ISSN 2347 - 3983
Volume 8. No. 6, June 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter24862020.pdf
https://doi.org/10.30534/ijeter/2020/24862020

Bamboo Fibers, Fabrication of Bamboo Fiber reinforced Composites, and their Mechanical Properties- A Review

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ABSTRACT

Bamboo fiber is a natural fiber that is easily degraded by microbes and potentially becomes an alternative fiber in the future due to its availability, which is abundantly cheap, and grows throughout the year and also isn't affected by the season. The application of bamboo fiber is a solution for environmental issues and a business prospect of synthetic fibers that are expected to decrease in line with petroleum. This study presents result of the studies of various types of bamboo, fiber extraction process both mechanically and chemically, composite fabrication based on various matrices, characterization carried out to reveal performance related to the requirements of various applications, weaknesses and improvements. Based on the result of this study, the researchers obtain information related to development and research status of bamboo fiber along with the application and weakness, as well as opportunity to make some improvements.

Key words: Bamboo fiber, fiber extraction process, type of matrix, mechanical properties, composite fabrication.

1. INTRODUCTION

There are so many natural fiber producer resources, especially from plants namely hemp, rice straw, wood, rice husks, wheat, barley, wheat, rye, sugar cane (sugar and bamboo), grass, reeds, kenaf, hemp, oil palm empty fruit, bunches, sisal, coir, water hyacinth, pennywort, cottonwood, mulberry paper, raffia, banana fiber, pineapple leaf fiber and papyrus [1].

Bamboo can naturally grow and develop in 4 continents, namely Asia (China, India, Thailand, Bangladesh, Cambodia, Vietnam, Japan, Indonesia, Malaysia, Philippines, Korea, and Sri Lanka), Africa (Mozambique, Sudan, and Madagascar), America (Mexico, Guatemala, Costa Rica, Nicaragua, Honduras, Venezuela, and Brazil), and Australia. Bamboo can be found at 32º S.L.-46º N.L. Bamboo generally thrives in tropical or sub-tropical areas with temperatures between 20-30º C. But there are several types of bamboo that can survive in the temperatures up to 40-50º C., (oxytenanthera abyssinica bamboo in Africa) can even survive in hot and cold weather below 0º C (phyllostachys mitis, which mostly grows at altitudes between 100-800 meters), but it can also be found at altitudes above 3000 meters [2,3].

As one of the fiber producers, bamboo is estimated to have more than 1,250 species with world production reaching 10x106 tons and is the third largest production after wood and cotton. Bamboo fiber price reaches USD0.5-1.0/kg. Indonesia is the second largest exporter, with a value of USD269 million after China valuing USD1,034 million. Bamboo production in Asian countries reaches 65%, followed by the U.S. with 28% and Africa 7%. [4]. On the other hand, bamboo importers are Japan worth USD194 million, the U.S worth USD254 million and Europe USD230 million [4].

Bamboo belongs to Graminaeae family, Bambusoideae sub-family, from the Bambuceae tribe. Bamboo is a plant whose stem is reed-shaped, broad, has nodes, hollow, branches, spreading and also has a prominent reed cycle [5]. Furthermore, the diameter of a bamboo stem depends on the species and the environment in which it grows, with values varying between 0.5-20 cm. The diameter of mature stems can be recognized from the diameter of young bamboo shoots. Bamboo is divided into small parts by lateral tissue, namely nodes and internodes section. Bamboo stems consist of parenchyma cells, fibers, and vessels [6].

In Indonesia, bamboo can be found in the lowlands to the mountains with an altitude of around 3000 m above sea level, especially in Java, Bali, South Sulawesi and Sumatera [7]. Bamboo, in Indonesia, also consists of 143 types, with 60 varieties that are expected to grow in Java. Bamboo stems are ready to be harvested at 1-2 years old, suitable for pulp and handicraft production. Meanwhile at 3 years old, bamboo stems are generally suitable to be harvested for building materials, furniture and other industries. The results of the study found that 80% of bamboo in Indonesia are used for construction (including furniture), 10% for packaging materials, 5% for handicraft raw materials (small industries), and 5% for agricultural facilities [8].

Bamboo is environmentally friendly (does not consume too much energy) as well as wood, its strain energy is equivalent to steel and its resistance to deflection and arches is equivalent to wood, especially when earthquake happened. Bamboo has better mechanical properties compared to brick, concrete, wood, and even steel. Bamboo is obtained from natural resources, a result of cultivation activities carried out by humans through proliferation of various methods, both generatively through bamboo seeds and propagation, as well as in term of vegetative process through rhizomes, stem and branch cuttings, stem stumps in bamboo clumps, and plant tissue isolation method. Harvesting of bamboo depends on age, season, and the part used (stems or bamboo shoots). Harvesting period for stem production is carried out during the dry season or at the beginning of the dry season to prevent bamboo from borer attack. During the dry season, the amount starch is also very low [6,8]. The properties that determine the use of bamboo are stem dimension, stem sharpness, stem straightness, branch size and distribution, length of stem segments, shape and proportion of segments, relative proportions of existing tissues, density and strength of wood, and resistance to fungi and insect attack [9].

The average production of Apus Bamboo in East Java is 7.5 tons/ha/year. The results of a study conducted by the UGM Forestry Faculty team showed an estimate of bamboo potential in the Special Region of Yogyakarta reaching 2,900,000 bamboo plants/year, West Java 14,130,000 bamboo plants/year, Central Java 24,730,000 bamboo plants/year, and East Java 29,950,000 bamboo plants/year [8]. Figure 1 shows that similar to acacia plants, bamboo plants are planted more in Java, reaching 29.14 million clumps or around 76.83% of the total population of Indonesian bamboo, while the remaining around 8.79 million clumps (23, 17%) are outside of Java. Bamboo plants in Java are concentrated in three consecutive provinces, namely West Java (28.09%), Central Java (21.59%), and East Java (19.38%), while outside Java in South Sulawesi Province (3.69%) [10].

Bamboo is a fast growing plant and is able to absorb carbon dioxide in the air. Bamboo can be harvested at 3-4 years old. Bamboo belongs to a group of grass species called Bambu soideae and compared to other plant fibers, bamboo has several advantages, namely low cost, light specific gravity, high growth rate, good strength and stiffness value [11,12]. Bamboo can be used for technical materials in intact condition or in the form of strips and fiber [13]. Bamboo fiber consists of cellulose, hemicellulose and lignin. Cellulose and hemicellulose level in the form of holocellulose can be more than 50% [14]. Bamboo fiber mechanically has a high tensile strength (140-800 MPa), and a high modulus of elasticity (33 GPa) with a low density of 0.6 - 0.8 g / cm3. Specific characteristics of bamboo fibers such as low specific gravity, strength and specific stiffness can be compared with glass fibers [15,16]. Table 1 shows the comparison of the mechanical properties characteristics of bamboo fiber and glass fiber and Table 2 Comparison of the characteristics of bamboo fiber and glass fiber.

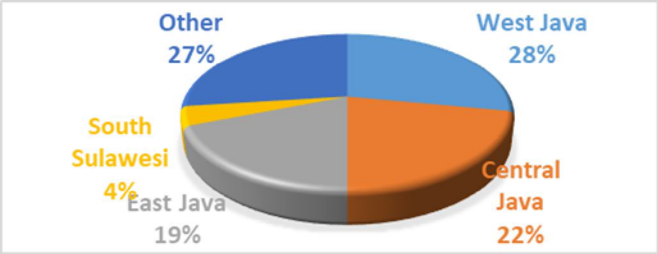

Figure 1: Bamboo Mapping in Indonesia

The purpose of this study is to map the development and progress of research covering, but not limited to

1. Types of bamboo fibers for composite materials,
2. Parameters of processing extraction and characterization of fibers
3. Types of resins, fiber ratios and matrices, orientation of longitudinal, random, woven fibers , and the shape of the laminae,
4. Parameters of the composite processing such as temperature and pressure, the selection of the fiber shape, the volume fraction
5. The mechanical and physical characteristics of the composite material.

2. METHODOLOGY

Methodology is a framework for thinking related to input-process-output and their characteristics based on standard requirements. Methodology of mapping journal review will be carried out as shown in Figure 2.

3. RESULTS

Based on the journal mapping, it was obtained

1. The status of the research and development of the type and parameters of the extraction process and the characteristics of the mechanical properties of bamboo fiber,
2. The type of matrix used for the fabrication of bamboo fiber composites and its mechanical and physical properties.

The results of this mapping will be used as a reference for designing the next research that includes extraction process parameters and types of fiber characteristics and composite fabrication process parameters and types of testing.

Table 1: Comparison of mechanical properties of bamboo fiber composite and glass fiber

No	Fiber	Volume Fraction (vf: %)	Tensile strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (GPa)	Density (g/cm3)	Ref
1	BF		500-575	27-40	1.9-3.2	100-150	10-13	1.2-1.5	[4]
2	GF		124-150	7-10	2.5-4.8	110-150	5-9	2.35-2.5	
Composite Materials									
3	BF+Epoxy	65	87-165	3-15	1.7-2.2	107-140	10-12	1.16-1.25	[14]
4	GF+Epoxy	65	180-220	5-10	2.7-3.5	195-220	7-12	1.96-2.02	[4]

Table 2: Comparison of the characteristics of bamboo fiber and glass fiber

Characteristics	Bamboo Fiber	Glass Fiber
Density	Low	Higher than bamboo
Price	Low	Higher than bamboo
Disposal	Biodegradable	Non-Biodegradable
CO2 Absorption	Yes	No.
Recyclability	Yes	No.
Renewability	Yes	No.
Energy for extraction	Low	High

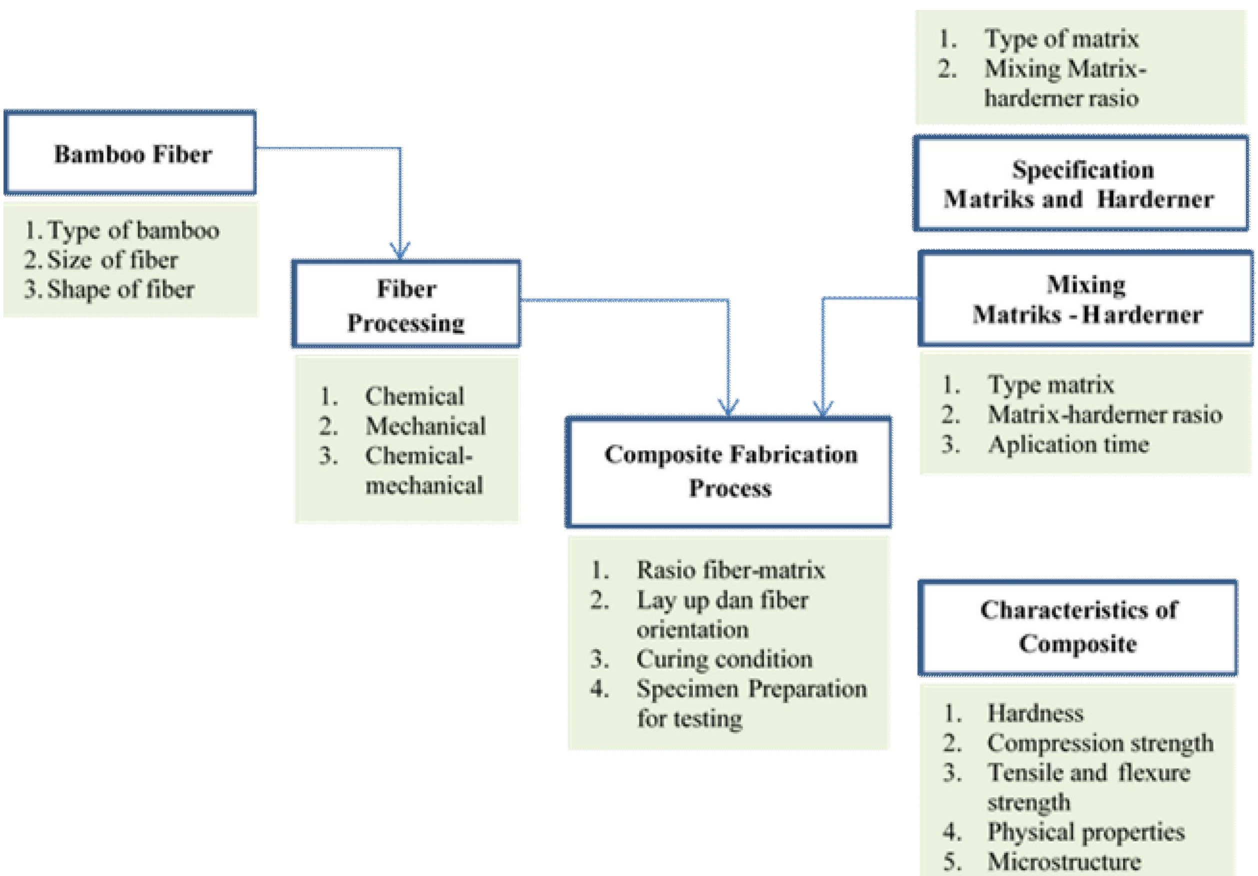

Figure 2: Methodology of The Mapping of Journal Review of the Bamboo Fiber-Reinforced Composite Materials

Table 3: Process of Bamboo Fiber Processing

Chemical Methods	*Mechanical Methods*	*Chemical and Mechanical Methods*
Chemical retting [17,18].	*Steam Explosion Method* [17,23,24,[25,26]	CMT [32].
Alkali [19,20].	*Crushing* [17,25].	RMT [32].
Acid Retting [21,22].	*Grinding* [27,28].	
	Rolling Mill [11,29].	
	Retting [30,31].	

3.1 Bamboo Fiber Processing Method

Bamboo fiber processing methods can be carried out through three methods. Those are chemical processing methods, mechanical processing, and combination of chemical and mechanical processing methods. Chemical extraction methods such as Chemical Retting and Alkaline or Acid Retting are used to remove or reduce the lignin element from the fibers. This chemical extraction method also affects other elements contained in fiber such as pectin and hemicellulose [17,22, 32].

Meanwhile, fiber processing processes with mechanical methods are Steam Explosion, Crushing, Grinding, Rolling Mill and Retting. This method is used to produce fibers that can be implemented in various industries and is used as fiber raw materials in composite materials. The third method is a combination of chemical and mechanical processes. The process can be seen in the Table 3.

3.2 *Chemical Retting*

Chemical Assisted Natural (CAN) is a retting process used by the researchers to reduce lignin and water level in the fiber. The bamboo culm is cut longitudinally into thin sheets. Manually separated fibers are soaked in Zn (NO3) 2 solution with concentrations of 1%, 2% and 3% for the ratio of material is 1:20 to the solvent. This fiber is soaked at a temperature of 40° C for 116 hours in neutral pH and stored in an incubator BOD and then the fiber is boiled in water for 1 hour. This procedure can remove the level of lignin better than alkaline and acid retting process, but fiber has a high moisture [17].

In another study, bamboo culms are cut into thin sheets with a thickness of 2 cm and then put in the oven at a temperature of 150° C for 30 minutes. Thin bamboo sheets are soaked in water for 24 hours at 60° C and dried in the open air. The next process, the fiber is cooked with 2% sodium silicate, 2% sodium sulphite, 2% sodium polyphosphate and 0.5% NaOH (w/v) at 100° C for 60 minutes with a ratio of solvent to fiber is 1: 20. The fiber is then washed with hot water and treated with 0.04% xylanase and 0.5% diethylene triamine penta acetic acid at 70° C with a pH of 6.5 for 60 minutes. The fiber is then cooked at 100° C for 60 minutes with the same procedure, but with 0.7% NaOH. The fiber is then put into a plastic bag (polyethylene type) and undergoes bleaching process with 0.5% sodium silicate, 4% H2O2 and 0.2% sodium hydroxide for 50 minutes. The ratio of the solvent is maintained at 1:20 to fiber and pH at 10.5. And the last, the fiber is added with 0.5% sulfuric acid for 10 minutes and an emulsification process for 5 days, to obtain smooth bamboo fibers. This study finds that fibers which have microfibrils with small orientation angles, and compared to hemp and cotton fibers, this type of fiber is suitable for reinforcement fibers in composites [18].

3.3 Alkaline or Acid Retting

Alkali

Alkaline process is applied to bamboo that has been cut into strips, and then soaked in 1.5 N NaOh in a steel stainless bowl at temperature of 70° C for 5 hours. Then the alkali bamboo strips are pressed using a press machine to obtain bamboo fibers, after which they are washed with water and dried in an oven. With this extraction method the damage to the fiber cross section decreases [19]. Other study influencing the cellulose and non-cellulosic portions of bamboo fiber is chip-sized bamboo strips are soaked in a 4% NaOH solution for 2 hours. In term of fiber extracts in the form of pulp, this procedure is repeated several times at a certain pressure. However, the problem with this extraction procedure is that it produces bundles of large fibers [22]. In another study, small bamboo strips are soaked in 1 N sodium hydroxide solution for 72 hours to produce fiber [22], Other research for gigantochloa apus with the alkaline treatment process will increase the value of tensile strength and bending strength compared to fibers that do not go through the stages of the alkaline treatment process. The value of tensile and bending strength increases by 46%.

Acid Retting

Trifluoroacetic acid (TFA) and alkali solutions that are some of the solutions used to extract fibers and lignin elements will dissolve under acidic and basic conditions. The researchers show that there is still a large amount of lignin in the middle of the fiber that must be removed. The results show that in the alkaline procedure there is remaining lignin in the middle and and most of them will be removed through TFA process [33]. Interfacial bonding and surface adhesion of composites to the alkaline process has improved better than other methods [21]; [22].

3.4 Steam Explosion Method

This Method is a low energy consumption method and produces pulp. In this process, the separation occurs in plant cell walls. This method is the right process to separate lignin from the plant surface, but produces rigid and opaque fibers [34]. In another study, fibers are separated from the bundles by using a sifter machine, producing fibers with a diameter of 125-210 µm. The fiber is then dried at 120° C for 2 hours. This method is a very effective process for removing lignin from wood and bamboo fibers [23]. Steam explosion process is carried out for raw bamboo, which has been cut into strips and put into an autoclave at 175° C for 60 minutes at a pressure of 0.7-0.8MPa. The steam is, then, released immediately in every 5 minutes for nine times. Next, the fiber is washed with hot water at 90-95 ° C and then being mixed with soap and is dried in an oven at 105° C for 24 hours. It is because most of the lignin on the surface of the fiber will lead to decreasing adhesion between the resin and fiber [15]. In the process of steam explosion, the cell wall of the fiber breaks and produces fine bamboo fibers. In other studies, lignin removal process is carried out through the isocyanate silane method.

From the results, it is found that the bamboo fiber extracted by steam explosion has a higher tensile strength than the isocyanate silane treatment process [24]. The tensile strength of the fiber that is reinforced with polymer material has decreased due to improper fiber treatment / extraction, which results in weak bonding of the fiber interface with the matrix. The proper surface treatment process of the fibers will be needed to achieve a good adhesion bonding between the fiber and the matrix [25]. Another study uses 0.25 bamboo fiber which has been prepared and put in autoclave.

The degumming process in the autoclave is carried out with a composition of 10 ml of non-ionic rucogen surfactant FWK 50, 10% NaOH solution with a variation of 400 and 800 mL, and water up to 4L. Bamboo is processed in an autoclave at a temperature of 90° C and a pressure of 0.9-1.0 kg / cm2 for 60 minutes. Next, bamboo is washed with water for 3-4 times until the water looks pretty clear. As the result, bundles of bamboo fiber obtained from the experiment will contain lower lignin and hemicellulose elements in bamboo that has been processed through autoclave process with NaOH solution. This will increase adhesion bonding between the fiber and matrices [26].

The Steam Explosion method carried out for the result of fiber tensile strength experiment shows that bamboo fibers (bundles) have a certain strength that is sufficient, which is equivalent to conventional glass fibers. The tensile and modulus strength of the fiber-reinforced composite material resulting from steam explosion process using a Polypropylene matrix increases by 15% and 30%, compared to composites using fibers whose processing is carried out mechanically. Steam explosion technique is an effective method for extracting bamboo fibers to strengthen thermoplastics [23].

3.5 Crushing

In this procedure, raw bamboo is cut into small pieces using a roll crusher. Then the rough fiber is obtained from small pieces of bamboo using a pin-roller. Then the fibers are cooked at a temperature of 90 ° C for 10 hours to remove fat and then dried with a rotary dryer and put in a dehydrator [17].

The main problem with this process is that it produces short fibers, and the next mechanical processing will produce powder [25].

3.6 Grinding

In this procedure, bamboo culms without nodes are then soaked in water for 24 hours. Then the strips are cut into smaller pieces with a knife. The strip passes through the extruder and the bamboo strip is cut into thin bamboo sheets. This small bamboo chip is refined using a high speed blender for 30 minutes to get bamboo fibers. Using several filters with various holes, the fibers are separated by size. The extracted fibers are finally dried in an oven at 10° C for 72 hours [27]. Fiber length has an effect on the strength of the tensile load. Thus, it increases the modulus of the composite materials. Some researchers use the same method for extracting bamboo fibers, as well as rheological behavior and composite morphology of bamboo fibers [35]. This method has also been used in studies to obtain bamboo particles / fibers in nano size [28].

3.7 Rolling Mill

In this procedure, bamboo culms are cut into slices with a thickness of 1 mm. To facilitate the separation of fibers from the slices, the strips are soaked in water for 1 hour. The bamboo strip is rolled in a low pressure and speed. The rolled strips are soaked for 30 minutes in water and then the fibers are separated using a razor. Then, the fibers are dried under the sun for 2 weeks and their length ranges from 220-270 mm [11]. In another study, to produce fiber extraction, bamboo strips are cut from bamboo culm and pressed between two pairs of cylindrical steel and without being soaked in water [29]. Meanwhile in another study, bamboo strips are sliced through steaming process and soaked in water to soften the lignin and fibers and then a roll process is carried out, resulting in fiber extraction with lengths ranging from 30 to 60 cm.

3.8 Retting

In this procedure, bamboo culm is peeled to get the strips. The bundles of strips are kept in water for three days. The strip is beaten with a hammer, then the bamboo is brushed [30]. In this method, the scraping process has a strong effect on the quality of the fiber and reduces damage to the fiber.

Table 4: Comparison of mechanical and physical properties for bamboo fiber characteristics with various bamboo fiber extraction treatments

Fiber	Fiber processing process	Tensile strength (MPa)	Young's modulus (GPa)	Fiber Diameter (µm)	Fiber Length (mm)	Density (g/cm3)	References
Bamboo	*Steam explosion*	441 ± 220	36 ± 13	15–210	–	–	[16].
	Steam explosion	383	28		1440		[19].
	Steam explosion	516	17				[16].
	Crushing	420	38	262 ± 160	–	–	[15].
	Grinding	450–800	18–30	–	–	1.4	[16].
	Rolling mill	270	–	100–600	220–270	–	[16].
	Retting	503	35.9	–	–	0.91	[30].
	Chemical	329	22		1356		[19].
	Chemical	450	18	270	10	1.3	
	Alkaline	419	30	-	1643	–	[19].
	Alkaline (5% NaOH for 2 hours)	420	-	-	-	-	
	Chemical + Compression	645 - 1000	–	50–400	>10	0.8–0.9	[32].
	Chemical + Roller mill	370 - 480	–	50–100	120–170	–	[32].

In another study, bamboo is merely cut into several longitudinal sections without removing the node and epidermis. The bamboo strip is then cleaned with running water and fermented in water at room temperature for 2 months. Two types of Retting processes, aerobic and anaerobic, are used to produce fiber bundles, single fibers and long fibers [31].

3.9 Combination of fiber processing through mechanical and chemical process

Usually after alkaline and chemical treatment, compression moulding technique (CMT) and roller mill technique (RMT) are used to extract fibers. In a study, bamboo strips that have been undergone chemical treatment are placed in two flat plates with a pressure of under 10 ton using CMT.

In order to separate good quality of fibers, thickness and pressure time are important factors to consider. At RMT, two rollers, one fixed roller and the other roller are rotated, are used and bamboo strips are inserted between the two rollers.

The compression molding technique (CMT) and roller mill technique (RMT) processes combined with chemical treatment will result in the extraction of fibers from bamboo strips [32]. The results of the processing of fiber on bamboo will affect the mechanical and physical properties of bamboo fibers, to see the comparative data from bamboo fibers as the effect of fiber treatments (chemical, mechanical and a combination of both) can be seen in Table 4.

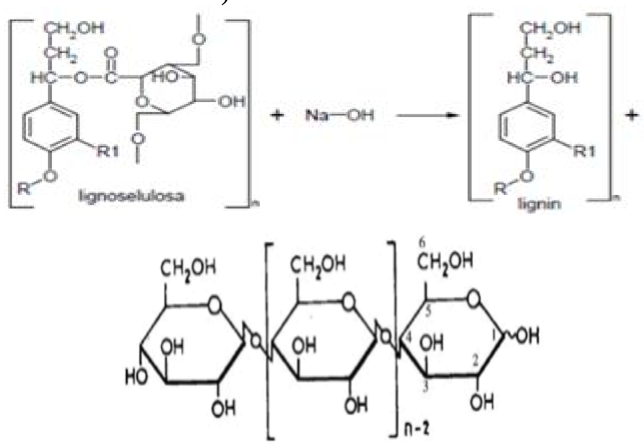

Figure 3: Lignocellulose reaction in NaOH solution [37]

Figure 4: Extraction process and Alkaline treatment of bamboo fiber

a) Bamboo strips immersed in water
b) Beating of bamboo strips with hammer
c) Final phase of manually extracted bamboo fiber
d) Bamboo fiber soaked by NaOH
e) Bamboo fiber after soaked with sodium hydroxide
f) Alkaline treated and dried bamboo fiber

The alkali treatment of bamboo fibers is one of the chemical treatments that has been known to increase cellulose content through removal of hemicellulose and lignin, so that it will produce better mechanical properties of the fiber [36]. Based on figure 3, OH- (results of dissociation of NaOH into Na^+ and OH^-) reacts with the H group on lignin, then forms H_2O. Cluster O forms free radicals and reacts with C to form epoxy rings (C-O-C). The reaction produces two separate benzene rings, where each ring has a reactive O group. This reactive group O reacts with Na^+ and dissolves in alkaline solutions so that lignin is removed when rinsed [31]. The process of alkalising the fiber can be seen in Figure 4.

3.10 Characteristics of Bamboo-Reinforced Composite Materials

The characteristics of bamboo-reinforced composite materials are influenced by composite production process which is determined by several parameters, including the choice of fiber type (natural fiber / synthesis fiber element) and matrix (thermoset, thermoplastic), fiber dimensions, fiber shape (fiber, powder, lamina), fiber orientation , and process parameters (temperature, pressure, time).

Studies that have been conducted on the parameters of composites production, namely research on the effect of lamina on the characteristics of composite materials has been conducted by several researchers, including the manufacture of LFRC (Laminate Fiber Reinforcement Composite) consisting of bamboo strips and epoxy in the form of layers 3, 5 and 7, where each layer consists of unidirectional bamboo pieces [29].

From the LFRC test results by varying the amount of laminated composites, it can be obtained good LFRC test results in tensile tests (up to 243 MPa), compressive tests (up to 129 MPa) and flexural tests (up to 255 MPa). It proves that BFRC guarantees its use for construction and other purposes. Tensile, flexural and impact strength tests that are carried out in multidirectional, bidirectional, 5,7, and 9 bamboo-coated bamboo fibers and bamboo composite mats result in unidirectional composite that has a highest tensile strength up to 175.27 MPa, in a study conducted by [14].

Fabrication procedure to produce layered BFRC (Bamboo Fiber Reinforcement Composite) which combines bamboo slices that are obtained from bamboo stems using a slotted cutting machine and epoxy resin. Three configurations of layered bamboo composite using adhesives and butt joints are unidirectional configuration [0 ° / 0 ° / 0 ° / 0 ° / 0 °], symmetrical configuration [0 ° / 45 ° / 0 ° / 45 ° / 0 °] and cross-ply symmetrical configuration [0 ° / 90 ° / 0 ° / 90 ° / 0 °]. The specimens are tested for tensile, compressive and flexural properties, the results can be seen in table 3, related to the relationship between lamina configuration to composite mechanical properties and optimal values obtained from unidirectional configuration [0 ° / 0 ° / 0 ° / 0 ° / 0 °]. [38];[39]. Resume of the study on the effect of lamina and fiber orientation on the mechanical properties can be seen in table 5.

Study on the characteristics of bamboo fiber-reinforced composite materials is focused on the granular size of bamboo particles (20, 40, 60) mesh, bamboo fiber and PVC matrix (Polyvinyl Chloride) volume fraction with variations in fiber fraction (30%, 40%, 50%), composite production process through a hot press with process parameters for 6 MPa pressure, a pressure temperature of 448.15 K with a pressure time of 8 minutes. Combination of 40 mesh bamboo particle size with a fiber volume fraction used at 50% provides optimum strength values [40].

The process of composites production by varying the composition of fibers and matrices is done by [41], with the composition of (30, 50, 70)% of fibers with the highest value at 70% of bamboo fiber composition for a tensile strength of 265 MPa and tensile modulus of 12.4 GPa , theoretically the greater the volume fraction used, the strength value will increase.

Other studies with the amount of fiber used in the process of composites production will have an effect on increasing the value of tensile strength, by varying (0,4,8,12,16)%, the greater the volume fraction of the fibers used, then the composite tensile strength will increase [42]. Studies on the form of fiber used (fiber, powder) by varying the volume fraction (0%, 50% and 100%) and bamboo fiber function as a fiber or matrices.

Temperature parameters vary (160˚C, 180˚C, 200˚C) at a pressure of 65 MPa, resulting in modulus of flexural value and tensile strength increasing in line with increasing fiber level [41]. The design of the composite production process is carried out by varying the volume of fiber fraction and combining natural fibers (bamboo) and alumina fibers.

The volume fraction for bamboo fibers (15,30,45)% and alumina fibers (0,5,10,15)% using Polyester matrices, leads in increasing composite tensile strength in line with the number of fiber fraction and alumina added to the polyester matrix [43]. Study on the effect of fiber volume fraction on the mechanical properties of bamboo fiber composite materials both pure bamboo fiber and the combination of 2 different types of fibers as well as has an effect on increasing strength along with the addition of fiber volume fraction [44]; [45]; [46]; [47]; [48]; [49]. Resume of study on volume fraction and fiber diameter, method of fabrication of Bamboo Fiber composites can be seen in table 6. Composite fabrication by vacuum bagging system can be seen in Figure 5.

Table 5: Resume of the study on the effect of lamina and fiber orientation on the mechanical properties of bamboo fiber-reinforced composite materials

Types of Fiber and Matrices	Amount of Lamina/layer	Fiber Orientation	Tensile Strength (MPa)	Pressure Strength (MPa)	Flexural strength (MPa)	References
Bamboo+Polyester + 5% Alkaline	7	-	126	-	149	[50]
Bamboo+Epoxy + 5% Alkaline	7	-	135	-	161	
Bamboo +Epoxy	7	Strand mat	233	-	194	
Bamboo + Polyester	7	Strand mat	232	-	250	
Bamboo + Epoxy	4	0/90	43.47	52.56	60.97	[51]
Bamboo + Epoxy	3	-	243	129	255	[29]
	5	-	189	59	208	
	7	-	178	90	245	
Indian Bamboo +Araldite	1	Unidirectional (0)	175.27	-	151.83	[14]
	5	Multidirectional (0/45/90)	99.34	-	130.23	
	7	Multidirectional (0/30/60/90)	82.2	-	161,1	
	9	Multidirectional (0/22.5/45/67.5/90)	70.13	-	186.38	
Bamboo + Epoxy	5	[0°/0°/0°/0°/0°]	205	80	128.4	[38]
		[0°/45°/0°/45°/0°]	188	55	68.28	
		[0°/90°/0°/90°/0°]	169	66	105.74	

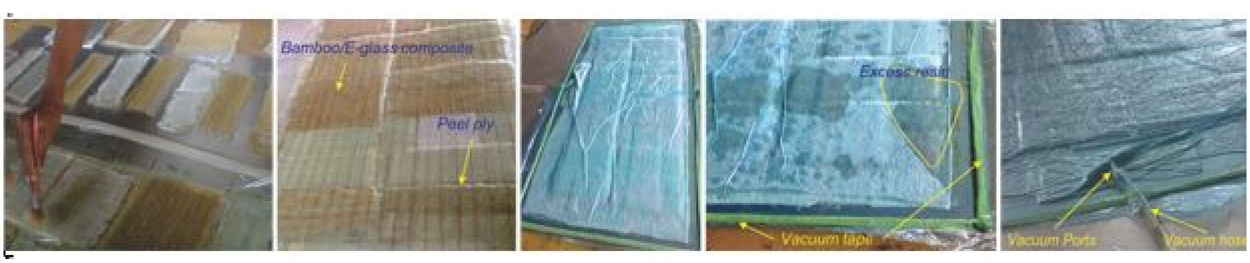

Figure 5: Composite fabrication by vacuum bagging system

Table 6: Resume of Study on Volume Fraction and Fiber diameter, Method of fabrication of Bamboo Fiber composite materials to Tensile Strength

Type of Fiber	Volume Fraction of Fiber (% wt)	Fiber Diameter (µm)	Methods	Tensile Strength (MPa)	References
Bamboo	50,60,70	841,420,250	Hot Press: Pressure= 6 MPa Temperature = 448.15K Time = 8 minutes	1.53 – 7.50	[40]
Bamboo	10,20,30,40	-	Hot Press: Pressure= 3.2 MPa Temperature = 190 ^{o}C Time = 30 minutes	13 - 17	
Bamboo	30,50,70	100,300	Hot Press : Pressure= 10 MPa Temperature = (140,160,180,200)^{o}C Time = 15 to 120 minutes	120.2 – 265.5	[41]
Bamboo	0,4,8,12,16	-	Compression – Molding Process Pressure = 0.05 MPa (50 kN) Temperature = 180 ^{o}C Time = -	8 - 30	[42]
Bamboo	0,50,100	50 – 100 (particles) 100 – 300 (fibers)	Hot Press : Pressure= 65 MPa Temperature= (160,180,200)^{o}C Time = -	25 - 169.9	[41]
Bamboo	15,30,45	80 - 100	Hot Press : Pressure= 0.98 MPa Temperature = 40^{o}C Time = 24 h	7.241- 18.767	[43]
Bamboo	0 to 100	-	Hand Lay Up + Compression – Molding Process	60 - 11	[44]
Bamboo	0,10,20,30	35	Injection Molding Temperatur 160 oC	27.98 – 41.35	[46]
Bamboo	30,40,50	380 - 580	Hot Press: Pressure = 0.80 MPa Temperature = 185^{o}C	40 - 70	[47]
Bamboo	10,20,30,40,50	175 - 250	Hand Lay Up + Compression – Molding Press : Pressure= 0.05 MPa Temperature= 80^{o}C Time = 2 hours	30 - 120	[30]
Bamboo	30,40,50,60	90 - 125	Compression Moulding Press: Pressure = 25 Ton Temperature = 160^{o}C Time = 5 minutes	24.50 – 50.26	[17]
Bamboo Fiber	35,50	100 -300	Hand Lay Up + Compression – Molding Press : Pressure = 32 MPa	70.13 – 175.27	[14]
Laminated Bamboo	60,63,65,70	100 -300	Hand Lay Up + Compression – Molding Press : Pressure= 32 MPa	80.5 – 110.5	

Note = 1 kilonewton/meter² [kN/m²] = 0.001 megapascal [MPa], 1 kilogram-force/centimeter² = 0.0980665 megapascal

Table 7: Resumes of the study on the Effect of Matrix Type to Mechanical characteristics of Bamboo Fiber Composites

Fiber	Type of matrix	Tensile strength (MPa)	Tensile Modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact Strength (J/m)	Ref
Indian Balcooa Bamboo	PP + MA-g PP	24.50 - 28.95 24.50 - 50.26	0.560 – 1.633 0.560-1.776	38 – 68.85 38 – 49.56	1.650 – 4.127 1.650 – 3.307	26.54 – 38.92 26.54 – 27.54	[17]
Bamboo	Epoxy Polyester	135 126	8.204 5.515	149 161	9.5 9.612	- -	[50]
Bamboo (Without alkali)	Polyester Epoxy	74 86	4.2 6.736	107 119	4.373 11.9	- -	[21]
Bamboo (acrylonitrile, 1h)	Polyester Epoxy	97 125	8.4 9.9	79 133	4.2 6.6	- -	
Bamboo (acrylonitrile,5h)	Polyester Epoxy	84 102	5.8 9.9	78 121	2.5 5.8	- -	
Bamboo	Polyester Vinyl Ester	- -	- -	30.6 – 41.1 44.9 – 55.1	3.3 – 4.2 3.2 – 3.6	- -	
Bamboo	HDPE	18.58 – 25.47	0.33 – 2.26	22.75-27.86	1.16 – 2.987	51.21 – 71.24	
Bamboo (Vf 30%wt)	PP PP+MA 3%	43.96 48.50	1.24 1.425	45.42 54.26	1.920 2.096	53.6 59.50	
Bamboo (Vf 68%wt)	Polyester	101.8 +/-2.8	-	108.8 +/-6.4	8.2 +/-1.8	-	[52]
Bamboo (with alkaline treatment, Vf 69%wt)	Polyester	112.2 +/-2.2	-	132.4 +/- 3.2	9.8 +/-2.4	-	
Bamboo (Vf 60%wt)	Epoxy	112.8 +/-1.4	-	118.5 +/-1.5	7.8 +/-3.8	-	
Bamboo (With alkaline treatment, Vf 60%wt)	Epoxy	144.8 +/-0.7	-	162.1 +/-2.8	8.2 +/-2.1	-	

Fiber	Type of matrix	Tensile strength (MPa)	Tensile Modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact Strength (J/m)	Ref
Bamboo (10%, 20%, 30%)	Polypropylene	30.77-41.35	1.89-2.82	69.93-93.63	6.03 – 10.66	34.03 -57.78	[46]
Bamboo	Epoxy	26.417	2.48	-	-	-	[53]
Bamboo: Flax Vf(0,10,20,30,40)%wt	Epoxy	23.45-34.27	-	58.11 -89.60	-	1.25-2.35	[49]
Bamboo (Fiber Diameter: 0.2,0.3,0.4) mm	Epoxy	30.11-32.05	3.344-3.346	-	-	-	[54]
Bamboo (Vf (60,70) %)	Polypropylene	-	-	11.67 -19.15	3.05 – 3.13	-	[55]
Bamboo	PP + MA	35.1 +/- 2.42	4.69+/-0.55				[29]
Bamboo (Vf 57%)	Epoxy	392+/-8.51	29+/-1,25	226 +/-25.13	19+/-1.32	-	[56]
Bamboo	Epoxy	43.47	6.63	60.97	3.2	-	[51]
Ci bamboo	Phenolic	16.43-20.30	1.48-1.68	-	-	-	[57]

(Neosinocalamus affinins)						
Short Fiber Bamboo	Phenolic	29.9	2.92	-	-	-
Short Fiber Bamboo	Epoxy	36.1	3.26	-	-	-
Long Fiber Bamboo	Epoxy	203	51	-	-	-
Laminated Bamboo	Phenolic	114.4	-	-	-	-

Note: PP = polypropylene, HDPE = High Density Polyethylene, MA=Maleic Anhydride

Other studies that analyze the characteristics of bamboo-reinforced composite material with varied parameters are the type of matrix to the strength of the composite material. The type of matrix will affect the mechanical properties of bamboo fiber-reinforced composite materials. This process has been carried out by researchers. The effect of matrix type on tensile strength, tensile modulus, flexural strength, Flexural modulus, and impact strength can be seen in Table 7 [17,21]. Resume of the study on the effect of matrix type to mechanical characteristics of bamboo fiber composites can seen in table 7.

3.11 Application of Bamboo Fiber Composite Materials

Utilization of bamboo material for various purposes has been done since long time ago for household purposes such as containers, chopsticks, woven mats, fishing rods, handicrafts, and furniture. In addition, bamboo has been widely used in building applications, such as floors, ceilings, walls, windows, doors, fences, residential roofs, trusses, rafters and purlin. Bamboo is even used in construction as structural materials for bridges, water transportation facilities and ceiling. By paying attention to the high strength of bamboo and supported by the fact that high quality bamboo can be obtained at the age of 2 to 5 years old, a relatively short period of time, and considering that bamboo is easy to plant, and does not require a special care, then bamboo has a big opportunity to replace wood [4].

Bamboo fiber composite material has been used in producing a prototype (inner board of trunk door panel) by Mitsubishi Japan. They use polybutylene resin to develop the prototype. This product was developed by Mitsubishi to reduce the cost of producing materials used today and CO2 emissions [58]. Other material research are also found in various applications [59-61]. Extensive changes from an economic perspective are needed in an advance composite; the only choice is the use of natural plant fibers. Bamboo can serve as an excellent source to replace the existing crisis, namely the cost and availability of raw materials.

4. CONCLUSION

Bamboo fiber is discussed in the results of a journal review, from bamboo that grows in Asia, especially China, India and Indonesia. Bamboo fiber is one of the natural fibers that can be used as raw material for natural fibers, considered from the advantages of bamboo fiber compared to glass fiber that has a low cost aspect, abundant raw materials, environmentally friendly, light specific gravity, high growth rate, good strength and stiffness value. Bamboo fiber consists of cellulose, hemicellulose and lignin. The level of cellulose and hemicellulose in the form of holocellulose can be more than 50%.

Fiber processing methods can be carried out chemically, mechanically and combination of both. Fiber processing carried out by an alkaline process will have a positive impact on the strength of the bamboo fiber composite material. Steam explosion method (Steam explosion) is one of the effective methods to produce bamboo fiber with good quality in terms of strength.

The characteristics of bamboo fiber composite materials (mechanical and physical properties) will be affected by the parameters of composite materials production process, namely the choice of fiber type, matrix type, fiber orientation, fiber volume fraction, fiber size, fiber orientation, fiber shape, and composite fabrication parameters (types of process, temperature, pressure, time).
During this time, the benefits bamboo have been used since long time ago for household purposes such as containers, chopsticks, woven mats, fishing rods, handicrafts, and furniture. Besides bamboo has also been widely used in building applications, such as floors, ceilings, walls, windows, doors, fences, residential roofs, trusses, rafters and purlin. Bamboo is even used in construction as structural materials for bridges, water transportation facilities and ceiling.

Scientists around the world have conducted various studies with new ideas to provide basic support for works and also employ the community. Current research on bamboo fiber based composites uses the basic and applied science in terms of modification, mechano-physical, thermal and other properties. The final goal is to utilize bamboo fiber that has been far behind the projected target, especially in Malaysia, although other countries such as India and China have moved a long way forward in utilizing bamboo fiber in a socio-economic sense. The sustainable future of the bamboo-based composite industry will help in utilizing bamboo in ways other than traditional modes.

Effective characterization of bamboo fiber and bamboo fiber-based composites must be more advanced in terms of analysis and testing. In this review article, researchers have tried to gather information about the analysis and testing methods used. However, scientists have conducted a lot of studies on bamboo-based composites, but they are still required to conduct more researches and innovation in this area (especially Indonesia) to overcome potential challenges in the future. These things will make life easier for urban and rural communities who are more dependent on synthetic-based composites.

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