

Bamboo reinforced polymer composite - A comprehensive review

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Abstract. Bamboo has greatly attention of researchers due to their advantages over synthetic polymers. It is entirely renewable, environmentally-friendly, non-toxic, cheap, non-abrasive and fully biodegradable. This review paper summarized an overview of the bamboo, fiber extraction and mechanical behavior of bamboo reinforced composites. A number of studies proved that mechanical properties of bamboo fibers reinforced reinforced polymer composites are excellent and competent to be utilized in high-tech applications. The properties of the laminate are influenced by the fiber loading, fibre orientation, physical and interlaminar adhesion between fibre and matrix. In contrast, the presence of chemical constituents such as cellulose, lignin, hemicellulose and wax substances in natural fibres preventing them from firmly binding with polymer resin. Thus, led to poor mechanical properties for composites. Many attempt has been made in order to overcome this issue by using the chemical treatment.

1. Introduction

Bamboo is one of the woody plants that always gain most manufacturers' attention due to several advantages such as ease of growth in diverse climates which make it durability and low cost material when compared to others [1–4]. Eventhough bamboo is one of the old and traditional building materials, it is actively being practiced until today. Bamboo, as shown in **Figure 1.**, are abundantly growing mainly in South America and Asia, including Malaysia. Wong [5] reported that Malaysia has about 70 species of bamboo in which 50% in Peninsular Malaysia, 30% in Sabah and 20% in Sarawak. There are about 10 main genera of bamboo that which are *Bambusa*, *Dinochloa*, *Yushania*, *Chusquea*, *Gigantochloa*, *Phyllostachys*, *Dendrocalamus*, *Racemobambos*, *Thyrsostachys* and *Schizostachyu* [5, 6].





Figure 1. Photo of bamboo plants

Table 1. lists part of bamboo species available in Peninsular Malaysia with their respective uses. Thus, it is no wonder that bamboo is listed as one of the raw material that being harvested the most in Malaysia [7]. Still, Malaysia has not been able to delve it into engineering materials specifically polymer composites. By having excellent properties such as renewable, sustainability and durability, bamboo has potential to be utilized in polymer composite industry [1–4]. Employment of bamboo in polymer composites development has definitely enhanced the socio-economic among the developers that growing and harvesting the bamboo.

Table 1. The available bamboo species in Peninsular Malaysia [6, 8]

Species	Local Name	Uses	State
<i>Bambusa heterostachya</i>	Buluh galah/ tilan/ pering/ pengat	Poles, frames, tooth picks, blinds, skewer sticks	Johor
<i>Bambusa vulgaris</i>	Buluh minyak/ aao/ aro/ gading/ Tamalang/ pa	Ornamental, tooth picks, chopsticks, skewer sticks, shoots as food	Pahang, Perak, Selangor
<i>Dendrocalamus asper</i>	Buluh beting/ pering	Shoots as food, higo materials, chopstick	Kedah, Melaka, Pahang, Selangor, Terengganu
<i>Gigantochloa scortechinii</i>	Buluh semantan/ rayah/ gala/ paao/ Seremai/ telur	Handicraft, smallscale industries, incense sticks	Kedah, Kelantan, Perak, Selangor, Terengganu
<i>Gigantochloa wrayi</i>	Buluh beti/ raga	Handicraft, blinds, tooth picks, skewer sticks, shoots as food	Perak
<i>Schizostachyum brachycladum</i>	Buluh nipis/ lemang/ padi/ urat/ rusa/ Pelang	Handicraft, rice vessels (lemant)	Pahang

2. The anatomy of bamboo

As illustrated in **Figure 2.**, the anatomy of a bamboo consists of culm, root, rhizome structure, shoots, branches and leaves. Some species of bamboo produce flowers sporadically, like *Phyllostachys Elegans* in the U.S. and *Phyllostachys edulis* 'Moso' in China [9]. Sporadic flowering means the flowering occur due to environmental factor, rather than genetics.

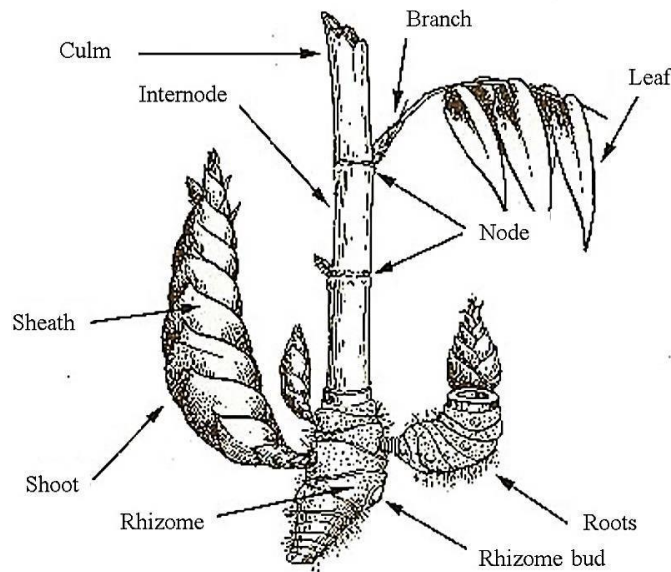


Figure 2. Photo of bamboo's anatomy [10]

Zhang et al. [11] and Jiang et al. [12] stated that the morphology (outward appearance) of bamboo is divided into two major parts; the rhizome and the culm systems. Also, the bamboo plant can be categorized into two parts; the underground part (composed of rhizomes, roots and buds) and above ground part (composed of stems, branches and foliage). **Table 2.** summarizes the functions of existing structure of bamboo. Every functions that carried out by each structure of bamboo are related to each other as to ensure the bamboo plant able to grow steadily.

Table 2. The structure of bamboo [13]

Structure	Description
Rhizome	A horizontal and segmented stem that projecting from the origin plant which travel underground for colonizing new territory purpose. It is covered with a protective sheath. The function of sheath is to give the protection needed by plant in breaching the surface as to form a culm. Rhizome collects, stores and distributes water and nutrients for function of parenchyma and conduction tissue, includes the vegetative production by growing into the new shoots or bamboo culms at their nodes.
Culm	A cylinder-formed woody stem that consists of nodes and internodes. Culms are usually hollow. Still, there are some species of bamboo that have solid culm. A culm is acclaimed by sheath, foliage, leaves, flowers and branching system. It is supported by the root system which allows it to withstand more weight of growing leaves. A culm is fully mature after 3 or 4 years and as it matures, it becomes stronger and harder.
Root	The main function of roots is to support the culms which allows them to stand against exposed damages such as bad weather. Also, allows the culm to hold more weight, giving it the ability to grow more leaves over wider distances. Another function of root is to store nutrients. They form at the base of the culm from the rhizome nodes and generally go no deeper than one foot below the surface. In appearance, the roots are typically symmetrical in size and shape.
Branches	Almost bamboo species grow multiple branches from a single bud that located at the node. However, some genera, like Chusquea, able to grow multiple buds at from each node.
Leaves	Every main parts of bamboo (rhizomes, culm and branches) have leaves. Anatomy of a leaf consists of blade, sheath and ligule. Leaves are first present in the rhizome where they are almost completely comprised of the sheath. At this stage, leaves serve as a protective cover to encase the rhizome as it travels underground. After the rhizome shoots through the soil and becomes a culm, the blade will become the predominant feature. The blade provides the photosynthetic function of the plant by converting sunlight into energy. The appearance of the blade varies among species. The appearance of leaves plays a large role in the identification of bamboo.

3. Bamboo as reinforcing fiber

As a fiber, the overall mechanical properties of bamboo are comparable to or even better than those of wood [14]. Moreover, the specific gravity of bamboo is relatively high when compared to the hardwoods or heavy tropical timber species which are normally used in composites panels manufacturing [13]. Thus, it should be used for the high density composite products such as High Density Fiberboard. These advantages make it highly competitive nature fibre reinforcement in polymer composites.

Table 3. presents the properties of bamboo that are comparable to other natural fibres such as kenaf, jute and sisal [15]. The table also includes the properties of E-Glass, a fibre that commonly used in composite manufacturing and the least one when compared to other types of glass and existing fibre like Kevlar in terms of strength. From the table, the specific young modulus (Specific E) of bamboo is comparable to that of the E-glass fibre. This means the bamboo has a high stiffness with minimum

weights. Also, if the string-like bamboo fibre bundles as mentioned by Phong et al. [16] are able to be extracted, those fibres can be used as a replacement for jute and kenaf fibres.

Table 3. The mechanical properties of natural fibres compare with E-glass [15]

Fibres	Density (g/cm ³)	Tensile Strength (MPa)	Young's Modulus, E (GPa)	Specific Young's Modulus, E (E/d)	Elongation at failure (%)	Moisture absorption (%)
E-glass	2.55	2400	73	29	3	-
Bamboo	0.6-1.1	140-230	11-17	10-28	-	8.9
Hemp	1.48	550-900	70	47	1.6	8
Jute	1.46	400-800	10-30	7-21	1.8	12
Kenaf	1.45	930	53	36.5	1.6	-
Ramie	1.5	500	44	29	2	12-17
Sisal	1.33	600-700	38	29	2-3	11

4. The extraction of bamboo fiber

The form of extracted bamboo fiber will determined the final forms of composite whether as laminated fibre reinforced composites, short or randomly oriented fibre or formed into sandwich structure. These forms are essential in order to meet the industry expectation. The common forms of extracted bamboo which are strip, flake, long fibre, short fibre, sliver and powder as shown in **Figure 3**.

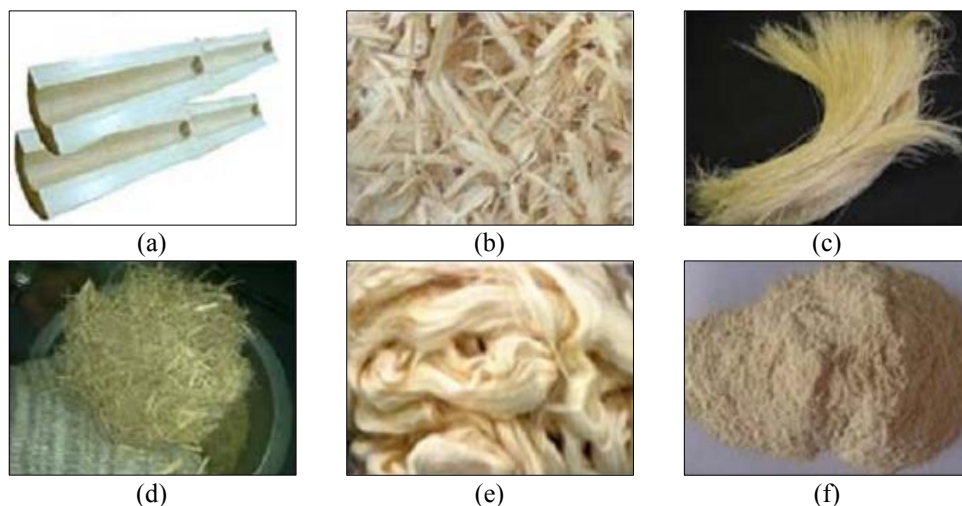


Figure 3. Photos of bamboo that being used as the composite reinforcement in a form of (a) strips (b) flake (c) long fibre (d) short fibre (e) silver and (f) powder [17–20].

In contrast, there is a limited knowledge regarding bamboo fibre extraction, only a few investigations have been done with different processes to define the mechanical properties and the usage of bamboo fibre as reinforced polymer composite. Subsequently, various methods have been used to extract bamboo fibres based on their application in the industries. These processes are classified as chemical, mechanical and combination of both processes.

5. Mechanical properties of bamboo fibre reinforced epoxy composites

Mechanical properties of bamboo fiber reinforced polymer composites (NFPC) are greatly influenced by few factors. The most common factors are listed as follow:

- i. Fiber orientation
- ii. Physical properties of fiber (short or long fiber)
- iii. Interfacial adhesion properties of fibre and matrix

As shown in **Figure 4.**, an example of NFPCs exhibited with different value of tensile strength due to interaction with the different type of matrix resin. Bamboo fibre reinforced epoxy composites also offer different findings under various mechanical testing. Here, the process of bamboo extraction, methods for reinforcing bamboo fibre with epoxy resin and types of mechanical tests conducted severely affect the end results of experiments.

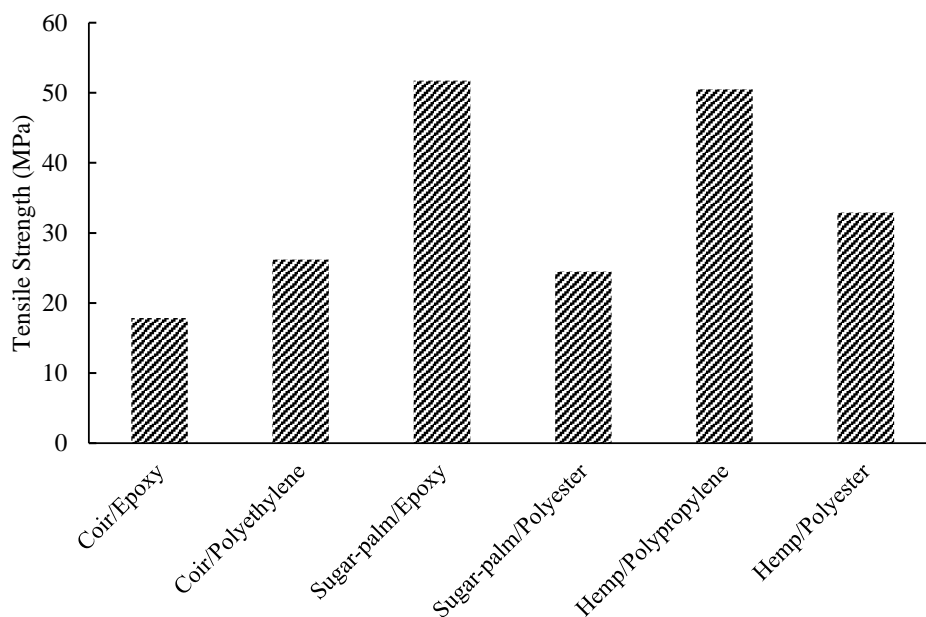


Figure 4. The tensile strength of natural fibres reinforced polymer composites [21–25]

The effect of bamboo fiber orientation

NFPCs are such composites whose mechanical efficiency is dependent upon the fiber direction. They tend to be stronger in which fibre direction is parallel to axis of applied load. This is because the resistance force exhibited by the composites is equal to the applied force. Moreover, the increasing of fibre degree from the load axis, can cause matrix failure. In this condition, the resistance composite hold against the applied force is not effectively as in the condition where fibres are parallel to axis of applied force.

A study of mechanical behaviors of layered laminate bamboo/epoxy composite was done by Verma and Chariar [26, 27]. In their study, they fabricated three types of LLBC that consist of bamboo silver and epoxy in five layers and each layer have different fibre orientations. The first type of LLBC they made was laminated of $(0^\circ/0^\circ/0^\circ/0^\circ/0^\circ)$ bamboo fibre. The second and third LLBC was composed of $(0^\circ/45^\circ/0^\circ/45^\circ/0^\circ)$ and $(0^\circ/90^\circ/0^\circ/90^\circ/0^\circ)$. Five test specimens were prepared from each type of LLBCs samples respectively using cross cutting and grinding as per ASTM standards D3039M, D3410 and D7264 for tensile, compressive and flexural testing respectively. The experimental data showed that the tensile and compressive properties of LLBCs decreased with increase in lamina angle. **Figure 5.** shows the experimental data obtained from the work conducted by Verma and Chariar [27].

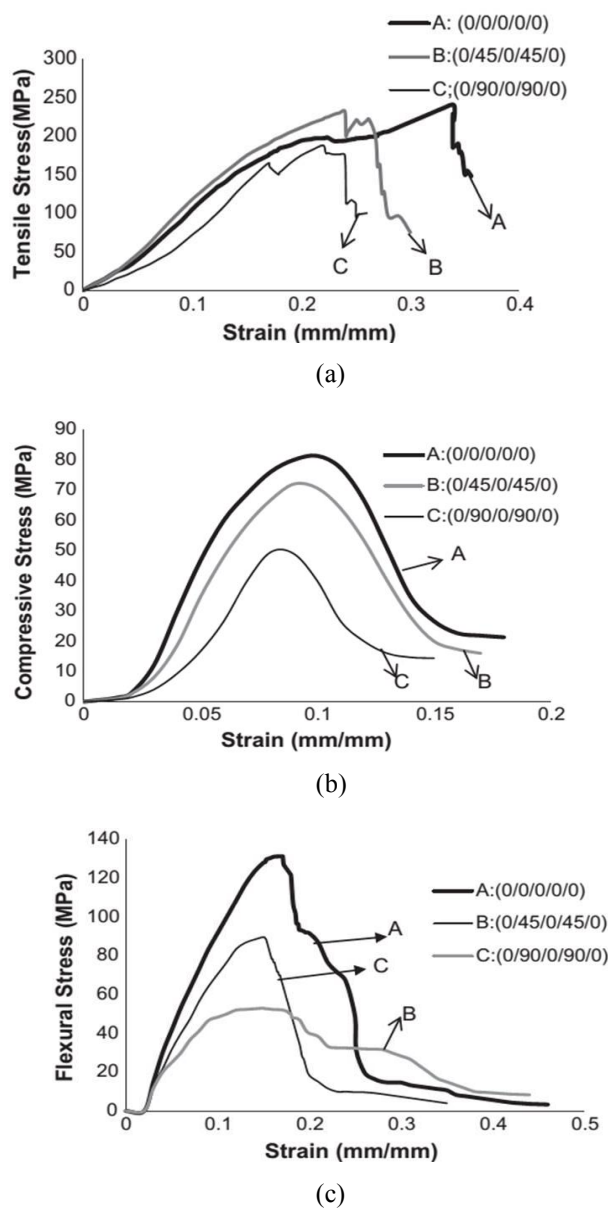
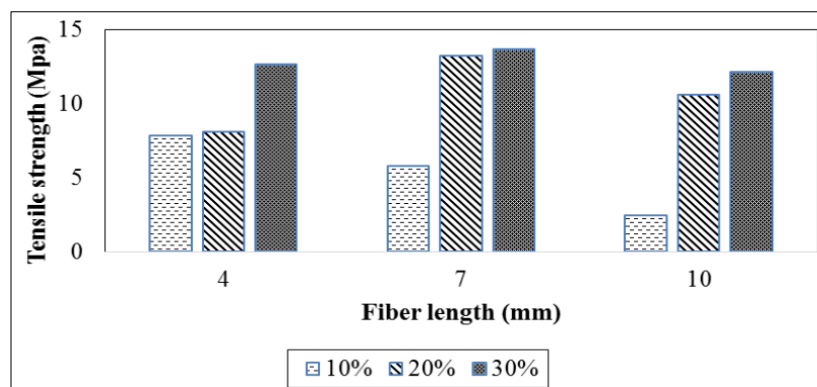


Figure 5. The output data of (a) tensile (b) compression and (c) flexure tests done by Verma and Chariar [27]

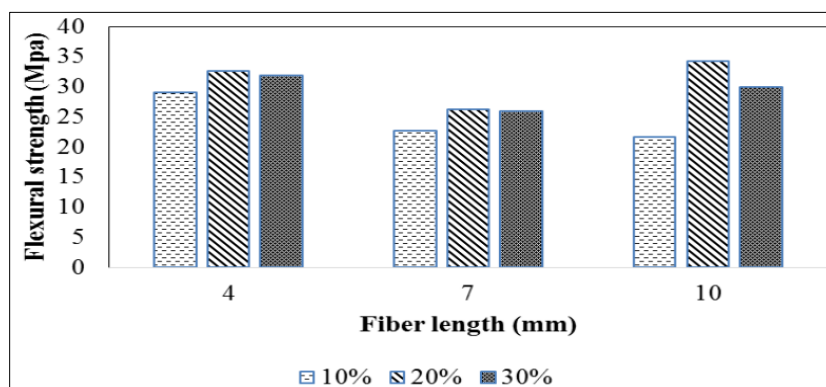
Chandrasekhar et al. [28] conducted tensile, flexural and impact tests to investigate the effect fibre orientations in bamboo/epoxy laminates. The orientations were tested at 30°, 45°, 60°, and 90°. The laminated bamboo/epoxy was produced by hand lay-up technique. The investigation was concluded that the maximum flexural and impact strengths were achieved at 60° of bamboo fibre orientation and the tensile strength was maximum in 30° of bamboo fibre orientation. The same investigation was carried out by Roslan et al. [29] where they tested of fibre orientations of laminated bamboo/epoxy composites were at 0°, 45° and 90°. The maximum tensile strength was achieved when the bamboo fibre at 0°, a condition where the fibre is parallel with the load applied.

The effect of physical properties of bamboo fiber

Gupta [30] studied the effect of physical and different of weight loading of bamboo fibre reinforced epoxy composites. The performance of composites were evaluated by conducting tensile and flexure tests. Before reinforcing the bamboo fibre with epoxy, they cut the fibre into 4, 7 and 10 mm of length. Then mixed with epoxy resin and prepared into 10 wt%, 20 wt% and 30 wt%. **Figure 6.** presents the results obtained from the conducted tests. Based on the data, tensile strength higher when the fibre content at 30 wt% for 4 mm, 7 mm and 10 mm of fibre length respectively. In contrast, the flexure strength showed a fluctuating pattern. They concluded that the excess of bamboo fibers in composite materials deteriorate the mechanical properties of the composite due to the lack of proper bonding between the matrix and fiber around their interface.



(a)



(b)

Figure 6. The data output of (a) tensile and (b) flexure strength by Gupta [30]

On the other hand, Anu Gupta et al. [31] investigated the influence of fibre loading and impingement angle on mechanical and erosion wear behaviour of bamboo/epoxy composites. The results showed the impact strength increased steadily with the increase in fibre loading from 0 to 20 weight%. While the peak erosion rate of the composites with different impingement angle was found to occur at 60° and 75°.

The effect of interfacial adhesion between bamboo fibre and epoxy

The lack of interfacial adhesion between bamboo fibre and epoxy polymer degrades the strength of bamboo/epoxy composite. Thus, chemical treatment was introduced to enhance the bonding between these two interphases. This treatment has been said able to improve the surface of natural fibre by removing the excess moisture, as a result better interlocking with polymer matrix.

Zhang et al. [32] chemically treated bamboo fibre with 4 wt% sodium hydroxide (NaOH) for 1 hour. Based on results from tensile test conducted, the present concentration has significant effect on the fibre tensile strength. Moreover, it was found that the treatment increases the effective surface area for better bonding with matrix by removal of bonding materials such as hemicellulose and lignin. However, according to Mishra et al. [33], higher concentration of NaOH worsened the properties of bamboo fibre. **Figure 7** shows the scanning electron microscopy (SEM) images between the untreated bamboo and alkali treated bamboo fibre [34].

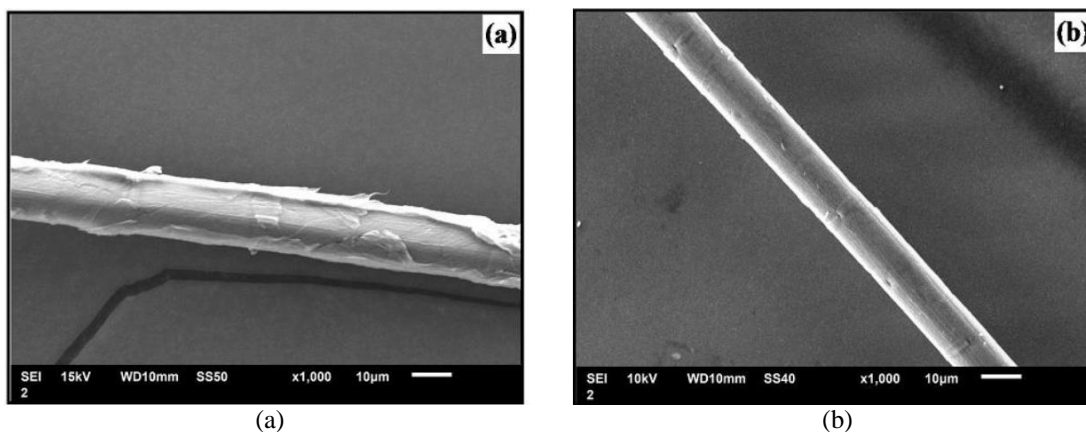


Figure 7. Images of (a) untreated and (b) alkali treated bamboo fibres

6. Conclusion

Owing to the use of bamboo fibers in a wide range of engineering applications, it can provide a chance for economic development in the rural areas. Moreover, mechanical properties of bamboo reinforced polymer especially bamboo/epoxy composite is comparable to synthetic fibre polymer composites. However, many factors that affect the final mechanical properties of bamboo reinforced polymer including fibre length, fibre orientation, and treatment of the fibre have been studied. In order to improve the adhesion between matrix and bamboo fibre, the chemical treatment is introduced. Research that focusing on optimum the chemical concentration, mainly alkali treatment, should be carried out in order to enhance the interfacial properties of the laminate.

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