deshpande et al. 2000). The current scenario of research and investigation on bamboo fibers is limited because of limited extraction of fibers from bamboo plant (Jain et al. 1992; Jindal 1988).

2.2 Bamboo Fiber Preparation

Bamboo fiber preparation methods can be divided into two types:

1. Mechanical method
2. Chemical method

Mechanical methods give natural bamboo fibers and involve flax production whereas chemical methods are of two types namely Bamboo Viscose Rayon method and Bamboo Lyocell method.

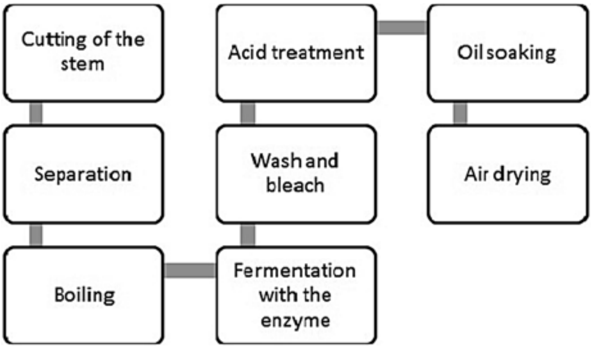

Fig. 2.1 Bamboo fiber preparation procedure

The preparation of rough and fine bamboo fiber is different. Rough bamboo fiber preparation does not involve harsh treatments like the use of bleaches and acids and soaking in oil. Preparation of rough bamboo fiber involves the following steps (Yao and Zhang 2011; Fig. 2.1):

1. Cutting of the stem
2. Separation
3. Boiling
4. Fermentation with the enzyme

The preparation of fine bamboo fiber is much similar to that of rough but also includes additional steps. The overall process involves (Yao and Zhang 2011):

1. Boiling
2. Fermentation with enzyme
3. Wash and bleach
4. Acid treatment
5. Oil soaking
6. Air-drying

2.3 Bamboo Fiber Processing

Bamboo processing is a lengthy process and has the following requirements:

1. Machine for separating rough bamboo fiber
2. High temperature pressure-cooking pot
3. Pool for bleaching and softening
4. Steam boiler
5. Equipments for washing
6. Drying room
7. Dehydrator

Table 2.1 Yield and quality of bamboo fibers depending upon their processing technique

Fiber processing procedure	Yield of fiber	Quality of yielded fiber
Rolling	High yield	Good
Mechanical comb fiber technology	Low yield	Good
Degumming defibrase system	High yield	Bad
Chemical mechanical processing technology	Low yield	Good
Processing technology by cracking	High yield	Good

Several technologies are available for the processing of bamboo fibers. Each of them has its own merits, demerits, and specifications and employs a different process. The following paragraphs include the details of the five of the technologies used for the processing of the bamboo.

2.3.1 Processing by Rolling

Rolling technology slices bamboo, which is then softened by steam so that lignin middle lamella separates out. The bonding of the fiber is then weakened through rolling or hammering. Through mechanical friction, bamboo is eventually decomposed (Yao and Zhang 2011). Quality and yield of fiber produced by this method is shown in Table 2.1.

2.3.2 Mechanical Comb Fiber Technology

With the help of mechanical equipments, bamboo is ground to make bamboo fiber. Although the strength and flexibility of the fiber is considerably damaged during the mechanical treatment process but the fiber produced is thick and short and is used in the production of bamboo fiberboard and some other low value products (Yao and Zhang 2011). Quality and yield of fiber produced by this method is shown in Table 2.1.

2.3.3 Degumming Defibrase System Technology by Explosion

As bamboo plant has high lignin content so it is difficult to perform degumming on it. Therefore, liquid water is taken and bamboo is treated at high temperature and pressure. Although this method is chemical and pollution free, has high fiber rate and uniform fiber recovery, but the process is intricate and costly and the fibers obtained are also dark colored (Yao and Zhang 2011). Quality and yield of fiber produced by this method is shown in Table 2.1.

2.3.4 Chemical Mechanical Processing Technology

In this method, bamboo is pretreated with chemical substances to dissolve the lignin, glia, and hemi-cellulose and to weaken the binding force between fibers. The fibers are then formed by mechanical external force. Deshpande introduced a chemical mechanical processing system, which can extract the bamboo fiber. It combines traditional techniques to molding grinding processes. The extracted bamboo fiber can be used for processing of isotropic composite material. This method has low fiber rate, requires more chemicals, fiber has a certain pH, and the process is complex and costly (Yao and Zhang 2011; Deshpande et al. 2000).

The above-mentioned method of production of bamboo fiber can be used as strengthening method to make a variety of composite materials. The products are further developed, and bamboo fiber produced in these methods cannot be used for weaving (Yao and Zhang 2011).

2.3.5 Processing Technology by Cracking

In 2005, Yao Wenbin and Zhang Wei of Zhejiang Forestry College put forward the cracking technology of bamboo fiber pyrolysis and separating (Yao and Zhang 2011).

Firstly, using high pressure-cooking vessel softens bamboo slices and then micro-cracks are formed. The slices are delaminated by splitting the bamboo through machine and the cracks and delamination expand along the direction parallel to the fiber leading to bamboo detaching. In external load synergies, the macro-crack of bamboo continues to expand, achieve its interfacial debonding stratified and obtain crude fiber bamboo. Coarse bamboo fibers become fine fibers after softening, carding and a series of processes (Yao and Zhang 2011).

The notable feature in this method is small damage to the fiber intensity, fiber product has even type, and also very adaptable. Bamboo fiber processed by this method has the length of 50–90 cm and the fineness of 0.06 mm (Yao and Zhang 2011). The quality and yield of bamboo fiber produced by this method is shown in Table 2.1.

2.4 Properties of Bamboo Fiber

2.4.1 Durability

The durability of bamboo fiber reinforced polypropylene can be increased by hybridizing it with small amount of glass fiber (Thwe and Liao 2002a). Bamboo glass fiber reinforced polypropylene composites have a very high fatigue resistance, which results in its extremely good durability (Thwe and Liao 2003).

The durability of bamboo fiber depends on high tensile strength, flexural strength, tensile load, moisture absorption, and molding capacity (Thwe and Liao 2002a). Unlike vegetal materials, bamboo durability is not affected by high pH. Bamboo fibers are set into concrete prisms and exposed to wetting and drying for 24 h. Then specimens without concrete and specimens with concrete are immersed in tap water. Different mechanical properties are measured after 7, 15, 30, 45, and 60 cycles. The results showed that there is no considerable change in these mechanical properties. These aggressive tests thus attest the durability of bamboo fibers (Lima et al. 2008).

2.4.2 Elasticity

Elasticity of bamboo culms is observed to increase with age. Specific modulus for elasticity measured for 1-year culm is 16,268, for 3 year culm is 14,346, and for 5 year culm is 17,414. This proves that elasticity in bamboo culms is enhanced with age. Elasticity of bamboo culms is directly proportional to specific gravity. When outer layer of bamboo is removed, specific gravity is lowered and hence elasticity decreases (Li 2004). The highest elasticity is observed in steam exploded bamboo filaments put into poly lactic acid matrix (Tokoro et al. 2008). There is a significant decrease in modulus of elasticity between longitudinal and transverse directions. Modulus of elasticity of longitudinal direction is 16.1 GPa and that of transverse direction is 5.91 GPa in the cell walls (Yu et al. 2007). Increase in filler loading increases the elasticity of bamboo fibers (Ismail 2003). Dynamic modulus of elasticity increases with increase in density, drilling resistance, modulus of elasticity, and modulus of rupture (Lin et al. 2006). As the surface area percentage of fiber band becomes larger, the modulus of elasticity increases (Sheng-Xia et al. 2005). Bamboo fibers owe their elasticity to combination of fiber rich outer part and compressible inner part (Obataya et al. 2007).

2.4.3 Elongation

Bamboo when treated with caustic soda of different concentration, show significant decrease in percent elongation at break with the increase in concentration of caustic soda (Das and Chakraborty 2008).

2.4.4 Flexural Strength

Bamboo fiber reinforced mortar laminates with reformed bamboo plate on bottom as tensile layer and a fiber reinforced mortar sheet at the top as compressive layer are exposed to have flexural strength of upto 90 MPa (Yao and Li 2003). Flexural strength shows a considerable increase at 50 % volume fraction of extracted bamboo fibers in composites (Chattopadhyay et al. 2010). Flexural strength of bamboo fiber reinforced epoxy resins is calculated to be 230.09 MN m^{-2} (Jain et al. 1992). Flexural strength of maleic anhydride treated bamboo polyester composite is increased by 50 % (Kushwaha and Kumar 2010). Autoclaved bamboo fibers reinforced cement composites have a flexural strength greater than 18 MPa. By screening out fines found in original bamboo pulp, flexural strength can be increased upto 20 MPa (Coutts and Ni 1995). Flexural strength of bamboo fibers shows a significant increase on addition of amino propyl trimethoxysilane and tetramethoxy orthosilicate after alkali treatment (Lee et al. 2009). Bamboo glass composite fibers at bamboo to glass ratio of 1:4 show flexural strength of 140 MPa (Dieu et al. 2004). Bamboo fiber reinforced cementitious plate (FRC) is found to have a very high flexural strength, which may be upto 96 MPa (Li et al. 2002).

2.4.5 Hardness

Bamboo fibers owe their hardness to the presence of cobble like polygonal cellulose nano grains with a diameter of 21–198 nm in their cell walls. These nano grains are basic building blocks of bamboo fibers. It is observed that nano grain structured fibers are not brittle (Zou et al. 2009). A continuous increase in hardness from center to outer surface is observed (Chand et al. 2006). Hardness of bamboo fibers is same in longitudinal as well as transverse directions. Measured hardness for parenchyma cell wall is 0.23 GPa. Hardness shows a decrease when moving from outer layer to inner layer (Yu et al. 2007). Research has also exposed that young bamboo culms are harder as compared to old culms and have high fracture toughness. The hardness of bamboo culms can be judged by crack deflection and crack bridging (Low et al. 2006). The hardness of bamboo reduces due to steaming treatment (Lin et al. 2006). Tangled micro-fibrillated cellulose fibers when added to poly lactic acid/bamboo fiber composites, increase the hardness and prevent crack development (Naoya et al. 2004). Bamboo is 23 % harder than oak and 13 % harder than rock maple. Fracture toughness of bamboo is measured to be 56.8 MPa $m^{1/2}$ (Amada and Untao 2001).

2.4.6 Impact Strength

Impact strength of bamboo fiber concretes is distinctly higher (Ramaswamy et al. 1983). The impact strength of steam exploded bamboo fiber filaments is very high (Tokoro et al. 2008). Bamboo fiber reinforced epoxy resins have impact strength of 63.54 KJ m^{-2} (Jain et al. 1992). The impact strength of poly lactic acid/bamboo fiber composites increases after addition of micro-fibrillated cellulose (MFC) (Naoya et al. 2004). The high percentage of alkali content in bamboo fibers reduces their impact strength (Kushwaha and Kumar 2009).

2.4.7 Linear Density

The linear density of bamboo fiber is calculated to be 1.44 (Erdumlu and Ozipek 2008). It is approximately one eighth of the density of mild steel whereas its tensile strength is higher than mild steel. Hence this fiber can be used as an alternate of plastic fibers for formation of many materials (Jindal 1986). Linear density of autoclaved bamboo fiber reinforced cement composites is 1.3 g cm^{-3} (Coutts and Ni 1995). Bamboo zephyr boards (BZB) exhibit less thickness and low density under dry wet conditioning cycles (Nugroho and Ando 2000). The density decreases with increase in amount of bamboo fibers in short bamboo fiber reinforced epoxy composites with varying fiber content (Rajulu et al. 2004). The linear density of BZB exhibits a huge effect on moduli of elasticity and rupture, internal bond strength, water absorption, and thickness swelling. The linear density is not seen to have any effect on linear expansion (Nugroho and Ando 2000).

2.4.8 Moisture Absorption

The process of moisture absorption in bamboo is observed to follow the kinetics described in Fick's theory (Kushwaha and Kumar 2010). The moisture absorption of bamboo fibers is observed to be 13 %, which is more than that of cotton, lyocell, viscose rayon, modal, and soybean (Erdumlu and Ozipek 2008). Bamboo fiber provides a reservoir of moisture, which usually diffuses into interfacial regions and decreases the shear strength (Chen et al. 2009). The moisture absorption of bamboo epoxy composite is 41 % and when it is subjected to benzoylation, moisture absorption decreases to 16 % (Kushwaha and Kumar 2010). The moisture absorption in bamboo fibers after 9 days of water immersion results in decrease in interfacial shear strength (IFSS) to at least 40 % (Chen et al. 2009). Bamboo possesses very high moisture content; green bamboo has 100 % moisture with innermost layers having 155 % moisture (Li 2004). *Phyllostachys bambusoides*; bamboo specie has moisture content of 138 %. Increased moisture absorption in bamboo/vinyl ester composite fibers leads to a decrease in IFSS. This reduction in IFSS is due to the fact that bamboo strips provide reservoir of moisture which diffuse to interfacial area and inhibit the hardening of composite (Chen et al. 2009). Moisture absorption in bamboo can be decreased from 41 to 26 %. Silane treatment also reduces the water absorption (Kushwaha and Kumar 2010).

2.4.9 Specific Gravity

The specific gravity of bamboo varies between 0.4 and 0.8 depending on its anatomical structure. The specific gravity of 1-year-old bamboo is very low as compared to 3- or 5-year-old bamboo culms. The average specific gravity increases about 58 %

from 1 to 3 years of age. The specific gravity value of outer layer of bamboo is observed to be twice than that of inner layer (Li 2004). The specific gravity of bamboo fiber reinforced plastic composite is measured as 0.924 (Jain et al. 1993).

2.4.10 Specific Strength

Bamboo fiber extracted by steam explosion method has a very high specific strength. The specific strength of steam exploded bamboo fiber is equivalent to conventional glass fiber (Okubo et al. 2004). The specific strength of bamboo fibers is higher than plastics, which makes them a very good choice for preparation of many substances including furniture (Lakkad and Patel 1981). Bamboo fiber's specific strength when compared with specific strength of mild steel is 3–4 times higher. Bamboo fiber reinforced plastic composites possess a very high specific strength (Jindal 1986). The specific strength of bamboo fibers can be increased by making a composite with maleic anhydride grafted polyethylene (Mohanty and Nayak 2010). A remarkable increase in specific strength of bamboo fibers is observed when they are reinforced with aluminum alloy sheets (Li et al. 1994).

The specific strength of bamboo decreases with increase in age. The best strength is observed in the bamboos of 3–6 years (Li 2004). The strength is also observed to increase with height. The strength increases from central to outer part (Li 2004). BZB is seen to have a higher specific strength than many of the commercially available wood fibers (Nugroho and Ando 2000).

2.4.11 Tensile Load

Short bamboo fiber reinforced epoxy composites with varying fiber length, when tested for resistance to acetic acid, hydrochloric acid, toluene, carbon tetrachloride, benzene, ammonia, sodium carbonate, sodium hydroxide, and nitric acid show variation in tensile load. This proves that bamboo fiber length affects the tensile load. The tensile load is found to be maximum at the fiber length of 30 mm (Rajulu et al. 1998).

2.4.12 Tensile Modulus

The tensile modulus of permanganate treated bamboo polyester fiber is seen to be increased by 118 % and that treated with benzoyl chloride is 118 % (Kushwaha and Kumar 2010). Bamboo fiber reinforced polypropylene composites show a significant increase in tensile modulus after addition of maleic anhydride polypropylene (MAPP) content in concentration of 24 % by weight. The composite is shown to have the tensile modulus of 5–6 GPa (Chen et al. 1998). Due to high tensile modulus, bamboo fibers are excellent material for making composites (Rao and Rao 2007). By the addition of glass fiber by 20 % mass the tensile modulus of bamboo glass fiber reinforced polypropylene composite increases by 12.5 %. The reduction of tensile modulus in bamboo glass fiber reinforced poly propylene hybrid composites is two times more than reduction of tensile modulus in bamboo fiber reinforced poly propylene composites after 1,200 h of aging in water (Thwe and Liao 2002b). Tensile modulus of poly propylene based bamboo composites which use steam exploded fibers increases to about 30 %, due to well impregnation and reduction in void numbers (Okubo et al. 2004). The tensile modulus improves significantly with the addition of silane coupling agent Si69 in bamboo fibers (Ismail et al. 2002).

2.4.13 Tensile Strength

The tensile strength of bamboo fibers is observed as 56.8 MPa, which is higher than that of aluminum alloy (Amada and Untao 2001). Bamboo fibers reinforced polypropylene composites and bamboo glass fiber reinforced polypropylene hybrid composites, when exposed to water, show a decrease in tensile strength and elastic modulus (Thwe and Liao 2003). The high density bamboo fibers are shown to have increased tensile strength when fabricated with maleated polyethylene contents (Han et al. 2008). The tensile strength of bamboo fiber obtained from bamboo fiber blocks is higher than that of separated fiber bundles. This is due to interaction between components in bamboo in which parenchyma cells can pass loads (Shao et al. 2010).

Poly butylene succinate bamboo fiber (PBS/BF) composite has a tensile strength of 21 MPa. When bamboo fiber esterified with maleic anhydride is added in the concentration of 5 %, the tensile strength increases to 28 MPa (Lee and Ohkita 2005). Alkali treated bamboo fiber reinforced composite is shown to have a reduction in tensile strength (Kushwaha and Kumar 2010). Bamboo fiber reinforced plastic composites have a measured tensile strength of 102.6 MN m^{-2} (Jain et al. 1993). The tensile strength of bamboo fiber reinforced epoxy resins is calculated to be 200.5 MN m^{-2} (Jain et al. 1992). The tensile strength of short bamboo glass fiber reinforced polypropylene composites is best at the fiber length of 1–6 mm (Thwe and Liao 2002b).

The tensile strength of outer periphery of bamboo fibers is approximately 160 kg mm^{-2} and that of inner periphery is approximately 45 kg mm^{-2} (Ray et al. 2005). The tensile strength of steam exploded bamboo fiber can be increased by impregnation and reduction in number of voids (Okubo et al. 2004). Green composites made from bamboo fibers show the tensile strength of 330 MPa at the fiber volume of 70 %. This tensile strength is observed to be higher than that of the composites prepared from biodegradable resins (Cao and Wu 2008). The tensile strength of permanganate treated bamboo polyester fibers is increased by 58 % and that treated with benzoyl chloride is 71 % (Kushwaha and Kumar 2010).

The tensile strength of bamboo fiber reinforced poly propylene composite after aging of 1,200 h at 25 °C temperature is reduced by 12.2 % and that of bamboo glass fiber reinforced poly propylene composite is reduced by 7.5 %. The strength reduction can be suppressed by using MAPP residues (Thwe and Liao 2003).

2.4.14 Thermal Resistance

The heat resistance of bamboo fibers is extremely good. The thermal resistance of fibers is increased by reinforcing it with epoxy resins (Shih 2007). The chemically modified water bamboo fibers when reinforced with biodegradable PBS show an improvement in thermal resistance of the resultant composite (Shih et al. 2006). Cotton/bamboo fiber composites when subjected to heat reveal that as the concentration of bamboo increases, their thermal conductivity reduces and resistance increases (Majumdar et al. 2010). Thermogravimetric analysis reveals that thermal stability of polypropylene bamboo/glass fiber reinforced hybrid composites increases as the amount of bamboo increases in the composite (Nayak et al. 2009).

2.4.15 Weight

Bamboo fibers are lightweight fibers and due to this property they can be used for the formation of composites (Rao and Rao 2007). Bamboo fiber strips when treated with sodium hydroxide solution show that increase in the percent of alkali results in decreasing the weight of strips (Das et al. 2006). Bamboo fibers have high strength to weight ratio. This ratio can be increased by reforming the bamboo (Yao and Li 2003). Increase in bamboo weight is directly related to aging (Li 2004).

2.4.16 Biodegradability

Bamboo fibers reinforced composites with poly lactic acid and poly butylene succinate are easily degraded by enzymes like proteinase K and lipase PS. Degradation rate of these composites is reduced by the addition of lysine based diisocyanate (LDI), which also enhances their tensile properties, water resistance, and inter facial adhesion (Lee and Wang 2006). Bamboo fibers obtained from compression molding technique and roller mill technique are reinforced into unidirectional composites of polyester. These composites are highly degradable by the use of enzymes (Deshpande et al. 2000). Water bamboo husk and poly butylene succinate novel reinforced composites are biodegradable in nature (Shih et al. 2006). Bamboo fiber filled poly lactic acid composites are ecocomposites as they are biodegradable and save the environment from pollution (Lee et al. 2005). Micro-sized bamboo fibers and modified soy protein resin are used to fabricate environmentally friendly composites.

These composites have increased fracture stress and young's modulus. These composites are fully biodegradable and have a great potential to replace traditional and expensive petroleum based materials in many applications (Huang and Netravali 2009). Bamboo fiber reinforced in poly butylene succinate matrix produces long fiber unidirectional composites. These composites have high values for tensile and mechanical properties. The mechanical properties are enhanced as the amount of bamboo fiber is increased. Young's modulus of these composites is predicted by laminate theory but experimental results show that ratio obtained by laminate theory is lower than the actual (Ogihara et al. 2008).

2.5 Applications of Bamboo Fibers

2.5.1 Biofuel Production

Bamboo is observed to be more productive as compared to many biofuel producing vegetable plants. Bamboo is suitable for fuel production because it has low alkali index and ash content. Moreover it has low heating value than many of the woody biomass feed stocks. Further research is required on bamboo fibers for commercialization of biofuel (Scurlock et al. 2000). Pyrolysis of bamboo in the presence of high temperature steam and inert atmosphere containing nitrogen produces a product. The product when analyzed indicates exploitation of derived char as activated carbon precursor or solid fuel for gasification. The composition of liquid fraction reveals it to be a biofuel (Kantarelis et al. 2010). The treatment of bamboo fibers with cold sodium hydroxide/urea disrupts the recalcitrance of bamboo fibers effectively and leads to generation of highly reactive cellulosic material. This material, on enzymatic hydrolysis is converted into bio-ethanol. Bamboo fiber derived bio-energy products include charcoal, biofuel, pyrolysis, firewood, gasification, briquettes, pellets, and biomass (Li et al. 2010). Bamboo hemi-cellulosic fibers having 2.4 % hemicellulose content have been extracted and pulped. The pulp produce can be used to produce biofuel and bio-ethanol after further modification (Vena et al. 2010).

2.5.2 Construction Material

Bamboo is one of the oldest and most versatile constructing materials. Bamboo has certain qualities due to which it can be used for construction purposes. These qualities include its hardness and lightweight. Bamboo does not require processing or finishing. Bamboo constructions are strong and resistant to even earth quakes (Jayanetti 2000). Bamboo fibers are used in concrete reinforcement, bamboo fencing, and housing (Diver 2001). It can be used as reinforcement alternative to steel in concrete due to its high specific strength, tensile strength, tensile modulus, hardness, and other mechanical properties (Youngsi 2007). Studies on microstructure of bamboo reveal that bamboo is functionally gradient material. This property can be used for the formation of reinforced concrete composites, which can be used in construction of strong buildings (Ghavami 2005; Aziz et al. 1981). Bamboo is used for concrete composite reinforcement (Lima et al. 2008).

2.5.3 *Food and Feedstock*

Fresh bamboo shoots and shoot fibers are used as foods. Bamboo shoots and fibers are very popular in Asian stir-fry and as pickled condiment. Most important genus for production of edible shoots is *Phyllostachys*. Bamboo fiber derived food products include bamboo tea, bamboo wine, bamboo vinegar, and charcoal coated dry fruits (Diver 2001). Bamboo fibers are also used for preparation of food packaging material like cellophane. The nutritive value of bamboo exposes that total carbohydrate content of bamboo leaves decreases throughout the growing season, remains stable for some time and increases during winter. Unlike carbohydrates, crude protein content is high in growing season and is decreased in winter season. The concentration of fiber and proteins make it a good source for feedstock. The bamboo has a potential for winter forage for goats and some other livestock. Bamboo also reduces the exposure of livestock animals to gastrointestinal parasites (Halvorson et al. 2011).

2.5.4 *Musical Instruments*

Grass bamboo can be used in preparation of musical instruments like wind, string, and percussion instruments. Bamboo is ideally suited for manufacture of xylophone bars and chimes, flutes and organs, violins and zithers and violin bows. Bamboo plates can be used for forming body and neck of acoustic guitar as it is easily available and is economical (Wegst 2008). Bamboo is nearly immutable, and hence resistant to change. Bamboo is straight and cylindrical; this structure is best suited for production of musical instruments like flute (Grame 1962). Bamboo used for formation of musical instruments should be harvested at 3–5 years of age for high strength and durability (Diver 2001). Bamboo culms are also used for production of wind chimes (Perdue 1958).

2.5.5 *Paper Industry*

The shape, chemical composition and structure of bamboo are very suitable for pulping. Pulping performance and pulp strength make bamboo fibers one of the most suitable materials for paper production. Bamboo pulp mill may result in improvement in paper industry like substituting pulping techniques. The paper produced from bamboo has certain advantages, which include reduction in pressure of wood demand, less pollution, and environmental protection (Kefu 2002). Bamboo pulp produced from hemi-cellulosic fibers can be used potently for the production of paper. In paper industry, bamboo fiber pulp can be used in the formation of newsprint, bond paper, toilet tissue, cardboard, cement sacks, and coffee filters (Vena et al. 2010).

2.5.6 *Pharmaceutical Industry*

Bamboo fibers have an excellent characteristic of inhibition of bacterial growth, absorption of peculiar smells, and hygroscopicity. Due to these characteristics, bamboo fibers are used as non-woven medical and hygienic materials (Yi 2004). Flavones can be extracted from bamboo leave fibers by leaching method. These flavones are used in preparation of many drugs (Gang et al. 2000). Chemical contents of bamboo fiber are bacteriostatic and bacteriolytic (Zhong-Kai et al. 2005). Eating bamboo fiber reduces the rate of intestinal natural flora and pathogens. This property is applied to produce a bamboo drug for gastrointestinal infections (Anping et al. 2005). Moreover bamboo fibers can also be used for the production of sanitary towels, gauze, bandages, absorbent pads, surgical wear, doctors' coats, and medical masks. Bamboo fibers have gentle make up, due to this reason only a few people are allergic to bamboo fibers; this property plays a role in production of masks etc. It is light, durable, and inexpensive (Bamboo Groove 2008).

2.5.7 *Textile Industry*

Natural bamboo fibers have some of the excellent properties, which make it a very potent material to be used in textile industry. Refined bamboo fibers with low non-cellulosic content can be used in textiles (Liu et al. 2011). Bamboo fiber luster is closer to that of silk. It can be used for knitting and weaving purposes (Yi 2004). Study on bamboo fibers revealed that its chemical composition is same as that of all the bast fibers, which means cellulose content is in majority and lignin content is present in small amount. The structural properties of bamboo are different from those of other textile producing plants. Bamboo is shown to have high potential in textile industry (Yueping et al. 2010). They are used for the formation of socks, under wears, T-shirts, bathing suits, bathing suit cover ups, towels, Sleep wear, face masks, sanitary napkins, bed sheets, pillows, baby diapers, bullet proof vests, table cloth, blinds, and mattresses. Bamboo fibers are observed to have excellent characteristics for spinning and weaving (Hengshu 2004). Dyeability of bamboo can be enhanced by plasma treatment. Longer the treatment time, higher the roughness and hence higher is the dyeability, which leads to increase in potential to be used as textile.

2.5.8 Cosmetic Industry

The potential of bamboo can be used in cosmetic industry (Liese 1992). Bamboo fibers are widely used in cosmetic industry in the formation of cosmetics for acne prone people (Qin-Rong 2006).

2.5.9 Sports Industry

Bamboo fibers can be used as reinforced composite materials in the formation of sports goods like polo balls, base balls, etc. These sport items made from bamboo fiber composites are highly durable and strong (Subic et al. 2009).

2.6 Conclusion and Future Prospects

Research and investigation regarding use of bamboo fiber for the well-being of human beings is limited because of limited availability and tough extraction process. The techniques used for bamboo fiber extraction nowadays give low fiber yield or low quality fiber. Studies are further required for improving the extraction, preparation, and processing techniques for bamboo fiber. Bamboo fiber is a potent fiber to be used for many applications. It is an outstanding biodegradable textile material, which does not absorb ultraviolet and infrared rays. For commercializing bamboo based products much research and knowledge is required so that the world may get benefit from an inexpensive source of fibers.

Super strong and durable bamboo is being used presently for flooring and paneling. Its stability, hardness, flexibility, and strength are its most remarkable qualities. Bamboo has a bright future as an alternate to wood for formation of furniture and construction material. Bamboo fiber can also serve as an alternate to cement and concrete in near future. As bamboo is easily pulped, it can be used efficiently for paper production and may benefit us with less cost and high availability. Textile industry is expected to get huge advantages from bamboo fibers in near future, as bamboo is lightweight, environmental friendly, and bacteriostatic. Also it is antiallergenic and soft like silk which makes it best suited for its use in textile industry.

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