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Review of the Applications and Properties of Bamboo Fiber Reinforced Composite Materials

Mekete Ababu[1], Ebrahim Husen[2], Birhanu Awraris[3], Neseredin Bashawal[4]

[1]Manufactueing Engineering, Wollo University; Institute of Kombolch Technology, Kombolcha, Ethiopia

[2] Automotive Engineering, Debre Tabor University, Debre Tabor, Ethiopia

[3] Automotive Engineering, Wollo University; Institute of Kombolch Technology, Kombolcha, Ethiopia

[4] Civil Engineering (hydraulic), Assosa University, Assosa, Ethiopia

Corresponding Author Address: - *phone: +251915873850*; *Email: husienababu@gmail.com*

Abstract

Bamboo fibres have excellent mechanical properties rather than other natural fibres. Because of its outstanding properties; it is used as reinforcement in composite production process to replace the synthetics fibres. Synthetic fibres are affecting our environment since they are non-biodegradable materials and they are not easily available. In addition to use as reinforcement material, it has also used in different engineering applications such as in automotive, aerospace and aircraft, wind turbine, and solar panels. The mechanical, physical, and thermal properties of bamboo fibre reinforced composite materials were altered by different parameters, from the additive particles, processing techniques, fibre orientation, size, volume or weight ratio, temperatures, and matrix and reinforcement material used in the production process. Some usage of matrix and reinforcement material reinforced composites in engineering applications; in automotive, aerospace and aircraft, wind turbine and solar panels. In sandwich honey structure composite using 0° fiber orientation is better mechanical properties than 45° and 90° and using high fiber volume fraction can reduce the mechanical properties of bamboo reinforced composite materials. To obtain excellent mechanical, physical, and thermal properties of bamboo fiber reinforced composite materials, controlling the parameters and using proper matrix and reinforced materials are preferable methods.

Keywords: Bamboo fibbers, filler particles, coupling agents, Strength, fibre orientation, fibre size

1. Introduction

In this industrial age, the requirement of advanced and composite materials is increased in the world. The expansions of industries in the world and even in Ethiopia have their own effects on environment. The emission of wastes and non-biodegradable products from industries can affect living things and the fertility of soil. To save our environment from these wastes; the best solution is to increase the forestation that stabilizes the environment and replace the non-biodegradable products by natural fibres. Cultivation of different species of plants like fibre plants has been used as an input for industrial/manufacturing process in addition to absorb C_{O2} and to retain the productiveness of soil. Among these different species of plants; bamboo grass is one of the widely used in human activities and it is the fastest growth relatively with the other fibre plants. In Africa, Asia, and Latin America, it is closely associated with indigenous culture and knowledge and is widely used for housing, forestry, agroforestry, agricultural activities, and utensils (Dixon, 2004; Yendhe *et al.*, 2015)**,** recently different researchers are investigating composite materials which are substituting the materials used in construction, automotive, aerospace, airspace and biomedical industry.

Kumar *et al.*, 2005; Mounika *et al.*, 2012; Zakikhani *et al.*, 2014; Yendhe *et al.*, 2015; Islam *et al.*, 2017, and other researchers were introduced that bamboo fibre materials have attracted broad attention as reinforcement in polymer composites due to their environmentally friendly, mechanical properties, recyclability, biodegradability, excellent corrosion resistance and anti-bacteria properties. Having the low density, low cost, high mechanical strength, stiffness, and high growth rate are the advantageous of bamboo fibres and some of its drawbacks are moisture content, the difficulty of extraction, fine and straight fibres, and thermal degradation during manufacturing. The natural fibre contains cellulose, hemicellulose, lignin, and pectin in their structure and permits moisture absorption from the environment which leads weak binding between matrix and reinforcement material. Weak binding between matrix and reinforcement can reduce the mechanical properties of composites (specifically, fracture is occurred when compression or flexural loads are applied to the composite) and lignin gives the brittle properties. Based on these properties; it is difficult to obtain proper fibres which are used for different engineering applications. To acquire the desired properties of fibre reinforced composite materials and to enhance the weakness of natural fibres, different researchers were used various processing mechanisms by considering parameters like volume fraction of fibres, fibre length and size, fibre weight aspect ratio, fibre-matrix adhesion, filler materials, fibre orientation, stress transfer at the interface and processing methods. The objective review paper is to understand the effect of parameters on the properties and applications of composite materials. Finally, bamboo fibre reinforced composite materials are obtained with their desired properties by controlling and balancing the parameters.

2. Mechanical Properties of Bamboo Fibres Reinforced Composites

2.1. Effects of size, composition, and structure of bamboo fibers

Short bamboo fibre reinforced epoxy-based composite and starch-based resin bamboo fibres green composite are affected by the length and composition of the fibres and the mechanical properties of tensile, flexural, impact and hardness strengths are highly influenced by the size/length and composition of the fibres used. Excess of fibres in the composite materials deteriorated the mechanical properties of the composite because of the lack of proper bonding between the matrix and fibres around the interface (Takagi and Ichihara, 2004).

Tensile strength is enhanced only at 10 mm fibre length and the highest tensile strength with an enhancement of 25% compared to neat polyester is achieved for 10 mm/40 vol. % composite. Young's modulus is deteriorated by fibre reinforcement, except at 10 mm/40 vol. % of reinforcement. Fracture toughness of all types of composites is higher compared to neat polyester and the maximum boost of 340% is achieved at 10 mm/50 vol. % of fibre reinforcement (Wong, Yousif and Low, 2010).

Use the triangular core rather than square core in unidirectional bamboo- epoxy honey sandwich structure composite with 0^0 fiber orientation in order to get good tensile strength, compression strength and high energy absorption capacity (Roslan1 *et al.*, 2015).

Table 1. The mechanical properties of bamboo-epoxy composites with different fiber orientations (Roslan1 *et al.*, 2015)

Angle of fiber orientation (°)	Tensile strength, σ (MPa)	Elongation at break, ε (%)	Elastic modulus, E (GPa)
0	138.88	2.70	4.96
45	8.42	0.62	1.37
A90	9	4	

The above table is showing that the result of tensile test for both triangular and square core bamboo epoxy honey sandwich structure by using a Shimadzu universal testing machine with 50 KN of load cell at a crosshead speed of 1 mm/min. The 0° fiber orientation of bamboo-epoxy composites has the highest tensile strength and elastic modulus of elasticity with high percentage of elongation break than 45° and 90° of fiber orientation. Fibers in the 0° orientation are parallel to the tensile load applied and the resistance of the bamboo fiber towards the pull force at this orientation is the greatest.so that, in such type of composite using 0° orientation to get the desired tensile strength.

2.2. Effect of filler materials on mechanical properties

Chen *et al.*, (1997), studied the effect of commercial polypropylene (PP) and malleated polypropylene (MAPP) were used as the matrix of the composite. The laboratory maleic anhydride-modified polypropylene powder, MAPP, was prepared in the laboratory. The maximum values of the tensile strength (32-36 MPa) and tensile modulus (5-6 GPa) were obtained at about 50 wt % bamboo content. At less than 50µm bamboo fiber size and approximately at 50wt. % concentration both PP and MAPP composites have high tensile strength and tensile modulus. However, MAPP crystallized on the bamboo fiber is preferable rather than PP. The processing temperature and fiber content for fabricating bamboo buddle and starch-based biodegradable resin unidirectional composite should be kept below $140^{o}c$ and 70% respectively in order to prevent strength reduction due to thermal degradation. When the fiber content is more than 70%, some void and fiber contact problems caused by insufficient amount of resin are observed in the spacemen (Ochi, 2012).

According to Madhu *et al.*, (2018), the effect of filler particle (Sic) on the mechanical properties of reinforced composite and water absorption properties of the specimen immersed in normal, distilled and salt water were studied. In study, the thickness of each layer 0.4mm for carbon, 0.27mm for bamboo and the thickness of each laminate is nearly 3mm.Based on the ASTM standard, considering 9 layers of bamboo (B) fiber for laminate L1 (Only bamboo fiber and epoxy-hardener mixture), six layers of carbon (C) fiber for laminate L2 is taken (Only carbon fiber and epoxy-hardener mixture), five layers of bamboo(B) fiber and four layers of carbon (C) fiber is taken for laminate L3 (Mixture of bamboo/carbon and epoxy-hardener mixture) and five layers of bamboo (B) and four layers of carbon (C) fiber with 21 g of filler material is taken for laminate L4 (Mixture of bamboo/carbon, epoxy-hardener with SiC mixture). These four-laminate specimens were tested by immersed in normal, distilled and salt water.

Table 2. Laminate's designation

Sequence	Composition
L1	B+B+B+B+B+B+B+B+B
L2	C+C+C+C+C+C
L3	B+C+B+C+B+C+B+C+B
L4	B+C+B+C+B+C+B+C+B (SiC)

The laminated composites L1, L2, L3, and L4 are fabricated according to ASTM standards and tested in UTM machine to obtain tensile properties. The properties like break load; tensile modulus and ultimate strength are listed in the following Table 3 shows that the laminated composite L4 consisting of filler material gives the maximum tensile strength of 165.32 MPa and the laminate L1 gives the least tensile strength of 32.45 Mpa.

Table3. Tensile properties of composite

Sequence	Break Load (N)	Tensile Modulus (N/mm2)	Ultimate Tensile strength (N/mm2)	Flexural strength (N/mm2)
L1	57.87	589.804	32.45	362
L2	9288.1	2580.73	162.94	562
L3	11.77	2293.97	150.48	381
L4	9423	1912.39	165.32	425

From the flexural and hardness tests, laminated composite L4 has high flexural strength and good hardness strength. From the water absorption test, the results, it was observed that water absorption can be reduced by the hybridization of bamboo/carbon composites. From the water absorption test, the laminate L1 is having higher water absorption behavior compared to other laminates and the absorption is more in distilled water for the laminate L1. Hardness results show that the laminate consisting of SiC filler material shows superior results compared to other laminates.

Addition of different nano clay and malleated polyethylene (MAPE) to high density polyethylene (HDPE)/bamboo composites can influence the mechanical properties. The equilibrium torque of both pure HDPE and HDPE/bamboo systems was decreased with the addition of the clay principal set, while adding MAPE increased the torque value of HDPE/bamboo system. For HDPE/bamboo system, the addition of MAPE was necessary to exfoliate the added clay. Yet, the addition of clay led to a destructive outcome on the mechanical properties of the HDPE/ bamboo composite system. For the bamboo fiber reinforced system, the tensile strength increased almost linearly with the increase of the MAPE content. And the bending modulus and strength increased with MAPE loading up to the 4–6% level, but they began to decrease when more MAPE was added (Han *et al.*, 2008).

Lee *et al.*, (2006)**,** investigated the influence of bio-based coupling agent on the mechanical properties of biodegradable polymer/bamboo fiber bio-composite was studied. The tensile properties, water resistance, and interfacial adhesion of both poly-lactic acid (PAL)/bamboo fiber (BF) and poly-butylene succinate (PBS)/bamboo fiber (BF) composites were improved by the addition of lysine-based diisocyanate (LDI), whereas thermal flow became difficult due to cross link between polymer matrix and bamboo fiber. Crystallization temperature and enthalpy in both composites were increased and decreased with increasing LDI content, respectively.

High moisture content of bamboo fibers led to weak interfacial bonding between fibers and the relatively more hydrophobic polymer matrices, thus compromising the mechanical properties of the composites. It is necessary to enhance the hydrophobicity of the natural fiber by chemical treatment with suitable coupling agents or by coating with appropriate resin to develop composites with better mechanical properties and environmental performance (Thwe *et al.*, 2000; Nayak K. *et al.*, 2009).

Reddy *et al.*, (2018)**,** studied the influence of addition of graphene in bamboo fiber reinforced polyester composites. Graphene reinforced laminate provided better mechanical properties like tensile strength and flexural strength. Tensile strength is more for 20% graphene and coming to 0% graphene it gradually decreased and flexural high value for 20% graphene and comes to the 0% value. Water absorption percentage is gradually decreasing with increasing of the amount graphene percentage.

The tensile modulus and hardness of the composite enhance with increasing filler loading and the presence of bonding agent. The adhesion between the bamboo fiber and natural rubber can be enhanced by the use of bonding agent (Ismail *et al.*, 2002). Mechanical properties of bamboo fiber (BF) reinforced polypropylene (PP) composite, such as the tensile strength, flexural strength, and impact strength decreased as bamboo fiber loading increased. However, the tensile modulus, flexural modulus, and water absorption were increased with the increase of bamboo fiber loading. The addition of aminopropyltrimethoxysilane (AS) and tetramethoxyorthosilicate (TMOS) after the alkali treatment to BF increased the tensile, flexural, impact strength and water desorption of the resultant composite, resulting in the improved adhesion between the PP matrix and BF by the adhesion of AS and TMOS. Melting temperature, melting enthalpy, crystallization enthalpy, and crystallinity were decreased by the increase of BF loading and addition of AS and TMOS. However, the crystalline temperature was increased (Lee *et al.*, 2009).

In poly-lactic acid-based bamboo fiber composites using micro-fibrillated cellulose as enhancer and in bamboo woven fabric using weft direction there are increased bending strength, fracture toughness, and flexural, the impact properties are enhanced respectively (Porras and Maranon, 2012; Okubo *et al.*, 2013).

The developed composite is an insulating material. This composite can be used in the building and automotive industry to save energy by reducing the rate of heat transfer. Thermal conductivity of the composite decreases with the increase in fiber content and quite opposite trend was observed with respect to temperature. Thermal conductivity increased with an increased in fiber angle. The study of Mounika *et al.*, (2012)**,** that shared the maximum volume fraction of fiber, the thermal conductivity of the composite has varied from 0.185w/mk to 0.196w/mk in the temperature range of 40-70℃.Bamboo fiber reinforced composite showed the least thermal conductivity when compared to polyester resin, glass composite. According to the Zatul *et al.*, (2016)**,** study, the addition of bamboo fiber affects the mechanical properties during compression. Treated bamboo fibers significantly improve strength and modulus during compression. When AR (As-Received) fibers are added, the compression strength remains the same at 0.25% loading and degraded when the loading is increased to 0.5%. In contrast, the compressive strength increased from 22.2Mpa for pure cement to 25.4Mpa and 24.9Mpa for cement composite with 0.25% and 0.5% machine treated fiber addition. AR bamboo fibers are added, the flexural modulus increases by more than 100% at 0.25% loading and by 62% at 0.5% loading and flexural strength increased from 3.2Mpa to 4.4Mpa at 0.25% and 0.5% AR fiber loading respectively.

Delgado *et al.*, (2012), studied the mechanical properties and showed that further improvements need to be made in the adhesion between phases. Compared to neat LDPE, reinforcement with bamboo flour decreased the tensile strength and elongation at break, whereas the elastic increased. These results could be due to the poor adhesion of bamboo fibers in the matrix as well as their lack of homogeneity in the matrix. In this way, the load acts as a defect rather than a reinforcement and does not absorb the stress efficiency or avoid the propagation of cracks. The addition of glycerol enhanced the processing of the composites, but was not effective in improving their mechanical properties.

2.3. Influence of process parameters on mechanical properties

According to Kumar *et al.*, 2005), the mechanical properties such as tensile strength of USP/PAN coated fibers were extremely increased than those of the treated and untreated bare fibers. The calculated tensile strength at break of neat and unsaturated polyester (USP) with polyacrylonitrile (PAN) coated bamboo fibers, after and before alkali treatment is in Table 3.

Table 3. Tensile strength of USP/PAN coated and bare bamboo fibers.

	Tensile Strength of the Fibers (N/mm^2)		Percentage Improvement in Tensile Strength	
Fiber System	Untreated	Alkali Treated	Untreated	Alkali Treated
Bare fiber	86	76.5	1.0	−11.0
Coated with USP/PAN (50/50)	127.7	108.0	+48.5	+25.6
Coated with USP/PAN (70/30)	140.3	118.7	+63.1	+38.0

From the above table untreated bare fiber has higher tensile strength ($86\frac{N}{mm^2}$) compared to the Na OH-treated bare fiber ($76.5\frac{N}{mm^2}$). The 70/30 weight ratio USP/PAN coated fiber has shown more tensile strength than the 50/50 weight ratio USP/PAN and the improvement in tensile strength and lower water absorption of the USP/PAN coated bamboo fibers may be due to the hydrogen bonding of the ester and nitrile groups of the IPNS with the cellulose matter of the fiber. Steam – exploded filament is upsurging the bending strength of PLA matrix composite and the addition of medium length bamboo fiber bundles into PLA; impact strength significantly increases. Thermal properties and heat resistance of PLA and PLA/BF composites are well improved by annealing (at 110 c^o for 5hrs (Tokoro *et al.*, 2008). The influence of moisture absorption on the interfacial shear strength (IFSS) of bamboo/vinyl ester composite was studied using the pull-out test. The relative humidity in composite manufacture had a severe impact on the IFSS of the resulting composites. The IFSS achieved at normal room conditions (20 _C, 60% RH) was only half of what is achieved in the dry condition. Composites produced at high relative humidity conditions (80% and 90%) had negligible interfacial strength (Chen *et al.*, 2009).

Okubo *et al.*, (2004), investigated the tensile strength and modulus of PP based composites using steam – exploded fibers increased about 15 and 30%, respectively, due to impregnation and the reduction of the number of voids. The steam explosion technique is an effective method to extract bamboo fibers for reinforcing thermoplastics.

The outcomes indicate that the blenching process results in a more pronounced degradation of lignin in comparison to the caramelized bamboo. Caramelization may have positive benefits for the global material properties and durability of bamboo (Ramage, 2018).

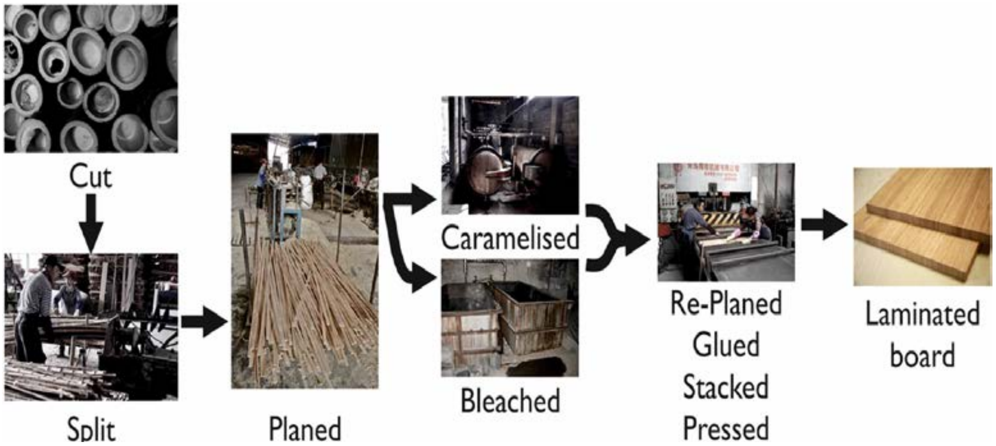

Figure1: Commercial manufacturing methods for laminated bamboo(Ramage, 2018).

Unidirectional long bamboo fiber/epoxy composites were successfully produced with excellent mechanical properties by a novel mechanical extraction process. However, alkali treatment is not indispensable to increase the strength of the composite, reduces the cost, Helmet is essentially made up of polyethylene thermoplastics. The mechanical properties of this composite helmet material are good-superior, or comparable to numerous engineering plastics used in the industry and the cost is also low.

The use of bamboo as reinforcement in concrete, it is established that bamboo can replace steel for modest having for the urban poor who live close to bamboo growing region. Structural behavior improving the reinforced concrete beam can be strengthened using bamboo sticks as a retrofitted material (Kar and Dutta, 1970; Yong and Yi-qiang, 2008; Gill *et al.*, 2017), studied that the fiber tensile strength slightly decreased with an increase of diameter, and a negative correlation (-0.61) is presented between the strength diameter. In this study, the results indicate the fiber strength distribution in a wide range, yet conform to a certain statistical distribution. Rough surface is exhibited and a large amount of impurities are attached to the surface and strengthens the environmental advantages of this natural fiber (Osorio *et al.*, 2011; Islam *et al.*, 2017), the studied attempt has been made to fabricate bamboo-glass fiber-based polymer composite helmet. Industrial

and some small amount of holes can be found visibly. Tensile strength and elastic modulus increase with the increase of pressure in BF/PVA composites and varying the fiber volume fraction from 0.5 to 0.7, the tensile strength correspondingly changes from 270 to 300Mpa and the elastic modulus are much higher than those of BF/PVA composites.

3. 3. Comparison of Some Articles on their Similarity and Difference on their Methodology

The following table tells us the similarity, differences and methodology of some articles. Different articles were tested commonly tested mechanical properties like tensile, flexural, impact, and hardness strength by using different methodologies of resins, filler and reinforcement material.

Table 4: show that the comparison of some parameters, methodology, and properties of composite material

No	Composite properties	resin materials	Reinforcement materials	Fillers, Additive, Orientation of fibers, and volume fraction materials	Methodology	Reference
1	Tensile strength, flexural strength, hardness and impact strength	Epoxy	Short bamboo fiber	No	LECNO micro hardness test, Izod impact test and TINIUS OLSEN H10KS test for both tensile and flexural strength	[4]
2	Tensile, Compression and impact strength	Epoxy	Unidirectional bamboo fiber	0°, 45°and 90° fiber orientation are used.	Shimadzu universal testing method is used for both compression and tensile strength and hand layup method is used to form composite	[9]
3	Tensile, flexural and hardness strength and water absorption test	Epoxy	Bidirectional fiber	SiC filler is used	Hand layup method used to form composite, Universal test machine used for tensile, flexural and hard ness test	[12]
4	Tensile, fracture and toughness strength	Thermosetting polyester resin (Reservol P 9509)	Short bamboo fiber	Fiber volume fraction	Scanning Electron Microscopy (SEM) method is used	[8]

4. Conclusions

Bamboo fibre reinforcement composite materials have been used as reinforcement in composite processes and are applicable in different engineering application likes; in automotive, biomedical, aerospace and aircraft, solar panels, wind blade and turbine blades. Different researchers concluded that the mechanical properties of bamboo reinforced composite are affected by different parameters. Tensile strength, tensile modulus, impact strength, compression strength, and moisture content reduction of composites are significantly affected by filler particles, bonding agents, processing techniques, size, and structure of fibres. Temperature, fibres orientation, volume and weight ratio or composition of fibres or additive materials are other parameters that affect composites. From the above revision, when the amount of fibre volume fraction increases, the composites will fracture. For sandwich honey structure, bamboo composite using 0° fibre orientation is better than 45° and 90°. In generally, properly controlling and balancing the parameters is a better methodology to obtain excellent mechanical properties of bamboo reinforced composite materials.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request. The corresponding author email address is husienababu@gmail.com.

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