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Characteristics laminates composite bamboo

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Abstract

The main plants in Indonesian people's plantations are apus bamboo (*Gigantochloa apus*), wulung bamboo (*Gigantochloa atroviolacea*) and tutul bamboo (*Bambusa maculat*). Apart from being used as a craft material, bamboo is also suitable for boards in the form of laminated composites bamboo which are usually called laminated bamboo boards. One of the main criteria for laminated bamboo boards is their good adhesion, which is determined by their shear performance (shear strength). The shear strength of laminated bamboo boards is influenced by several factors such as the type of bamboo used, adhesive/matrix type and laminate configuration. This research used three variations of bamboo species: *Gigantochloa apus* (GA), *Gigantochloa atroviolacea* (GV) and *Bambusa maculat* (BM). The matrix/adhesive used is phenol resorcinol formaldehyde (PRF). The bamboo laminated composite arrangement or horizontal configuration is assembled into a three-layer structure using a hand lay up technique. Testing to determine the performance of bamboo laminated composites, with a shear test, using an Instron universal testing machine (UTM) (serial number CP105207), maximum load cell 100 kN with 8 Kg. The results show that the type of bamboo has an effect on the shear performance of bamboo laminate composites. The BM, GV, GA bamboo, respectively, have better performance, greater shear strength.

Keywords: Laminated composites bamboo; Bamboo; Shear strength; *Gigantochloa apus*; *Gigantochloa atroviolacea*; *Bambusa maculat*

1. Introduction

Researchers are now focusing on natural fibers to strengthen polymer matrix composite materials. By considering good mechanical characteristics, low cost, biodegradability, durability, environmental friendliness, sustainability and corrosion resistance [1, 2]. Bamboo plant is one of the potential plant species as a producer of bamboo fiber which is cultivated in smallholder plantations in Indonesia. Types of bamboo commonly planted include: Bamboo fiber is the main type of reinforcement that can be considered for the synthesis of bamboo laminate composite materials or commonly called bamboo laminate boards.

In the taxonomy, bamboo is included in the grass family (Poaceae, Bambusoideae). Nevertheless, no one would argue that bamboo is one of the most important economic grasses and has a myriad of potential benefits. A total of 1,439 bamboo species throughout the world [3]. Specifically in Indonesia there are around 176 species of bamboo, including 140 native species and 105 endemic species which are only found in Indonesia [4]. Indonesian people have for generations used around 81 species of bamboo for their traditional daily needs, and also for industrial needs [5], especially the species apus bamboo (*Gigantochloa apus*), wulung bamboo (*Gigantochloa atroviolacea*) and spotted bamboo (*Bambusa maculat*).

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One of the impacts of industrialization is a reduction in tree populations, such as teak, mahogany, pine, meranti, and others. So scientists developed laminated bamboo boards as a substitute. Based on the work of [6] laminated bamboo boards are an excellent substitute for wood, with performance comparable to or exceeding wood. Laminated bamboo boards can also overcome the weaknesses of round bamboo such as limited dimensions and size irregularities between segments [7,8]. *Gigantochloa scortechinii* bamboo species has been widely used by researchers to produce laminated bamboo boards [9], plywood [10] and polymer bamboo composites [11,12]. Meanwhile, Gigantochloa levis has also been used to produce glued laminated bamboo [13], plywood [14] and bamboo/epoxy composites [15]. The properties and characteristics of G. levis bamboo are similar to *Gigantochloa apus*, *Gigantochloa atroviolacea*) and *Bambusa maculat*. Considering the many types of bamboo and their extraordinary strength properties, it can be viable commercial candidates in the laminated bamboo board industry.

The characteristics and performance of bamboo laminate composites are influenced by several factors such as layer structure [16], adhesive type, adhesive spreading rate and clamping pressure and time [17]. Adhesives are essential in the formation of high-quality and durable bonds and in achieving proper interfacial bonding and penetration between the fiber and the lamina [18]. Adhesives are generally classified based on their chemical properties, according to Stoeckel et al. [19]. Adhesives are classified into two types based on these criteria: in situ polymerized adhesives and pre-polymerized adhesives. Aminoplastic adhesives, phenol resorcinol formaldehyde (PRF), and polymer methylene diphenyl diisocyanate (pMDI) are examples of in situ polymerized adhesives that contain relatively stiff, highly cross-linked polymers. Meanwhile, polyurethane (PUR) and polyvinyl acetate (PVAc) are examples of pre-polymerized adhesives with flexible polymers. The ability of the two groups to distribute moisture-induced stresses in the adhesive bond varies widely, resulting in different failure mechanisms. However, the chemical properties of adhesives are not the only factor that needs to be considered when categorizing adhesives, the mechanical response of adhesives also needs to be given primary attention [20]. The type of adhesive has a significant effect on the shear bond strength between bamboo fibers [21] . The penetration of adhesive into the bamboo cell walls changes the bonding mechanism and has a significant impact on the mechanical properties of laminated bamboo materials of various bamboo types and densities. The work [22] studied the bonding performance of cross-laminated bamboo composites and concluded that the type of adhesive was the most important factor influencing its performance.

Compared to other mechanical properties, such as compressive, tensile and bending resistance, the bond shear strength of laminated materials, especially bamboo, has not been fully considered [18]. This research focuses on determining the effect of bamboo type on the shear strength of laminated bamboo composites. The bamboo used is three local bamboo species *Gigantochloa apus*, *Gigantochloa atroviolacea*) and *Bambusa maculat*. Phenol-resorcinol-formaldehyde (PRF) is used as an adhesive in the manufacture of laminated bamboo composites. The three-layer laminated bamboo structure uses a parallel configuration, made by hand lay-up. Shear strength, bamboo failure and delamination were evaluated as a function of the above-mentioned parameters.

2. Material and methods

2.1. Materials

The specifications for the bamboo used as bamboo laminate composite are: *Gigantochloa apus*, which is locally called Apus bamboo, *Gigantochloa atroviolacea*, the local name for Wulung bamboo and *Bambusa maculat*, which is locally called Tutul bamboo. Bamboo plants with an average age of three years from the bamboo plantation of Gangga Village, Gangga District, North Lombok Regency, West Nusa Tenggara Province, Indonesia. Bamboo has an average density of 725 kg/m^3 to 730 kg/m^3. The modulus of rupture and modulus of elasticity of the former are 120 N/mm^2 and 11.239 N/mm^2. The three types of bamboo are medium sized with an average stem diameter of 6–8 cm and wall thickness of 10–11 mm, with an estimated height and length of 15–20 m each and the length of this bamboo segment measuring 40 cm, as shown in Figure 1. The equipment used are a shear test, Instron universal testing machine (UTM) (serial number CP105207), maximum load cell 100 kN with 8 Kg., vacum pump, composite mold made of silicon, with a standard thickness of 6 mm and composite fabrication equipment.

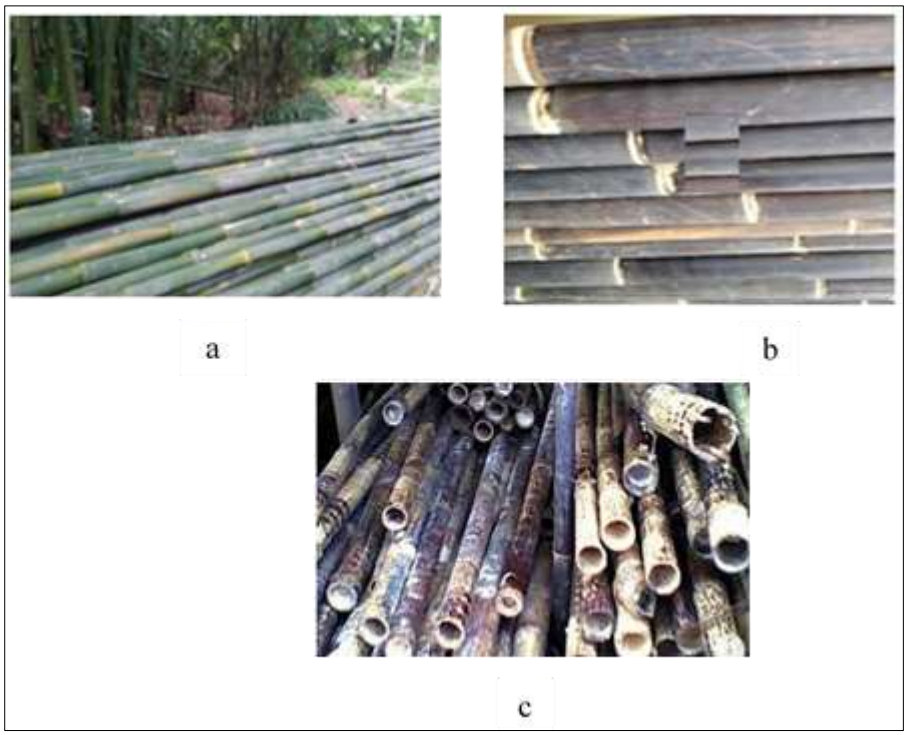

Figure 1 a. *Gigantochloa apus* (GA), b. *Gigantochloa atroviolacea* (GV), c. *Bambusa maculat* (BM)

2.2. Methods

Composite The classification of bamboo strips used in bamboo laminate composite fabrication is in two categories, namely: (i) straight and square strips for edge binding, (ii) few curved and square strips for gluing faces. Form an arrangement pattern as shown in Figure 2. Three lanes the arrangement, namely horizontal, is used as a pattern for making bamboo laminate composites. All pattern settings are laid in parallel oriented to straight and square curved lines and square lines for face gluing. Bamboo strip configuration with a lay-up pattern and the arrangement of the strips is horizontal, up to the adjacent layers.

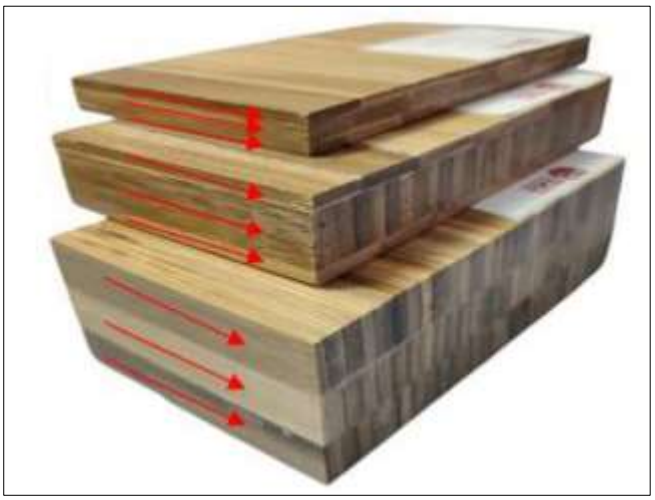

Figure 2 Paralel lay up of bamboo strip

The bamboo laminate composite specimens were then subjected to a shear test according to standards ASTM D5379/D5379M-12. The jig used for shear testing is shown in Figure 3. Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method.

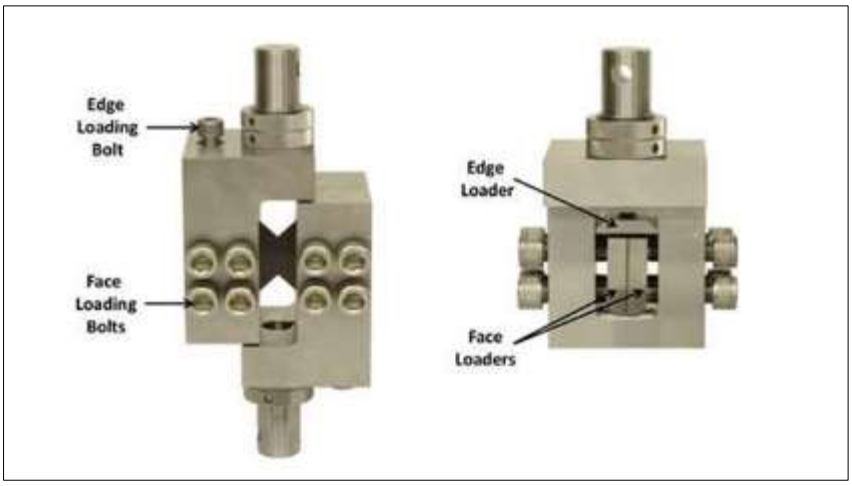

Figure 3 Jig of shear test laminate composite bamboo

3. Results and discussion

3.1. The shear strength of laminate compocite bamboo

Shear strength tests were carried out to determine the effect of variations in bamboo species on the shear strength of bamboo laminate composites. From the results of the shear strength test, the shear strength is obtained as shown in Figure 4.

The bamboo laminate composite specimens were then subjected to a shear test according to standards ASTM D5379/D5379M-12. The jig used for shear testing is shown in Figure 3. Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method. Based on the research results, the shear strength of laminated composite bamboo specimens using a variety of bamboo species *Gigantochloa apus* (GA), *Gigantochloa atroviolacea* (GV), *Bambusa maculat* (BM) is as shown in Figure 4. The position of bamboo segments also affects shear strength. The bamboo segment in the middle position has the highest shear strength, then the base and edge of the bamboo have the lowest shear strength. Bamboo species GA have the highest shear strength. In accordance with the results of the study [3].

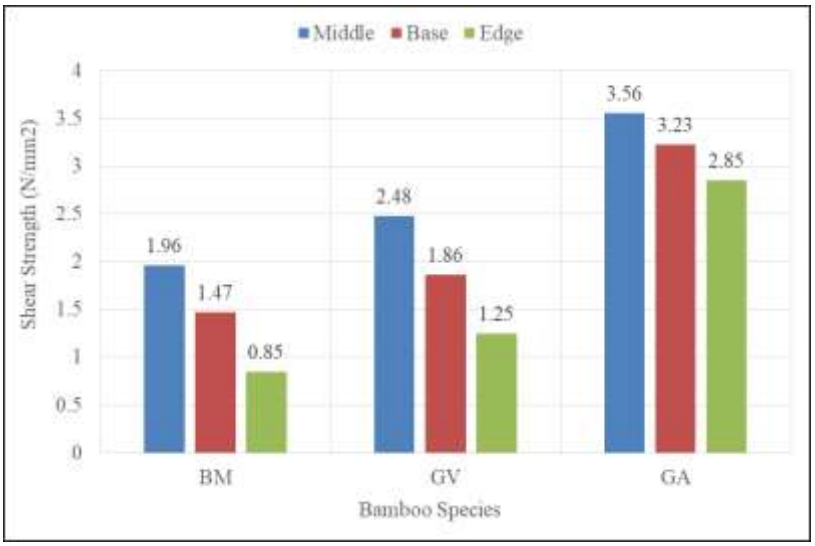

Figure 4 The shear strength of laminate composite bamboo

The use of bamboo GA also causes the highest increase in shear strength, about 3.56 N/mm^2, 2.48 N/mm^2 for bamboo GV and the lowest shear strength of 1.96 2.48 N/mm^2 for bamboo BM composite laminate.

3.2. The delamination of laminate composite bamboo

Delamination is one of the critical damage models that occurs in laminate composites. Delamination occurs due to several factors such as high interlaminar stress and stress concentration at the location of cracks or other damage to the laminate. Delamination occurs in *Gigantochloa atroviolacea* (GV) and *Bambusa maculat* (BM) type bamboo laminate composites. In the *Gigantochloa apus* (GA) type bamboo laminate composite, no delamination occurs. In the shear test of the GA bamboo laminate composite, there were no interlamina stresses and stress concentrations, in accordance with the results of the study (8)

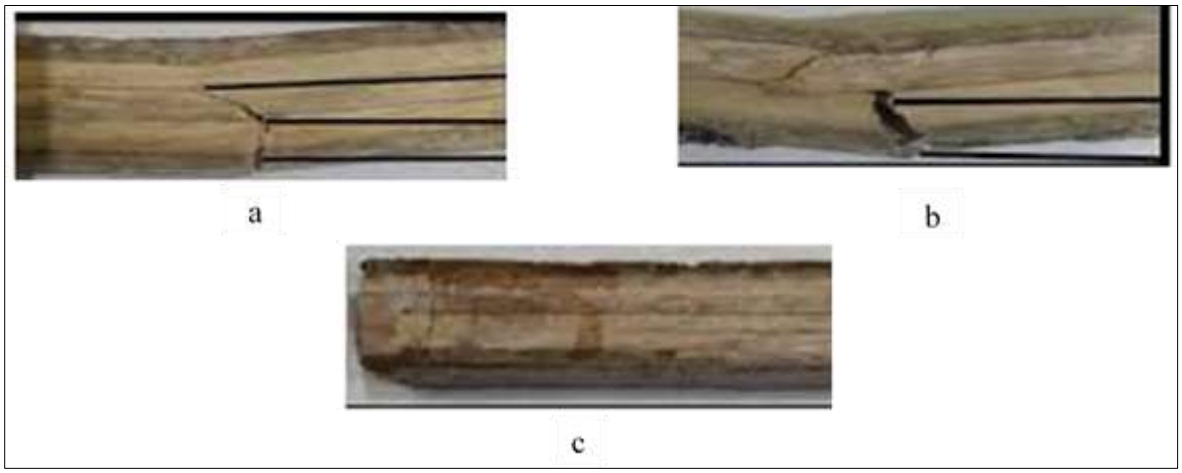

Figure 5 Delamination laminate composite, a. *Bambusa maculat* (BM), b. *Gigantochloa atroviolacea* (GV), c. *Gigantochloa apus* (GA)

The physical properties of GV and BM are hard, higher stiffness than GA, so the cohesion between molecules is low so they easily experience delamination. The surface of GV and BM is also smoother, the pores are denser, causing low PRF adhesive penetration so that the bond between PUF and bamboo laminate is easily separated, based on the study [7].

4. Conclusion

The type of bamboo species and the position of the bamboo segments influence the shear strength of the bamboo laminate composite. The bamboo species bamboo *Gigantochloa apus* (GA) and the position of the middle segment has the highest shear strength, about 3.56 N/mm^2. The species bamboo *Bambusa maculat* (BM) and the position of the edge bamboo segments have the lowest shear strength, about 0.85 N/mm^2. The phenol resorcinol formaldehyde (PRF) adhesive is suitable for laminated bamboo composites, with a horizontal configuration, little delamination occurs.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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