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Prof. Dmitriy Demin
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Editor-in-Chief
Eastern-European Journal of Enterprise Technologies

Dear Prof. Dmitriy Demin
Enclosed, please find the manuscript entitled: "*Mechanical Properties Characterization of Laminated Bamboo Apus (Gigantochloa Apus) Composite With Epoxy-Resin Matrix*," submitted for publication in Eastern-European Journal of Enterprise Technologies. The authors are: Parlindungan Manik, Agus Suprihanto, Sri Nugroho, Sulardjaka.
The essential findings are as follows.

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2. he effect of the number, thickness and direction of gigantochloa apus laminae and pressure compaction on tensile and bending strength of Laminated Bamboo Composites.
3. Photo macro analysis of the surface fracture of composites.

The manuscript is an original work, has not been previously published in whole or in part, and is not being considered for publication elsewhere. All authors have read the final manuscript, have approved the submission to the journal, and have accepted full responsibilities pertaining to the manuscript's delivery and contents. There is no conflict of interests regarding the paper submitted.

Kind regards,

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October 07, 2021
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Manuskrip artikel yang disubmit

MECHANICAL PROPERTIES CHARACTERIZATION OF LAMINATED BAMBOO APUS (GIGANTOCHLOA APUS) COMPOSITE WITH EPOXY-RESIN MATRIX

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ABSTRACT

This study aims to investigate the mechanical properties of bamboo apus (gigantochloa apus) as a natural reinforced composite material. Bamboo's laminae of gigantochloa apus was used as reinforcement on the epoxy resin matrix. The parameters examined in this study were the variation in the number, thickness and direction of the laminae. The stem of bamboo with a length of 400 mm was split to obtain bamboo laminae with a size of 400 mm x 20 mm. The thickness of bamboo laminae is varied between 1 mm, 1.5 mm, and 2 mm. The bamboo laminae is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution and dried in an oven until the water content reaches 10%. The Laminated Bamboo Composites (LBCs) were made with a hand lay-up method. After the LBCs are moulded, the mould were pressed with 3 variations of dies compaction 1.5 MPa, 2 MPa and 2.5 MPa. The tensile and bending test characteristics were carried out on the LBCs. Tensile testing is performed in accordance with ASTM standard D3039 and the bending tests were conducted based on ASTM standard D7264. The results shows at each compacting pressure, the highest tensile and bending strength was achieved by LBCs with a thickness of 1 mm of bamboo laminae and 7 layers of bamboo laminae. The LBCs with thinner bamboo laminae reinforcement and more layers has the highest tensile strength and bending strength, even it has lower mass fraction. The LBCs with laminae oriented 0^o exhibited greater tensile and bending strengths than the LBCs with laminae structured $-45^o/+45^o$ and $0^o/90^o$. The LBCs with 0^o laminae direction is matrix fracture than followed by laminae fracture. In the $0^o/90^o$ direction, matrix fracture followed by delamination in the 90^o lamine and the 0^o direction laminae. Delamination and laminae clefting were observed in LBCs with laminae oriented $+45^o/-45^o$.

Keyword: Laminae Bamboo Composites, Gigantochloa Apus, Tensile Strength, Bending strength.

1. Introduction

Bamboo is a group in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. There are more than 1,450 bamboo species are found in cold mountains to hot tropical regions. . Bamboo can be harvested in 3–4 years after planting, compared to the traditional timbers that need decades between planting and harvesting [1,2]. Bamboo has specific mechanical properties that are superior to other types of natural fibers due to the longitudinal arrangement of the fibers. The small microfibrillar angles of the bamboo fibers support high volume stability and excellent mechanical properties [3-5]. The advantages of the mechanical properties of bamboo and the availability of abundant materials have attracted many researchers to use bamboo as reinforcement in composite materials. The use of bamboo fibers as a reinforcing material provide many benefits. Natural fibers that are low in density can be employed as a useful lightweight engineering material compared to synthetic fibers like glass fibers or carbon fibers [6]. Unfortunately, as for the area of bamboo composites characterizations in thermoset setting, only a handful of studies have looked into laminate-based bamboo composites. The use of bamboo as a composite material provides solutions in the development of the materials industry. The tensile strength of bamboo is about twice as high as the tensile strength of lumber, with the compressive strength is approximately 1.5 times stronger than lumber. The strength to weight ratio of bamboo is higher than lumber and plain steel [7]. Bamboo fiber has the potential to replace glass fibers as reinforcing composites. The bamboo fiber has a specific young modulus (Specific E) comparable with the E-glass fiber. It means that the bamboo fiber has a high stiffness with minimum weights [8,9]. A rather recent study concerning bamboo strips had successfully characterized several imminent properties, for example, tensile, flexural, impact, and hardness of bamboo composite in a comprehensive manner [10].

Indonesia is a tropical country with various species of bamboo plants, including petung bamboo (*dendrocalamus asper*), wulung bamboo (*gigantochloa atroviolacea*), yellow bamboo (*bambusa vulgaris*), spotted bamboo (*bambusa maculata*), apus bamboo (*gigantochloa apus*) and others. Bamboo is widely used for flooring, roof construction, crafts/furniture, and fabrics. Apus bamboo (*gigantochloa apus*) is a type of bamboo that has the advantage of being easy to divide and cut up to the thickness of 1 mm. At this time, apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, ceiling/home asbestos and woven crafts. The abundant availability of apus bamboo and its good mechanical properties can be used to replace wood in various structural applications. The limitation of bamboo for engineering applications is due to its shape. Bamboo engineering with lamination technique is a method to increase the application of bamboo as a building structure. The purpose of this article is to develop a composite epoxy resin reinforced with laminat of bamboo apus (*gigantochloa apus*).

2. Literature review and problem statement

The use of bamboo as reinforcement in composite materials has been investigated with *gigantochloa scortechini* woven bamboo fibers. Bamboo matting is made from sheets of bamboo layers measuring: 0.5 mm thickness and 5.0 mm width. Composites with epoxy resin matrix were made with a hand lay-up method, in the number of 2-6 layers. The results of the mechanical properties test (tensile test, bending test, hardness test, and impact test) showed that the composite with two layers of woven reinforcement had high mechanical properties [11].

Lokesh et.al. have investigated the mechanical behavior of short untreated and treated with NaOH bamboo fiber reinforced epoxy resin composites. Bamboo fibers with various lengths and contents are reinforced with epoxy resin to produce a composite. The results showed that the mechanical properties of the tensile strength, flexural strength, and impact strength of composites were influenced by the NaOH treatment. The tensile strength of composite with three layers of treated fiber is 18.07 Mpa and 16.51 MPa for three layers of untreated fiber [12]. Soaking apus bamboo (*gigantochloa apus*) laminae in methanol solution increases the strength of laminated bamboo composites [13].

The laminated composites (LBCs) using four laminas of dendrocalamus strictus cold-pressed using epoxy resin result in maximum stress of LBCs of about 210 MPa. The specimens used had a cross-section of 16 mm x 10 mm. This study reported that compressive strengths of LBCs ranging between 55 MPa and 88 MPa. The fracture mode of LBCs found that the matrix failure occurs followed by fibers failure with metallic sound of anyone layer and subsequently other layers in specimens. There are good agreements between the theoretical values and experiment results for stiffness and strength [14]. Li et al. reported significant differences in strength and behavior between small specimens sourced from different growth portions with the full-size structural members (cross-section 100 mm x 100 mm) constructed from laminated bamboo sourced from different growth portions of the culm. This study found that the bamboo laminate sourced from the middle growth section has the largest elastic modulus [15].

Laminated Bamboo Composites (LBCs) of *dendrocalamus strictus* bamboo culms were manufactured from laminas and laminates using an epoxy resin matrix. The mechanical properties of LBCs have been evaluated with different loading conditions. The results show that the mechanical properties of LBCs are better than teak wood, which is one of the strongest woods [16].

The present study investigates polymer reinforced bamboo laminate developed by using a hand lay-up method with reinforcements with varying lamina sizes. The type of bamboo studied was rope bamboo or apus bamboo (*Gigantochloa apus*). Apus bamboo was chosen because it has flexible properties and is easy to make into thin sheets. The research was conducted by varying the tickness, number of laminae and compacting mold pressure.

3. The Aim and Objectives of The Study

The aim of the study is the investigation mechanical properties of *gigantochloa apus* laminae reinforced epoxy resin. The following objectives have been formulated:

- to investigate the effect of the number of bamboo laminae on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);
- to investigate the effect of direction of bamboo laminae on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);
- to investigate the effect of pressure compaction on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);
- to investigate fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs);

4. Materials and Methods

Material

Bamboo’s laminae of *gigantochloa apus* was used as primary reinforcement material. The bamboo used is three years old with an average diameter of 150 mm of bamboo. The selected part of the bamboo stem, 1 m to the base to 4 m, was used to make the laminae. The tensile strength of the bamboo laminae is 230 MPa. The matrix material used for the bamboo laminaetion process is epoxy-resin with a tensile strength of 57 MPa.

Methods

The process of making bamboo lamina begins with cutting the bamboo stalks to obtain a stem length of 40 cm. The bamboo stalks are then split into blades, making the bamboo slats by removing the outer shell. Then the splitting process is carried out to obtain a bamboo blade with a size of 40 cm × 20 mm. The formation of bamboo lamina blades is carried out using the four-side planning tool. This process is carried out to obtain the thickness of 1 mm, 1.5 mm, and 2 mm. Fig. 1 shows the bamboo lamina-making process.

The bamboo laminae is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution. After preservation, the bamboo laminae are dried. The bamboo lamina is dried in an oven until the water content reaches 10%. A moisturemeter measured the percentage of water content in the bamboo laminae. Drying takes approximately 2–4 weeks in an oven, depending on the weather. Dry bamboo slats are grouped according to their thickness and then sanded to smooth the surface using a sandpaper machine. The photo of bamboo laminae are depicted in Fig. 2.

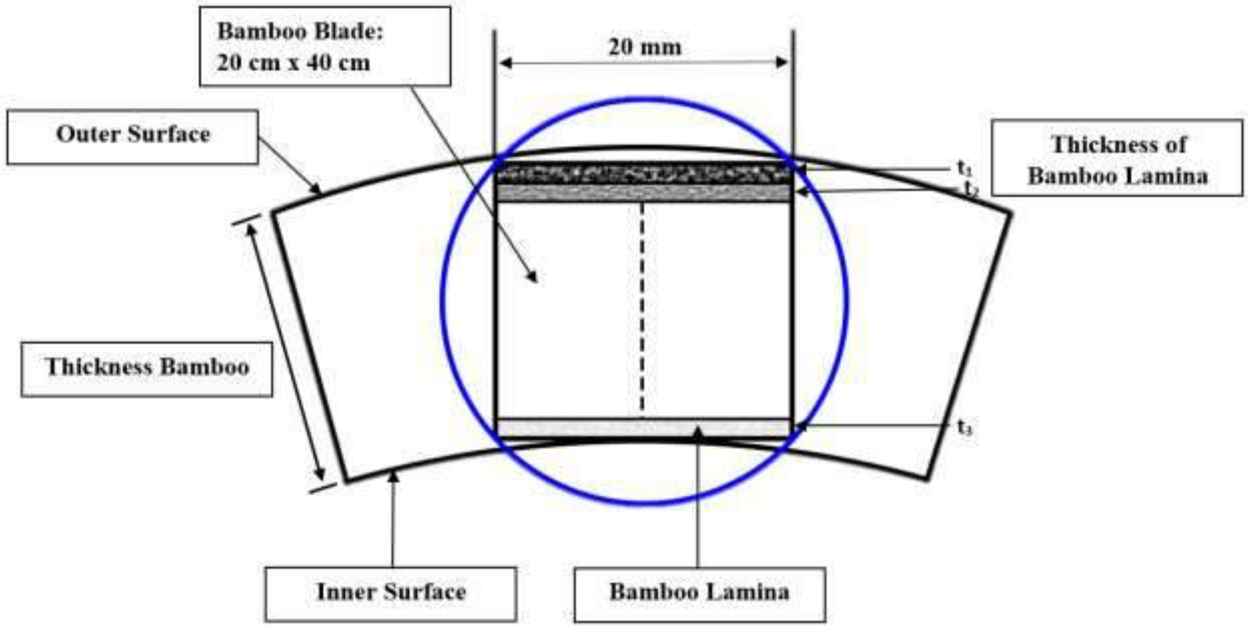

Fig. 1. Formation of the bamboo apus laminae (*gigantochloa apus*)


Fig. 2. Bamboo Laminae

The dried bamboo laminaes are then used as reinforcing composites to make Laminaeted Bamboo Composites (LBCs). An epoxy resin polymer is used as a matrix/adhesive material. LBCs were made using hand lay-up method followed by compression. LBCs are made with varying pressures: 1.5 MPa; 2.0 MPa; 2.5 MPa and variations in the number of laminae: 3, 5 and 7. Compacting is done using a press machine. The LBCs were pressed for 24 hours. Table 1 shows the resulting composites with variations in compacting pressure and the number of laminae forming LBCs. Composites are also made with a variety of fiber directions: 0, -45/+ 45 and 0/90. This process produces a composite with a size of 400 mm x 250 mm with various thicknesses as shown in Fig. 3a; 3b, 3c.

Table 1. The weight fraction of bamboo fibers and the epoxy resin matrix of the composites

No	Pressure compaction (MPa)	Laminae (layer)	Thickness laminae (mm)	Thickness LBCs (mm)	Bamboo Mass fraction (Kg/cm^3)	Epoxy-resin Mass faction (Kg/cm^3)
1		3	2.0	7.0	0.70	0.30
2	1.5 MPa	5	1.5	7.0	0.65	0.35
3		7	1.0	7.0	0.60	0.40
4		3	2.0	6.5	0.75	0.25
5	2.0 MPa	5	1.5	6.5	0.70	0.30
6		7	1.0	6.5	0.65	0.35
7		3	2.0	6.0	0.80	0.20
8	2.5 MPa	5	1.5	6.0	0.75	0.25
9		7	1.0	6.0	0.70	0.30

The tensile test refers to the ASTM standard D3039 with a specimen size of 250 mm x 25 mm x t mm. The bending test was carried out using the ASTM standard D7264 with a 130 mm × 13 mm × t mm specimen size. The test specimens were prepared using water jet cutting. Tensile and bending testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1000 KN. Each variation was repeated for five specimens. Fig. 4a and 4b present images of tensile and bending test specimens.

a. 0^o b. -45^o/+45^o c. 0^o/90^o

Fig. 3. Laminaete Bamboo Composites with the variation of laminae direction

a. Tensile test specimens b. Bending test specimens

Fig. 4. Tensile and bending test specimens

5. Results and Discussion

Fig. 5, 6, and 7 show the results of the tensile test of LBCs for variations in the number of laminae: 3, 5, and 7 and the compression pressure of 1.5 MPa, 2 MPa, and 2.5 MPa. The figure also shows the tensile strength of LBCs at various lamina directions: 0°, −45°/+45°, 0°/90°. Thus, as the number of layers in the LBCs increases from 3 to 7 the tensile strength also increases. At all pressure variations, LBCs with a 0º lamina direction has a higher tensile strength than LBCs with a −45°/+45°, 0°/90° direction. At a compacting pressure of 1.5 MPa, the tensile strength of the LBCs is 138 MPa (Figure 5). LBCs with a pressure of 2 MPa produce the highest tensile strength of 185 MPa (Figure 6). The graph in Figure 7 shows that at a pressure of 2.5 MPa the highest tensile strength of LBCs is around 180 MPa. At each compacting pressure value, the highest tensile strength was achieved by LBCs, with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo lamina. Figure 8 shows a graph of the relationship between the LBCs' tensile strength and mass fraction. The graph in Figure 8 shows that the highest tensile strength is in the composite with thinner bamboo reinforcement and more layers, even at a lower mass fraction. This is in accordance with the results of Venkatehwaran's research that the tensile strength of laminated composites is dependent on the interfacial properties of natural fibers and polymer composites. Additionally, the tensile properties are contingent upon the laminae directions [17].

Apus bamboo (gigantochloa apus) with a lamina's tensile strength of 230 MPa and an epoxynresin with a tensile strength of 57 MPa after being formed into a composite LBCs was able to produce the highest tensile strength of 185 MPa with a ratio of 70% lamina bamboo lamina mass fraction and 70% mass fraction. (wt) epoxy-resin 30%. Previous research reported using gigantochloa scortechinii (semantan reed) bamboo, woven bamboo (Woven Bamboo) with a ratio of 33% of the mass fraction (wt) of bamboo lamina and the mass fraction (wt) of 77% epoxy matrix was only able to produce a maximum tensile strength of 89 MPa [11].

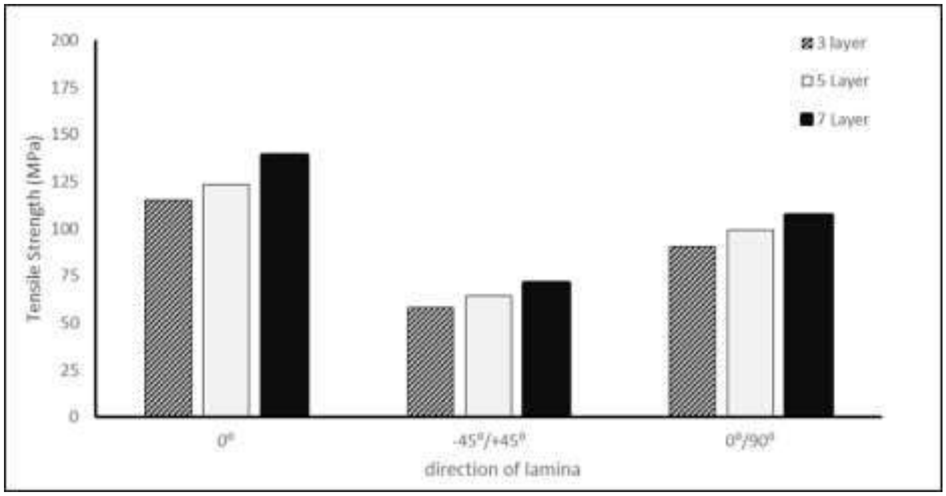

Fig. 5. Tensile strength of LBCs with 1.5 MPa pressure

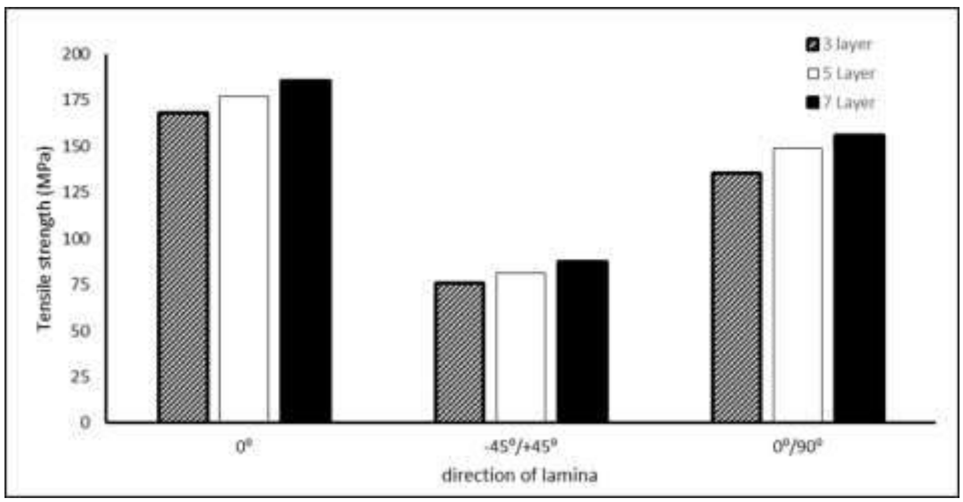

Fig. 6. Tensile strength of LBCs with 2 MPa pressure

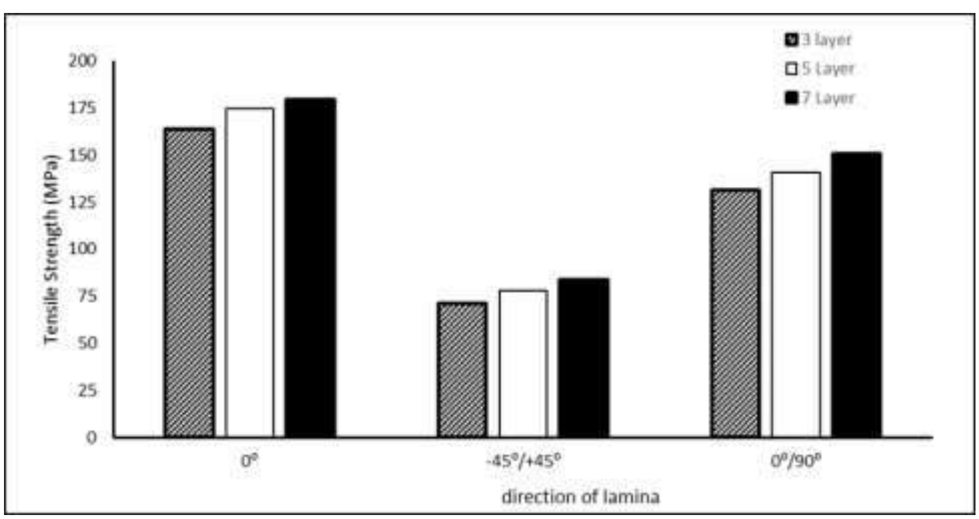

Fig. 7. Tensile strength of LBCs with 2.5 Mpa pressure

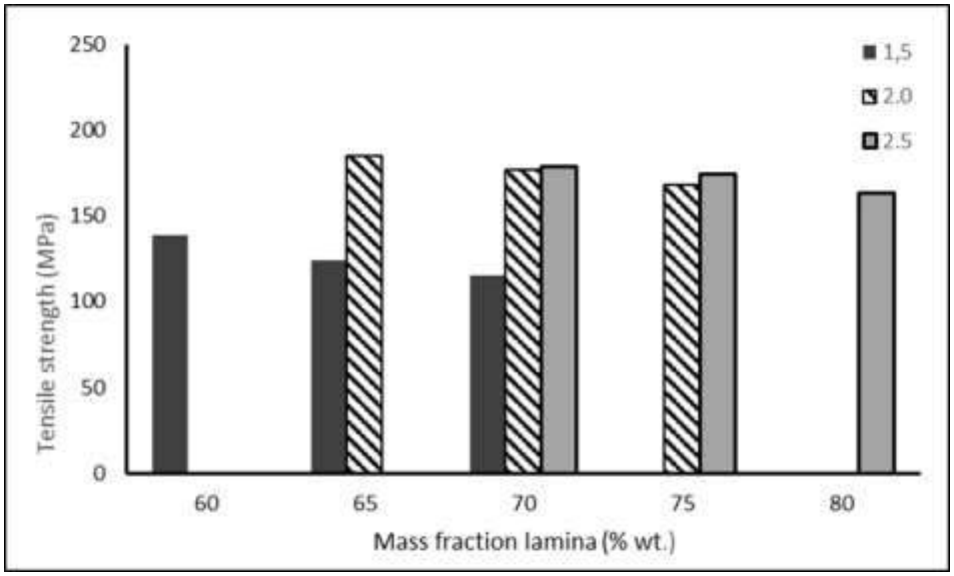

Fig. 8. The effect of mass fraction bamboo laminae and tensile strength of LBCs in composites with direction of 0°

Increasing the tensile strength properties of LBCs in the thinner bamboo lamina reinforcement with a higher number of composites forming layers is an important concern in this study. This could result from the ability of the epoxy resin to enter the thinner pores of the apus bamboo fiber, thereby increasing the interface strength of the composite-forming bamboo layer. The increased tensile strength produced by LBCs has a composition of 70% lamina and 30% epoxy-resin. The results are different from other researchers. Rassiah et al. examined laminated bamboo composites with different bamboo and matrices (*gigantochloa scortechinii* and unsaturated polyester). They reported that the thicker the bamboo blades, the higher the tensile stress and flexural stress [19]. Verma et al. reported that increasing the number of laminae forming the Layered Laminate Bamboo Composites (LLBCs) will increase tensile and flexural stress [7]. They also mentioned that the direction configuration of the composite laminae also affects the tensile stress and flexural stress of LLBCs. The configuration of the laminae with direction 0° gave the best result of tensile strength compared to the configuration of the direction of the fiber crossed 0°/45° and 0°/90°. Thus, the tensile strength of the LBCs decreases with increasing the angle of the laminae under the tensile stress. According to the Tsai–Hill criterion, the tensile and compressive properties of the composite will continue to decrease due to changes in the fiber orientation angle that increases from 0° [19]. This study's results prove that the direction of the lamina 0° provides the best tensile strength compared to the direction of the lamina −45°/+45°, 0°/90°.

The graph in Fig. 9 also shows the effect of compacting pressure on the tensile strength of LBCs at the mass fraction of 70%. This analysis selected a mass fraction of 70% wt because a mass fraction of 70% wt was generated for all variations studied (Figure 8). Fig. 9 shows that increasing the compression from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55% in the 0° lamina direction, 40% in the −45°/+45° lamina direction, and 64% in the 0º/90º laminae direction. Increasing the compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. The difference in tensile strength is smaller than the standard deviation of the test. Therefore, the increase in pressure from 2 MPa to 2.5 MPa does not affect the tensile strength of LBCs.

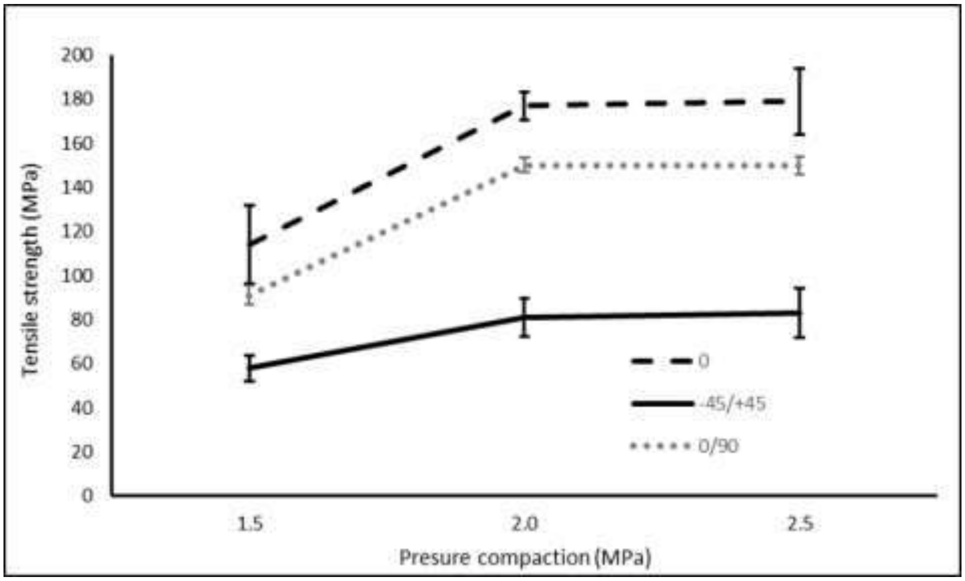

Fig. 9. The effect of Compaction Pressure on Tensile Strength of LBCs at 70% Mass Fraction

The compacting pressure applied to the manufacture of LBCs affects the mass fraction (wt) of the epoxy resin matrix contained in the LBCs. The compacting pressure will force the epoxy resin out of the LBCs mold while the mass fraction of the bamboo laminae remains. Higher compression pressure will reduce the % wt epoxy-resin. It is evident from the compression (Fig. 9) from 1.5 MPa to 2.0 MPa can reduce the weight fraction of epoxy resin in LBCs by 5% of the initial mass fraction, but can increase the tensile strength of LBCs by 55% at laminae direction 0°, 40% in the direction of laminae −45°/+45° and 64% in the direction of laminae 0°/90°. Another researcher reported that LBCs without compacting pressure could produce a maximum tensile strength of 89 MPa [9]. The optimum tensile stress of Laminated Bamboo Composites (LBCs) was obtained at a 2 MPa compaction pressure variation with a mass fraction (wt) of lamina of 70% and a mass fraction (wt) of epoxy-resin of 30%. The application of compacting pressure above 2 MPa on LBCs didn’t affect on the value of tensile stress. The anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs each by 5% for each variation of the tested specimens.

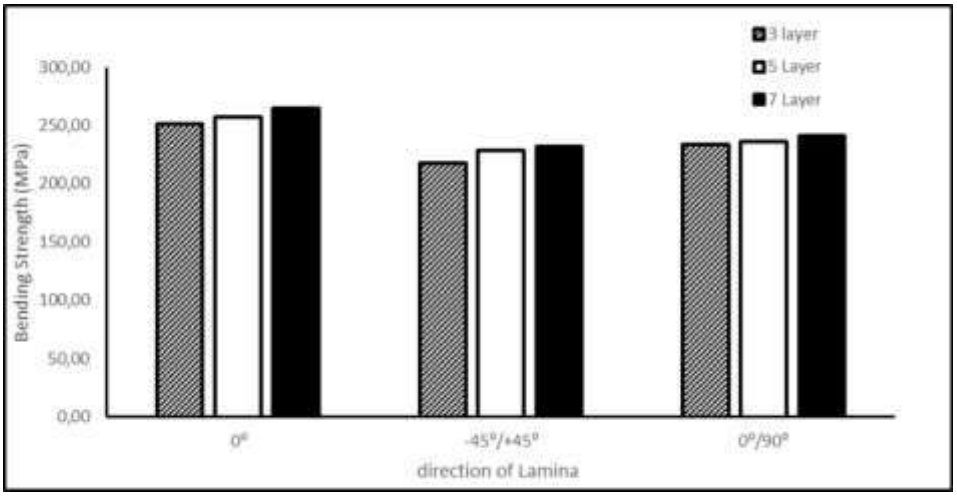

Fig. 10. Bending strength of LBCs with 1.5 MPa stress

Fig. 10, 11 and 12 show the bending strength of LBCs with variations (orientation) of the fibers with the direction of 0°, -45° / + 45°, 0° / 90° and variations in the number of laminae bamboo apus layers of 3, 5, and 7 layers with pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa. The bending stress of laminaeted bamboo composites is also influenced by the direction (orientation) of the bamboo laminaete and the number of layers. At each variation in the direction of the bamboo laminae and stress, the bending strength of the LBCs increased with the increasing number of layers of bamboo laminae. In the number of layers, the bending strength of LBCs with the laminae direction of 0° has the largest bending strength, followed by the crossed fiber direction of 90° and the lowest bending strength is the LBCs with the -45° / + 45° fiber direction. The highest bending strength of 321 MPa was produced in LBCs with 7 layers of bamboo laminae, 0° fiber direction and 2 MPa stress. Fig. 13 shows a graph of the relationship between the bending strength of LBCs and the mass fraction of LBCs. From the graph in Fig. 13, it can be concluded that the highest bending strength is in the composite with thinner bamboo reinforcement and a higher number of layers even at a lower mass fraction.

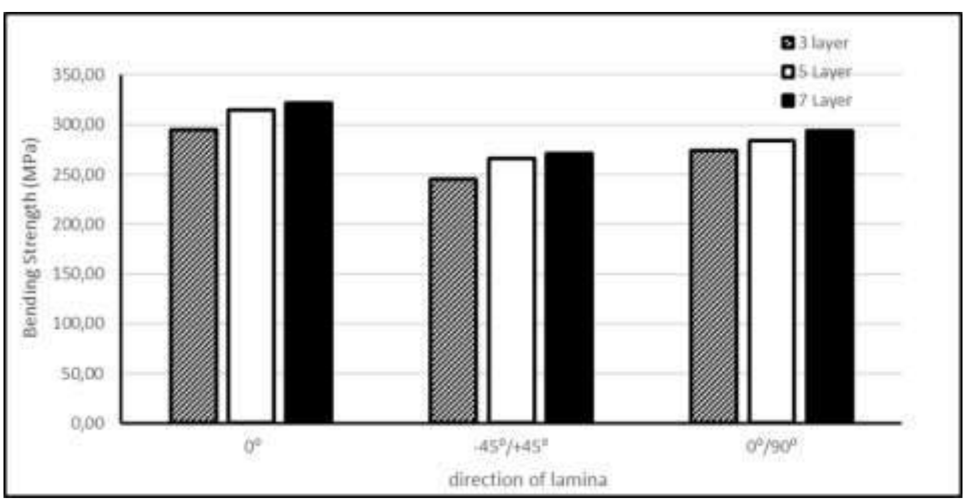

Fig. 11. Bending strength of LBCs with 2 MPa stress

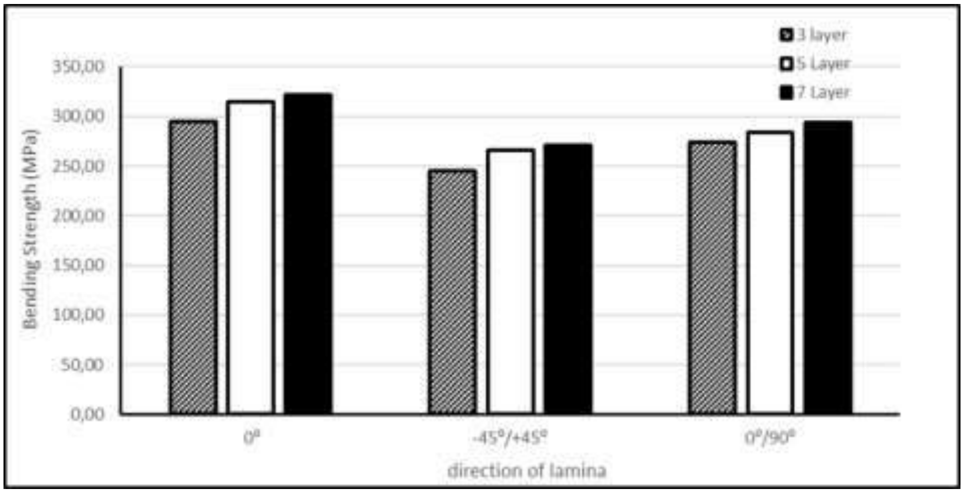

Fig. 12. The bending strength of LBCs with 2.5 MPa stress

Apus bamboo (*gigantochloa apus*) with a bending strength of 348 MPa laminae and an epoxy-resin with a tensile strength of 175 Mpa, after being formed into a composite LBCs, was able to produce the highest bending strength of 321 MPa with a ratio of mass fraction (wt) of 70% and mass fraction (%. wt) epoxy-resin 30%. *Gigantochloa scortechinii* (semantan reed) woven bamboo with a ratio of 33% of the mass fraction (wt) of bamboo laminae and the mass fraction (wt) of 67% epoxy matrix was only able to produce a maximum bending strength of 120 MPa [11]. The bamboo allowed large flexural deformations because its outer part retains the tensile stress while the softer inner part undergoes large compressive deformation [20]. The configuration of the 0^o direction of the laminae gave the best bending strength compared to the configuration of 0^o / 45^o and 0^o / 90^o crossed laminae [19].

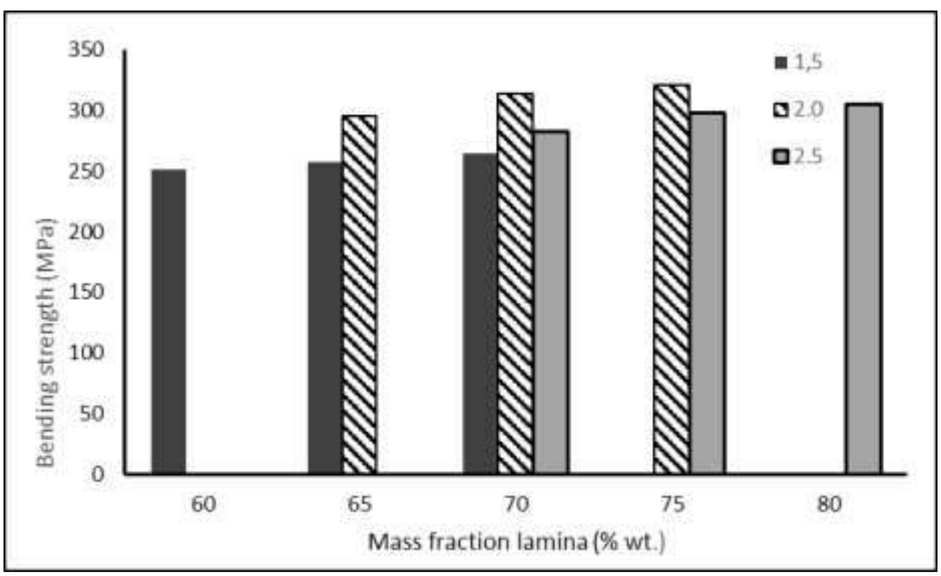

Fig. 13. The effect of mass fraction of laminae and bending strength of LBCs in composites with 0^o direction

The graph in Fig. 14 also shows the effect of compacting pressure on the bending strength of LBCs at the mass fraction of 70%. Like the tensile test results, the increase in compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the bending strength of LBCs.

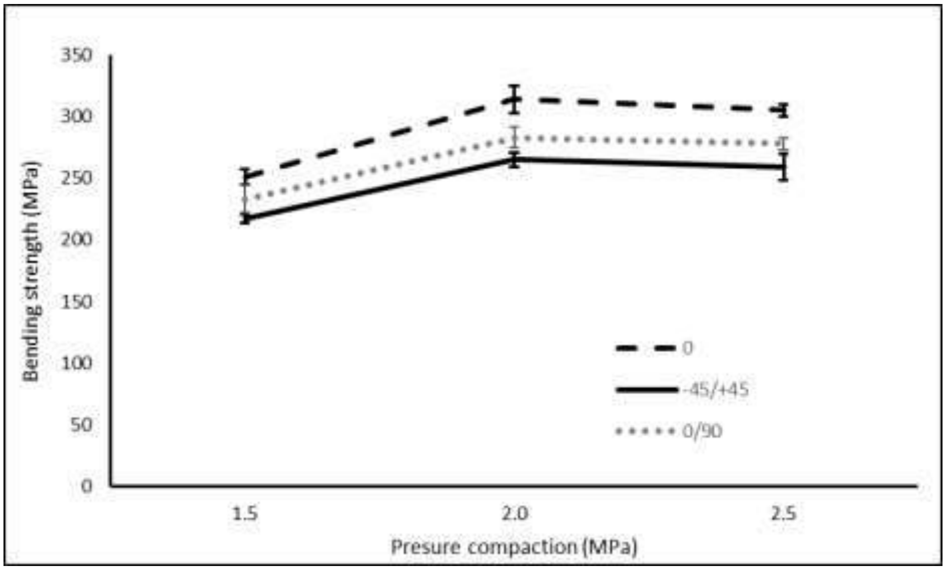

Fig.14. The effect of Compaction Pressure on the Bending Strength of LBCs at 70% Mass Fraction

a. Laminaeted Bamboo Composites (LBCs) 7 layer with the laminae's direction of 0º

b. Laminaeted Bamboo Composites (LBCs) 7 layer with the laminae's direction of intersection -45º/45º

c. Laminaeted Bamboo Composites (LBCs) 7 layer with the laminae's direction of intersection $0^o/90^o$

Fig.15. Photomacrography The Fracture of Cross Section of The Tensile Test of 7 Layers Laminaeted Bamboo Composites (LBCs)

Fig. 15. shows photo macro of surface fracture of LBCs. LBCs with laminae direction 0^o, the fracture mode that occurs is laminae (Fig. 15.a). The fracture surface of the LBCs with the laminae direction $-45^o/+45^o$ (Fig. 15.b) and The fracture surface of the LBCs with the laminae direction $-0^o/90^o$ (Fig. 15.c). LBCs 0^o direction of laminae, the first phenomenon of tensile test is matrix fracture, followed by load transfer to bamboo laminae and subsequent bamboo laminae fracture. Fracture of matrix in the $0^o/90^o$ direction of laminae, followed by delamination of laminae in the 90^o direction, and finally fracture of laminae in the 0^o direction. In LBCs with laminae oriented $+45^o/-45^o$, matrix fracture was followed by delamination and laminae clefting. Similar fracture modes were found in bending test results (Fig. 16).

a. LBCs 7 layers direction of 0^o

b. LBCs 7 layers direction of intersection $-45^o/45^o$

c. LBCs 7 layers direction of interserction $0^o/90^o$

Fig. 16. Bending Test Result Specimens of Laminaeted Bamboo Composites (LBCs) from 7 layers

6. Conclusions

The LBCs with 7 laminae with a thickness of 1 mm per laminae provides the higher tensile and bending strength than LBCs with 5 laminae with a thickness of 1.5 mm per laminae and 3 laminae with a thickness of 2 mm per laminae. The effect of laminae quantity on LBC reinforcement is bigger than the mass fraction of laminae.

The tensile stress and bending stress of the Laminaeted Bamboo Composites (LBCs) are influenced by the direction of the laminae of the LBCs. In comparison to LBCs with 0^o/ 90^o laminae or -45^o/$+45^o$ cross direction, the LBCs with 0^o laminae exhibited the higher tensile and bending strength.

The compacting pressure applied to the manufacturing process of Laminaeted Bamboo Composites (LBCs) affects the mass fraction (% wt) of the epoxy resin matrix contained in the LBCs, the greater the compacting pressure, will result in a decrease in % wt of the epoxy resin. The optimum tensile and bending stresses of Laminaeted Bamboo Composites (LBCs) were obtained at 2 MPa compaction pressure variations with 70% laminae mass fraction (wt) and 30% Epoxy-resin mass fraction (wt). The application of compacting pressure above 2 MPa on LBCs results in a decrease in the value of tensile and bending stresses, it is assumed that the anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs, 5% for each variation of the tested specimen.

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Re: from "Eastern-European Journal of Enterprise Technologies" - Sulardjaka (stage 2, December)

Artikel diterima dan diserahkan ke revewer

Oksana Nikitina <0661966nauka@gmail.com>
Fri 22/10/2021 22:47
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We wish you a great day and a good mood!
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Received date: 08.10.2021
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UDC

MECHANICAL PROPERTIES CHARACTERIZATION OF LAMINATED BAMBOO APUS (GIGANTOCHLOA APUS) COMPOSITE WITH EPOXY-RESIN MATRIX

From the title should follow what your research was: development, comparison, implementation, research, analysis, etc.

Parlindungan Manik, Agus Suprihanto, Sri Nugroho, Sulardjaka

This study aims to investigate the mechanical properties of bamboo apus (gigantochloa apus) as a natural reinforced composite material. Bamboo's laminae of gigantochloa apus was used as reinforcement on the epoxy resin matrix. The parameters examined in this study were the variation in the number, thickness and direction of the laminae. The stem of bamboo with a length of 400 mm was split to obtain bamboo laminae with a size of 400 mm x 20 mm. The thickness of bamboo laminae is varied between 1 mm, 1.5 mm, and 2 mm. The bamboo laminae is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution and dried in an oven until the water content reaches 10 %. The Laminated Bamboo Composites (LBCs) were made with a hand lay-up method. After the LBCs are moulded, the mould were pressed with 3 variations of dies compaction 1.5 MPa, 2 MPa and 2.5 MPa. The tensile and bending test characteristics were carried out on the LBCs. Tensile testing is performed in accordance with ASTM standard D3039 and the bending tests were conducted based on ASTM standard D7264. The results shows at each compacting pressure, the highest tensile and bending strength was achieved by LBCs with a thickness of 1 mm of bamboo laminae and 7 layers of bamboo laminae. The LBCs with thinner bamboo laminae reinforcement and more layers has the highest tensile strength and bending strength, even it has lower mass fraction. The LBCs with laminae oriented 0^o exhibited greater tensile and bending strengths than the LBCs with laminae structured -45^o/+45^o and 0^o/90^o. The LBCs with 0^o laminae direction is matrix fracture than followed by laminae fracture. In the 0^o/90^o direction, matrix fracture followed by delamination in the 90^o lamine and the 0^o direction laminae. Delamination and laminae clefting were observed in LBCs with laminae oriented +45^o/-45^o.

Keyword: Laminae Bamboo Composites, Gigantochloa Apus, Tensile Strength, Bending strength.

1. 1. Introduction

In this section of the article the relevance of scientific problems for the present should be justified. That is, it is necessary to answer two main questions:
– why in modern conditions it is necessary to conduct scientific research on this topic?
– what can the results of these studies give to practice?

This section of the article did not need to annotate the article. To finish this section of the article you need this text:
Therefore, studies that are devoted are….. scientific relevance

Bamboo is a group in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. There are more than 1,450 bamboo species are found in cold mountains to hot tropical regions. . Bamboo can be harvested in 3–4 years after planting, compared to the traditional timbers that need decades between planting and harvesting [1, 2]. Bamboo has specific mechanical properties that are superior to other types of natural fibers due to the longitudinal arrangement of the fibers. The small microfibrillar angles of the bamboo fibers support high volume stability and excellent mechanical properties [3–5]. The advantages of the mechanical properties of bamboo and the availability of abundant materials have attracted many researchers to use bamboo as reinforcement in composite materials. The use of bamboo fibers as a reinforcing material provide many benefits. Natural fibers that are low in density can be employed as a useful lightweight engineering material compared to synthetic fibers like glass fibers or carbon fibers [6]. Unfortunately, as for the area of bamboo composites characterizations in thermoset setting, only a handful of studies have looked into laminate-based bamboo composites. The use of bamboo as a composite material provides solutions in the development of the materials industry. The tensile strength of bamboo is about twice as high as the tensile strength of lumber, with the compressive strength is approximately 1.5 times stronger than lumber. The strength to weight ratio of bamboo is higher than lumber and plain steel [7]. Bamboo fiber has the potential to replace glass fibers as reinforcing composites. The bamboo fiber has a specific young modulus (Specific E) comparable with the E-glass fiber. It means that the bamboo fiber has a high stiffness with minimum weights [8, 9]. A rather recent study concerning bamboo strips had successfully characterized several imminent properties, for example, tensile, flexural, impact, and hardness of bamboo composite in a comprehensive manner [10].

Indonesia is a tropical country with various species of bamboo plants, including petung bamboo (*dendrocalamus asper*), wulung bamboo (*gigantochloa atroviolacea*), yellow bamboo (*bambusa vulgaris*), spotted bamboo (*bambusa maculata*), apus bamboo (*gigantochloa apus*) and others. Bamboo is widely used for flooring, roof construction, crafts/furniture, and fabrics. Apus bamboo (*gigantochloa apus*) is a type of bamboo that has the advantage of being easy to divide and cut up to the thickness of 1 mm. At this time, apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, ceiling/home asbestos and woven crafts. The abundant availability of apus bamboo and its good mechanical properties can be used to replace wood in various structural applications. The limitation of bamboo for engineering applications is due to its shape. Bamboo engineering with lamination technique is a method to increase the application of bamboo as a building structure. The purpose of this article is to develop a composite epoxy resin reinforced with laminat of bamboo apus (*gigantochloa apus*).

2. Literature review and problem statement

In this section of the article you have to say about each source of literature: which problems were studied in them, which part of the problem remained unexplored, why this part of the problem has not been studied? Can it be objective reasons, methodological or mathematical difficulties, etc.? You must say this specifically.

The following logic should be followed between this section and section **3. The aim and objectives of the study**:

Section 2 identifies the problem and articulates it at the end of Section 2.

Section 3 sets out a aim that should clearly indicate that achieving it will actually help solve the problem.

Recommended building the section according to the following logical scheme:

The work [.] *presents the results of research ... It is shown that ... But questions related to ... The reason for this may be (objective difficulties associated with ..., fundamental impossibility .. costly part in the plan. .., which makes the relevant research impractical, etc.). A variant of overcoming the corresponding difficulties can be ... It is this approach that was used in the work* [.], *However ... All this allows us to assert that it is expedient to conduct a study on ...*

Use 7–10 references to the literature, each of the used sources should be accompanied by a comment (at least one sentence)

The use of bamboo as reinforcement in composite materials has been investigated with *gigantochloa scortechini* woven bamboo fibers. Bamboo matting is made from sheets of bamboo layers measuring: 0.5 mm thickness and 5.0 mm width. Composites with epoxy resin matrix were made with a hand lay-up method, in the number of 2-6 layers. The results of the mechanical properties test (tensile test, bending test, hardness test, and impact test) showed that the composite with two layers of woven reinforcement had high mechanical properties [11].

Lokesh et.al. have investigated the mechanical behavior of short untreated and treated with NaOH bamboo fiber reinforced epoxy resin composites. Bamboo fibers with various lengths and contents are reinforced with epoxy resin to produce a composite. The results showed that the mechanical properties of the tensile strength, flexural strength, and impact strength of composites were influenced by the NaOH treatment. The tensile strength of composite with three layers of treated fiber is 18.07 Mpa and 16.51 MPa for three layers of untreated fiber [12]. Soaking apus bamboo (*gigantochloa apus*) laminae in methanol solution increases the strength of laminated bamboo composites [13].

The laminated composites (LBCs) using four laminas of dendrocalamus strictus cold-pressed using epoxy resin result in maximum stress of LBCs of about 210 MPa. The specimens used had a cross-section of 16 mm x 10 mm. This study reported that compressive strengths of LBCs ranging between 55 MPa and 88 MPa. The fracture mode of LBCs found that the matrix failure occurs followed by fibers failure with metallic sound of anyone layer and subsequently other layers in specimens. There are good agreements between the theoretical values and experiment results for stiffness and strength [14]. Li et al. reported significant differences in strength and behavior between small specimens sourced from different growth portions with the full-size structural members (cross-section 100 mm x 100 mm) constructed from laminated bamboo sourced from different growth portions of the culm. This study found that the bamboo laminate sourced from the middle growth section has the largest elastic modulus [15].

Laminated Bamboo Composites (LBCs) of *dendrocalamus strictus* bamboo culms were manufactured from laminas and laminates using an epoxy resin matrix. The mechanical properties of LBCs have been evaluated with different loading conditions. The results show that the mechanical properties of LBCs are better than teak wood, which is one of the strongest woods [16].

The present study investigates polymer reinforced bamboo laminate developed by using a hand lay-up method with reinforcements with varying lamina sizes. The type of bamboo studied was rope bamboo or apus bamboo (*Gigantochloa apus*). Apus bamboo was chosen because it has flexible properties and is easy to make into thin sheets. The research was conducted by varying the tickness, number of laminae and compacting mold pressure.

3. The aim and objectives of the study

The aim of the study is the investigation mechanical properties of *gigantochloa apus* laminae reinforced epoxy resin.

The following objectives have been formulated:

- – to investigate the effect of the number of bamboo laminae on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);
- to investigate the effect of direction of bamboo laminae on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);
- to investigate the effect of pressure compaction on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);
- to investigate fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs);

4. Materials and Methods

In this section, it is necessary to say only about how the research was carried out: equipment, software (if used), theoretical methods, experimental conditions. That is, this section talks about how exactly the results were obtained.
That is, it is only a research tool.

This section does not need to report research results

4. 1. Material

Bamboo's laminae of *gigantochloa apus* was used as primary reinforcement material. The bamboo used is three years old with an average diameter of 150 mm of bamboo. The selected part of the bamboo stem, 1 m to the base to 4 m, was used to make the laminae. The tensile strength of the bamboo laminae is 230 MPa. The matrix material used for the bamboo laminaetion process is epoxy-resin with a tensile strength of 57 MPa.

4. 2. Methods

The process of making bamboo lamina begins with cutting the bamboo stalks to obtain a stem length of 40 cm. The bamboo stalks are then split into blades, making the bamboo slats by removing the outer shell. Then the splitting process is carried out to obtain a bamboo blade with a size of 40 cm × 20 mm. The formation of bamboo lamina blades is carried out using the four-side planning tool. This process is carried out to obtain the thickness of 1 mm, 1.5 mm, and 2 mm. Fig. 1 shows the bamboo lamina-making process.

The bamboo laminae is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution. After preservation, the bamboo laminae are dried. The bamboo lamina is dried in an oven until the water content reaches 10 %. A moisturemeter measured the percentage of water content in the bamboo laminae. Drying takes approximately 2–4 weeks in an oven, depending on the weather. Dry bamboo slats are grouped according to their thickness and then sanded to smooth the surface using a sandpaper machine. The photo of bamboo laminae are depicted in Fig. 2.

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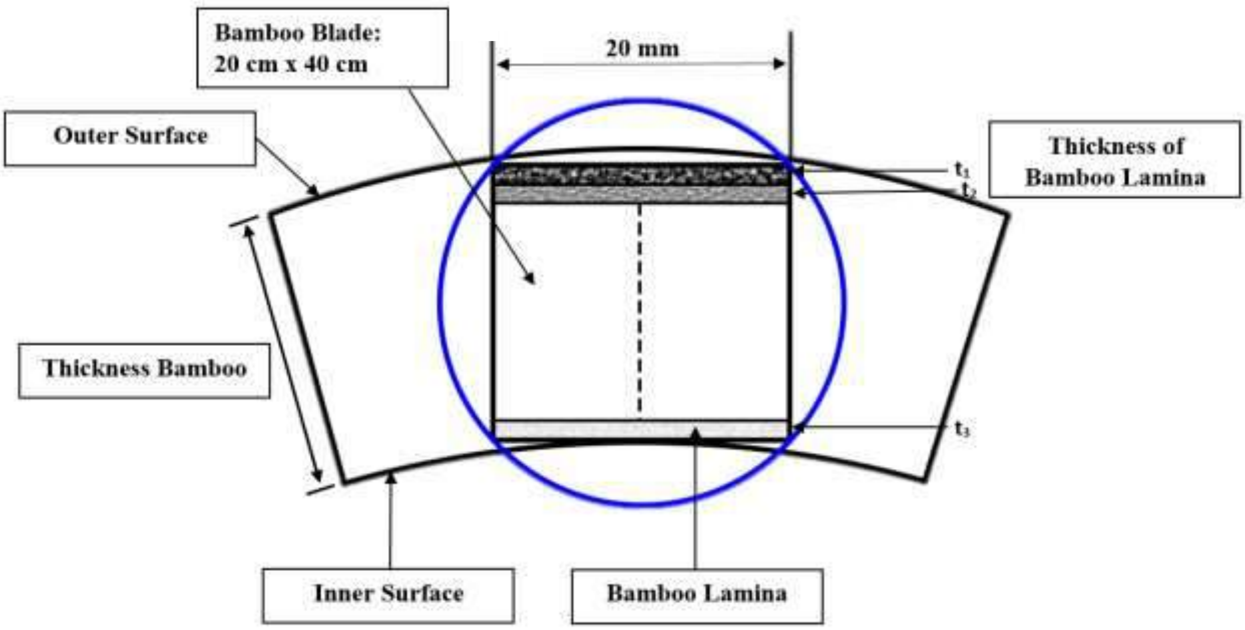

Fig. 1. Formation of the bamboo apus laminae (*gigantochloa apus*)

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Fig. 2. Bamboo Laminae

The dried bamboo laminaes are then used as reinforcing composites to make Laminaeted Bamboo Composites (LBCs). An epoxy resin polymer is used as a matrix/adhesive material. LBCs were made using hand lay-up method followed by compression. LBCs are made with varying pressures: 1.5 MPa; 2.0 MPa; 2.5 MPa and variations in the number of laminae: 3, 5 and 7. Compacting is done using a press machine. The LBCs were pressed for 24 hours. Table 1 shows the resulting composites with variations in compacting pressure and the number of laminae forming LBCs. Composites are also made with a variety of fiber directions: 0, -45/+ 45 and 0/90. This process produces a composite with a size of 400 mm x 250 mm with various thicknesses as shown in Fig. 3, *a–c*.

Table 1
The weight fraction of bamboo fibers and the epoxy resin matrix of the composites

No	Pressure compaction (MPa)	Laminae (layer)	Thickness laminae (mm)	Thickness LBCs (mm)	Bamboo Mass fraction (Kg/cm^3)	Epoxy-resin Mass faction (Kg/cm^3)
1	1.5 MPa	3	2.0	7.0	0.70	0.30
2		5	1.5	7.0	0.65	0.35
3		7	1.0	7.0	0.60	0.40
4	2.0 MPa	3	2.0	6.5	0.75	0.25
5		5	1.5	6.5	0.70	0.30
6		7	1.0	6.5	0.65	0.35
7	2.5 MPa	3	2.0	6.0	0.80	0.20
8		5	1.5	6.0	0.75	0.25
9		7	1.0	6.0	0.70	0.30

The tensile test refers to the ASTM standard D3039 with a specimen size of 250 mm x 25 mm x t mm. The bending test was carried out using the ASTM standard D7264 with a 130 mm × 13 mm × t mm specimen size. The test specimens were prepared using water jet cutting. Tensile and bending testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1000 KN. Each variation was repeated for five specimens. Fig. 4, *a*, *b* present images of tensile and bending test specimens.

draw a fig. from a hidden table

The Figure is of poor quality.

~~a.~~ 0º ~~b.~~ -45º/+45º ~~c.~~ 0º/90º

a b c

Sign by example:
Fig. 2. The main signature: *a* – .....; *b* – ....

Fig. 3. Laminaete Bamboo Composites with the variation of laminae direction

draw a fig. from a hidden table

The Figure is of poor quality.

a. Tensile test specimens b. Bending test specimens

a b

Sign by example:
Fig. 2. The main signature: *a* – .....; *b* – ....

Fig. 4. Tensile and bending test specimens

ENDING THE SECTION BY THE FIG. IS INCORRECTLY, NEED AN ANY INTERPRETATION

5. Results of research... ~~and Discussion~~

This section is directly related to the tasks and describes the solution of tasks set in section 3. Each task has its own section: 5.1, 5.2,... It is also important that this section 5 should not be interpreted, the results of each task should be given in the form of "dry residue": formulas, tables, figures.

Structure the "Research results" section according to the task at hand (section 3):

5. 1…. The title should answer the question "What are the results of the research?"

5. 4….. The title should answer the question "What are the results of the research?"

number of tasks (Section 3) = number of subsections Result

Fig. ~~5, 6, and 7~~ 5–7 show the results of the tensile test of LBCs for variations in the number of laminae: 3, 5, and 7 and the compression pressure of 1.5 MPa, 2 MPa, and 2.5 MPa. The Fig. also shows the tensile strength of LBCs at various lamina directions: 0°, −45°/+45°, 0°/90°. Thus, as the number of layers in the LBCs increases from 3 to 7 the tensile strength also increases. At all pressure variations, LBCs with a 0° lamina direction has a higher tensile strength than LBCs with a −45°/+45°, 0°/90° direction. At a compacting pressure of 1.5 MPa, the tensile strength of the LBCs is 138 MPa (Fig. 5). LBCs with a pressure of 2 MPa produce the highest tensile strength of 185 MPa (Fig. 6). The graph in Fig. 7 shows that at a pressure of 2.5 MPa the highest tensile strength of LBCs is around 180 MPa. At each compacting pressure value, the highest tensile strength was achieved by LBCs, with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo lamina. Fig. 8 shows a graph of the relationship between the LBCs' tensile strength and mass fraction. The graph in Fig. 8 shows that the highest tensile strength is in the composite with thinner bamboo reinforcement and more layers, even at a lower mass fraction. This is in accordance with the results of Venkatehwaran's research that the tensile strength of laminated composites is dependent on the interfacial properties of natural fibers and polymer composites. Additionally, the tensile properties are contingent upon the laminae directions [17].

Apus bamboo (gigantochloa apus) with a lamina's tensile strength of 230 MPa and an epoxynresin with a tensile strength of 57 MPa after being formed into a composite LBCs was able to produce the highest tensile strength of 185 MPa with a ratio of 70 % lamina bamboo lamina mass fraction and 70 % mass fraction. (wt) epoxy-resin 30 %. Previous research reported using gigantochloa scortechinii (semantan reed) bamboo, woven bamboo (Woven Bamboo) with a ratio of 33 % of the mass fraction (wt) of bamboo lamina and the mass fraction (wt) of 77 % epoxy matrix was only able to produce a maximum tensile strength of 89 MPa [11].

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Is it an Excel? If so, you can easily move your chart to Word from Excel. Copy chart in Excel (use ctrl+c for it), then on Home tab in Word select Paste->Paste Special and choose “Picture (Metafile Wondows)”.

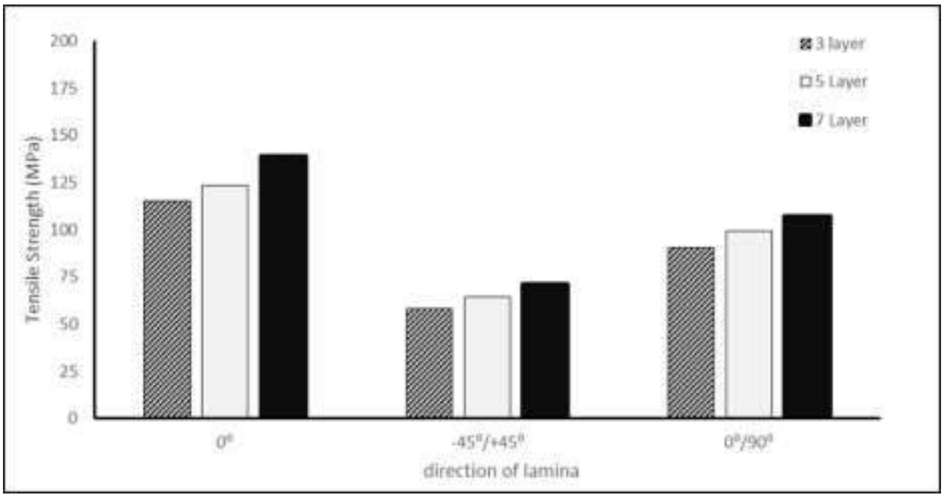

Fig. 5. Tensile strength of LBCs with 1.5 MPa pressure

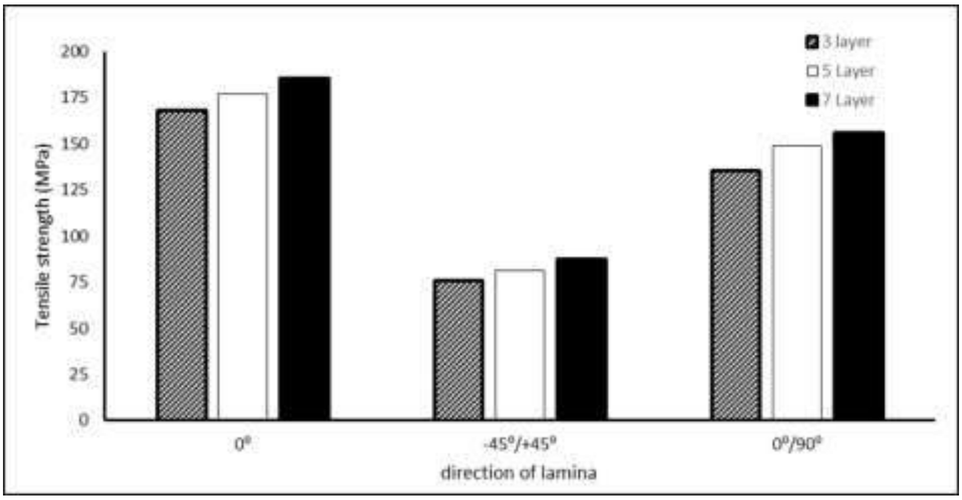

Fig. 6. Tensile strength of LBCs with 2 MPa pressure

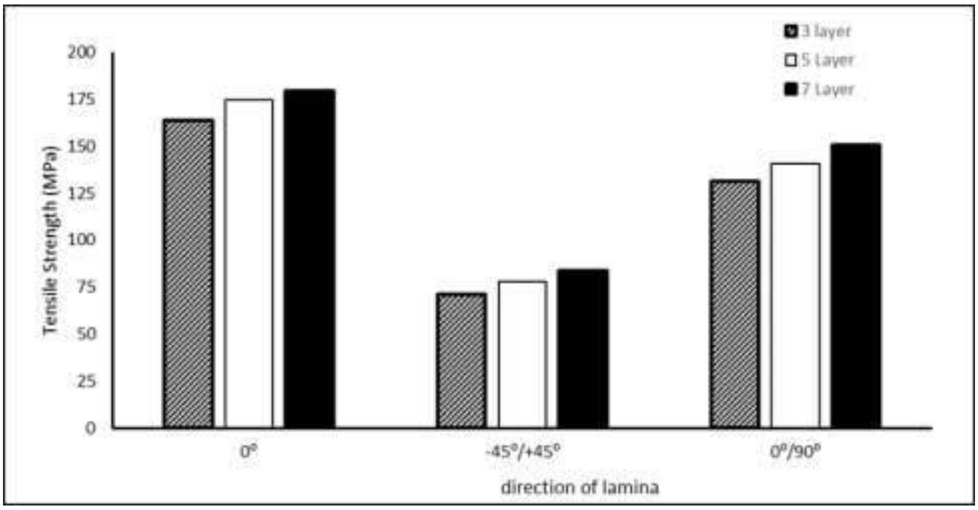

Fig. 7. Tensile strength of LBCs with 2.5 Mpa pressure

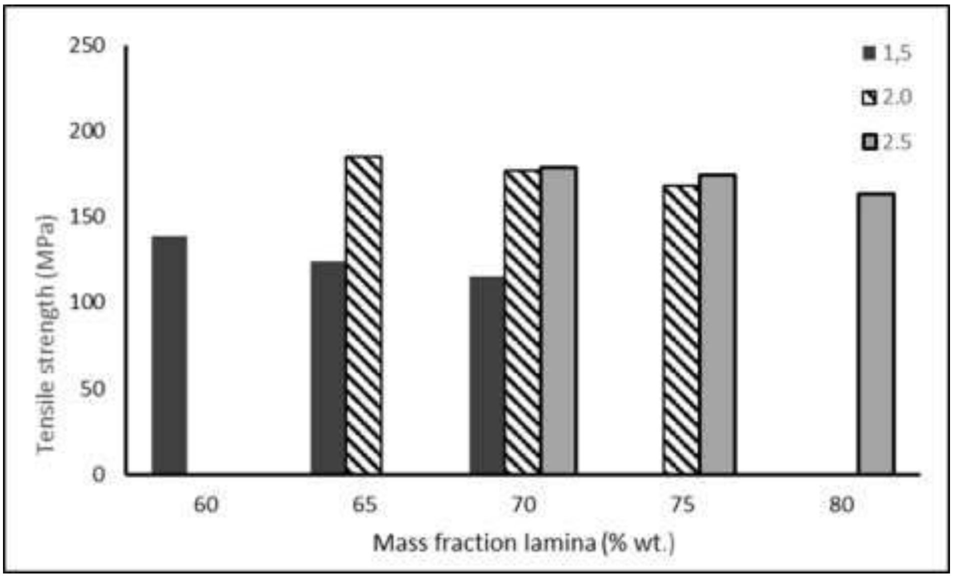

Fig. 8. The effect of mass fraction bamboo laminae and tensile strength of LBCs in composites with direction of 0°

Increasing the tensile strength properties of LBCs in the thinner bamboo lamina reinforcement with a higher number of composites forming layers is an important concern in this study. This could result from the ability of the epoxy resin to enter the thinner pores of the apus bamboo fiber, thereby increasing the interface strength of the composite-forming bamboo layer. The increased tensile strength produced by LBCs has a composition of 70 % lamina and 30 % epoxy-resin. The results are different from other researchers. Rassiah et al. surname is not mentioned in scientific articles, enough references to works examined laminated bamboo composites with different bamboo and matrices (*gigantochloa scortechinii* and unsaturated polyester). They reported that the thicker the bamboo blades, the higher the tensile stress and flexural stress [19]. Verma et al. surname is not mentioned in scientific articles, enough references to works reported that increasing the number of laminae forming the Layered Laminate Bamboo Composites (LLBCs) will increase tensile and flexural stress [7]. They also mentioned that the direction configuration of the composite laminae also affects the tensile stress and flexural stress of LLBCs. The configuration of the laminae with direction 0º gave the best result of tensile strength compared to the configuration of the direction of the fiber crossed 0°/45° and 0°/90°. Thus, the tensile strength of the LBCs decreases with increasing the angle of the laminae under the tensile stress. According to the Tsai–Hill criterion, the tensile and compressive properties of the composite will continue to decrease due to changes in the fiber orientation angle that increases from 0° [19]. This study's results prove that the direction of the lamina 0° provides the best tensile strength compared to the direction of the lamina −45°/+45°, 0°/90°.

The graph in Fig. 9 also shows the effect of compacting pressure on the tensile strength of LBCs at the mass fraction of 70 %. This analysis selected a mass fraction of 70 % wt because a mass fraction of 70 % wt was generated for all variations studied (Fig. 8). Fig. 9 shows that increasing the compression from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0º lamina direction, 40 % in the −45°/+45° lamina direction, and 64 % in the 0º/90º laminae direction. Increasing the compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. The difference in tensile strength is smaller than the standard deviation of the test. Therefore, the increase in pressure from 2 MPa to 2.5 MPa does not affect the tensile strength of LBCs.

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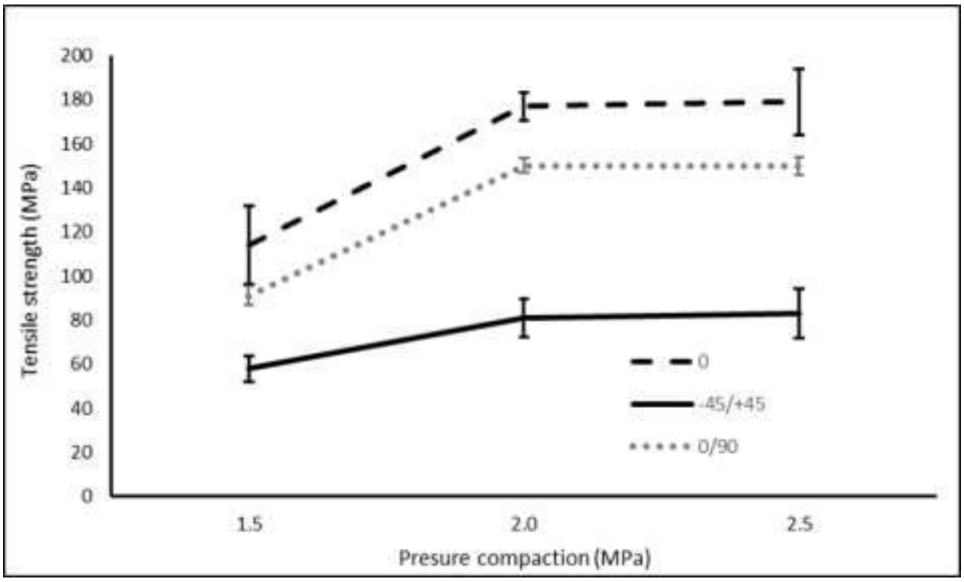

Fig. 9. The effect of Compaction Pressure on Tensile Strength of LBCs at 70 % Mass Fraction

The compacting pressure applied to the manufacture of LBCs affects the mass fraction (wt) of the epoxy resin matrix contained in the LBCs. The compacting pressure will force the epoxy resin out of the LBCs mold while the mass fraction of the bamboo laminae remains. Higher compression pressure will reduce the % wt epoxy-resin. It is evident from the compression (Fig. 9) from 1.5 MPa to 2.0 MPa can reduce the weight fraction of epoxy resin in LBCs by 5 % of the initial mass fraction, but can increase the tensile strength of LBCs by 55 % at laminae direction 0°, 40 % in the direction of laminae −45°/+45° and 64 % in the direction of laminae 0°/90°. Another researcher reported that LBCs without compacting pressure could produce a maximum tensile strength of 89 MPa [9]. The optimum tensile stress of Laminated Bamboo Composites (LBCs) was obtained at a 2 MPa compaction pressure variation with a mass fraction (wt) of lamina of 70 % and a mass fraction (wt) of epoxy-resin of 30 %. The application of compacting pressure above 2 MPa on LBCs didn't affect on the value of tensile stress. The anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs each by 5 % for each variation of the tested specimens.

Fig. 10–12 show the bending strength of LBCs with variations (orientation) of the fibers with the direction of 0^o, -45^o / + 45^o, 0^o / 90^o and variations in the number of laminae bamboo apus layers of 3, 5, and 7 layers with pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa. The bending stress of laminaeted bamboo composites is also influenced by the direction (orientation) of the bamboo laminaete and the number of layers. At each variation in the direction of the bamboo laminae and stress, the bending strength of the LBCs increased with the increasing number of layers of bamboo laminae. In the number of layers, the bending strength of LBCs with the laminae direction of 0^o has the largest bending strength, followed by the crossed fiber direction of 90^o and the lowest bending strength is the LBCs with the -45^o / + 45^o fiber direction. The highest bending strength of 321 MPa was produced in LBCs with 7 layers of bamboo laminae, 0^o fiber direction and 2 MPa stress. Fig. 13 shows a graph of the relationship between the bending strength of LBCs and the mass fraction of LBCs. From the graph in Fig. 13, it can be concluded that the highest bending strength is in the composite with thinner bamboo reinforcement and a higher number of layers even at a lower mass fraction.

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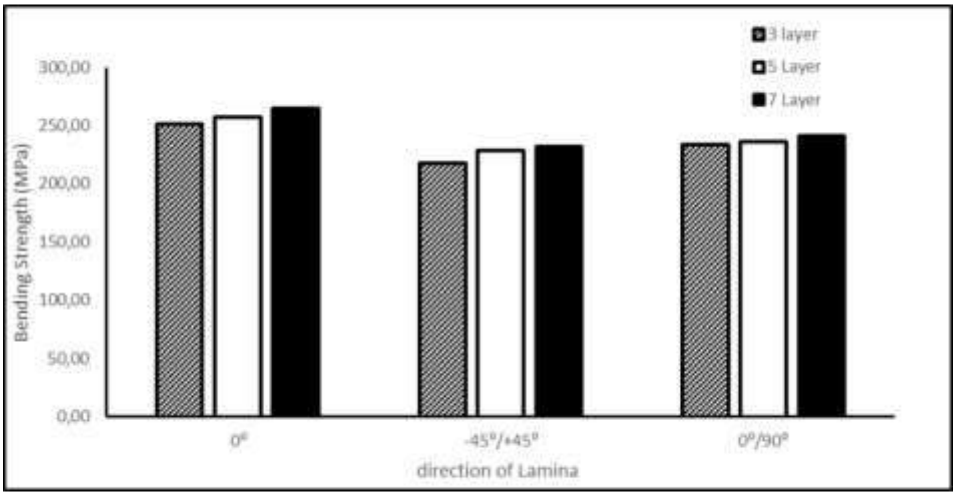


Fig. 10. Bending strength of LBCs with 1.5 MPa stress

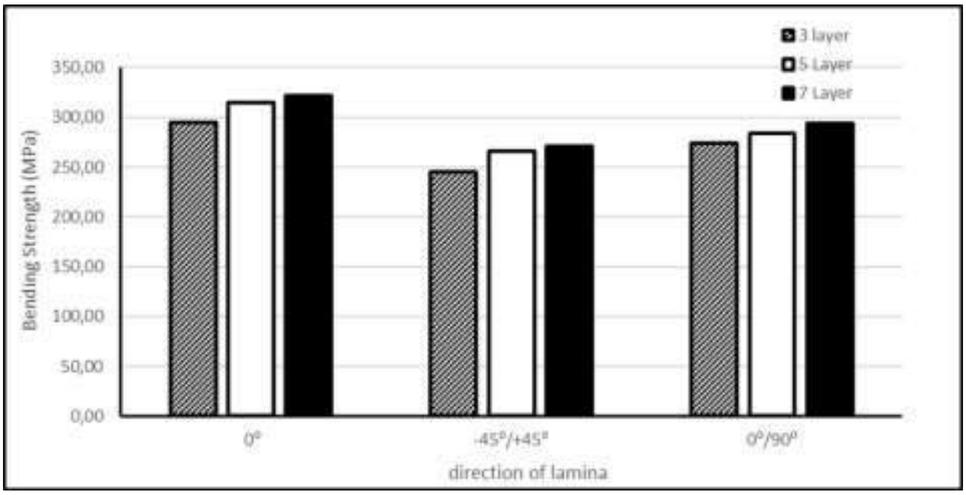


Fig. 11. Bending strength of LBCs with 2 MPa stress

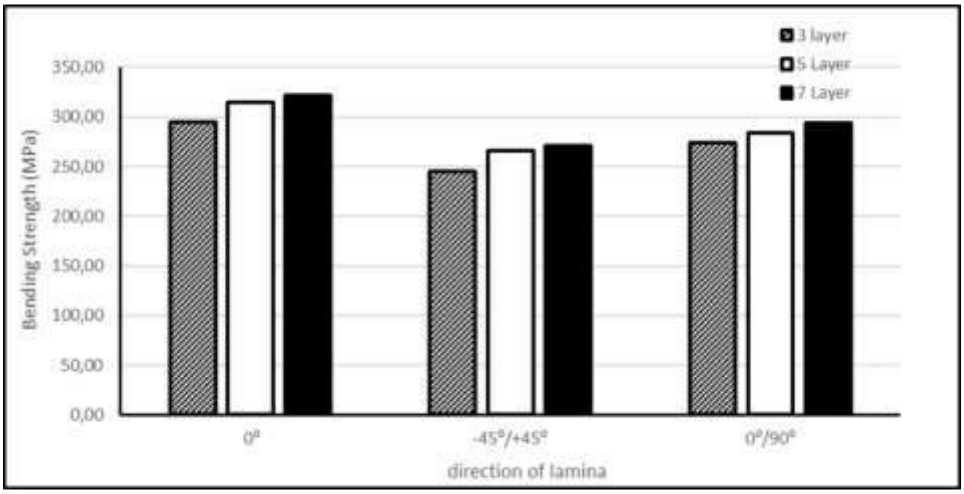


Fig. 12. The bending strength of LBCs with 2.5 MPa stress

Apus bamboo (*gigantochloa apus*) with a bending strength of 348 MPa laminae and an epoxy-resin with a tensile strength of 175 Mpa, after being formed into a composite LBCs, was able to produce the highest bending strength of 321 MPa with a ratio of mass fraction (wt) of 70 % and mass fraction (%. wt) epoxy-resin 30 %. *Gigantochloa scortechinii* (semantan reed) woven bamboo with a ratio of 33 % of the mass fraction (wt) of bamboo laminae and the mass fraction (wt) of 67 % epoxy matrix was only able to produce a maximum bending strength of 120 MPa [11]. The bamboo allowed large flexural deformations because its outer part retains the tensile stress while the softer inner part undergoes large compressive deformation [20]. The configuration of the 0^o direction of the laminae gave the best bending strength compared to the configuration of 0^o / 45^o and 0^o / 90^o crossed laminae [19].

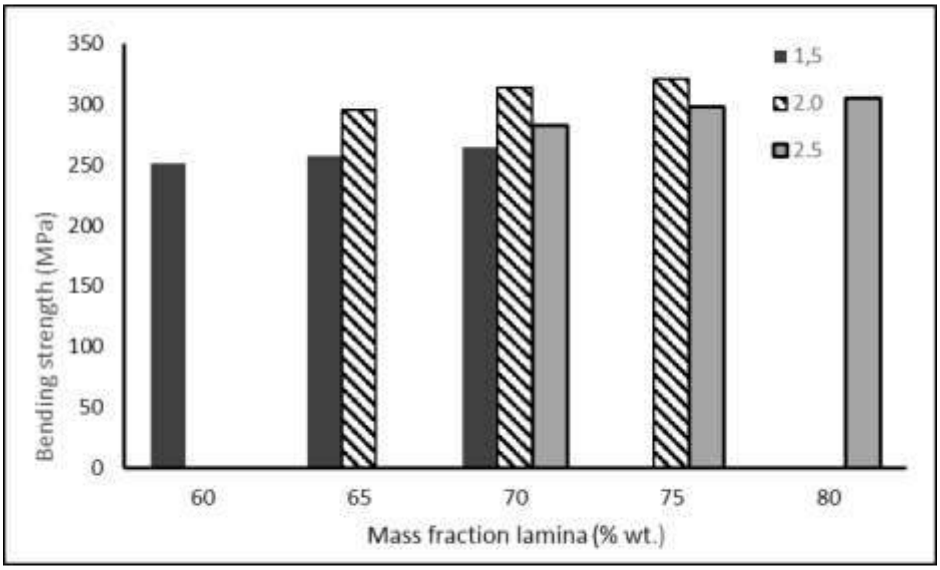


Fig. 13. The effect of mass fraction of laminae and bending strength of LBCs in composites with 0^o direction

The graph in Fig. 14 also shows the effect of compacting pressure on the bending strength of LBCs at the mass fraction of 70 %. Like the tensile test results, the increase in compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the bending strength of LBCs.

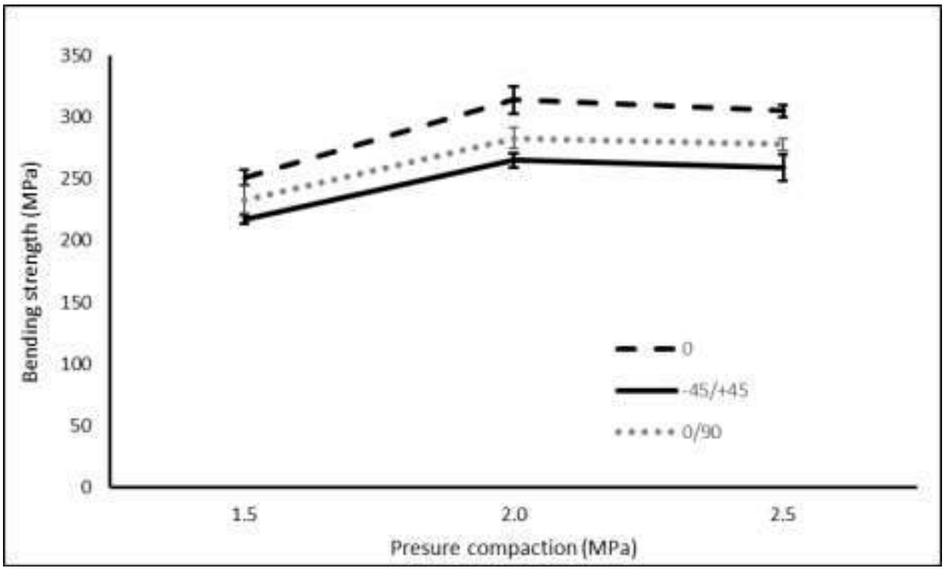


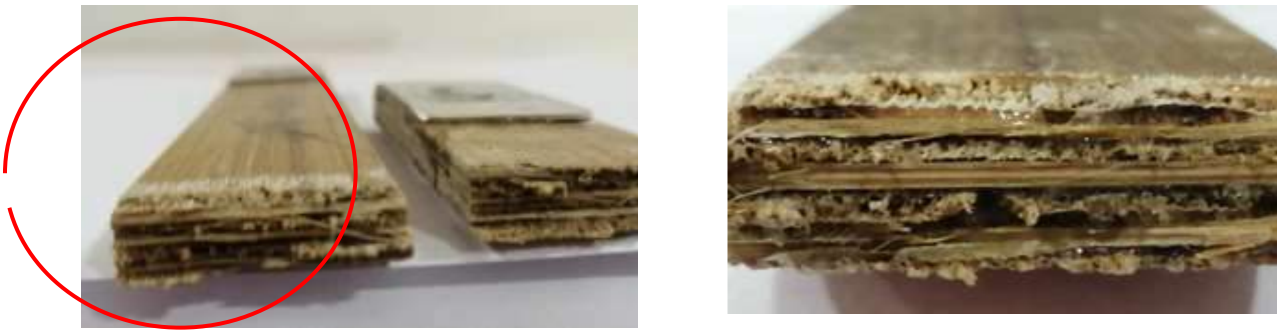
Fig.14. The effect of Compaction Pressure on the Bending Strength of LBCs at 70 % Mass Fraction

Fig. 15. shows photo macro of surface fracture of LBCs. LBCs with laminae direction 0^o, the fracture mode that occurs is laminae (Fig. 15, *a*). The fracture surface of the LBCs with the laminae direction $-45^o/+45^o$ (Fig. 15, *b*) and The fracture surface of the LBCs with the laminae direction $-0^o/90^o$ (Fig. 15, *c*). LBCs 0^o direction of laminae, the first phenomenon of tensile test is matrix fracture, followed by load transfer to bamboo laminae and subsequent bamboo laminae fracture. Fracture of matrix in the $0^o/90^o$ direction of laminae, followed by delamination of laminae in the 90^o direction, and finally fracture of laminae in the 0^o direction. In LBCs with laminae oriented $+45^o/-45^o$, matrix fracture was followed by delamination and laminae clefting. Similar fracture modes were found in bending test results (Fig. 16).

draw a picture from a hidden table

a. Laminaeted Bamboo Composites (LBCs) 7 layer with the laminae's direction of 0^o

b. Laminaeted Bamboo Composites (LBCs) 7 layer with the laminae's direction of intersection $-45^o/45^o$ \



c. Laminaeted Bamboo Composites (LBCs) 7 layer with the laminae's direction of intersection 0º/90º

a b c

Sign by example:
Fig. 2. The main signature: *a* – .....; *b* – ....

Fig. 15. Photomacrography The Fracture of Cross Section of The Tensile Test of 7 Layers Laminaeted Bamboo Composites (LBCs)

draw a picture from a hidden table

a. LBCs 7 layers direction of 0º

b. LBCs 7 layers direction of intersection -45º/45º

c. LBCs 7 layers direction of interserction 0º/90º

Sign by example:
Fig. 2. The main signature: *a* – .....; *b* – ....

Fig. 16. Bending Test Result Specimens of Laminaeted Bamboo Composites (LBCs) from 7 layers

ENDING THE SECTION BY THE FIGURE IS INCORRECTLY, NEED AN ANY INTERPRETATION

6. Discussion of experimental results (The title should answer the question "Discussion of the results of the study of what?")

The structurally-substantive scheme of this section:
- how can the results be explained? This interpretation part is the first main part of the discussion and there are important nuances of its presentation. It is necessary to explain the results obtained for each research objective, referring to those objects in the article that display the discussed results. Such objects in the general case are analytical expressions, figures, tables. That is, it should be seen which result is being discussed

at this point in the section.
- how do the proposed solutions/results allow to close the problem area identified by the author, and if so, in which part and due to what exactly? This is the second main part of the discussion, because it is this that closes the research (feedback): the problem is identified – the aim is set – the results are obtained – the results are explained using some kind of evidence base (section "Discussion ...")
- what can be considered the advantages of this study in comparison with those known on this subject. In this case, it is necessary to indicate alternative solutions and say, thanks to which particular features of the proposed solutions, advantages (or, in general, differences) are provided?
- what limitations are inherent in this study? This is the third main part of the discussion.
- what are the disadvantages of the study and in what direction should the study be developed?

6. 7. Conclusions number of objectives=number of conclusions

Each conclusion should be concretized in accordance with its research objective. Each conclusion should contain the following information: what is the result obtained for this research objective, what are its features and differences from known alternative data, how can this result be explained? Numerical estimates of the result are also recommended. It is these parts of each conclusion that indicate the originality and scientific novelty of the solutions obtained.

1. The number of conclusions should correspond to the number of objectives in section 3.

2. It is desirable to use some numerical estimates of the results in the conclusions

As a result of the research:
1. ... with indication of qualitative or quantitative indicators of research results
2. ... with indication of qualitative or quantitative indicators of research results
3. ... with an indication of qualitative or quantitative indicators of research results

~~The LBCs with 7 laminae with a thickness of 1 mm per laminae provides the higher tensile and bending strength than LBCs with 5 laminae with a thickness of 1.5 mm per laminae and 3 laminae with a thickness of 2 mm per laminae. The effect of laminae quantity on LBC reinforcement is bigger than the mass fraction of laminae.~~

~~The tensile stress and bending stress of the Laminaeted Bamboo Composites (LBCs) are influenced by the direction of the laminae of the LBCs. In comparison to LBCs with 0°/ 90° laminae or -45°/+45° cross direction, the LBCs with 0° laminae exhibited the higher tensile and bending strength.~~

~~The compacting pressure applied to the manufacturing process of Laminaeted Bamboo Composites (LBCs) affects the mass fraction (% wt) of the epoxy resin matrix~~

~~contained in the LBCs, the greater the compacting pressure, will result in a decrease in % wt of the epoxy resin. The optimum tensile and bending stresses of Laminaeted Bamboo Composites (LBCs) were obtained at 2 MPa compaction pressure variations with 70 % laminae mass fraction (wt) and 30 % Epoxy-resin mass fraction (wt). The application of compacting pressure above 2 MPa on LBCs results in a decrease in the value of tensile and bending stresses, it is assumed that the anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs, 5 % for each variation of the tested specimen.~~

Acknowledgments

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If possible, please provide active hyperlinks to the entire list of literature.

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From the title should follow what your research was: development, comparison, implementation, research, analysis, etc.

Parlindungan Manik, Agus Suprihanto, Sri Nugroho, Sulardjaka*

This study aims to investigate the mechanical properties of bamboo apus (gigantochloa apus) as a natural reinforced composite material. Bamboo's laminates of gigantochloa apus was used as reinforcement on the epoxy resin matrix. The parameters examined in this study were the variation in the number, thickness and direction of the laminates. The stem of bamboo with a length of 400 mm was split to obtain bamboo laminae with a size of 400 mm x 20 mm. The thickness of bamboo laminae is varied between 1 mm, 1.5 mm, and 2 mm. The bamboo laminas is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution and dried in an oven until the water content reaches 10 %. The Laminated Bamboo Composites (LBCs) were made with a hand lay-up method. After the LBCs are moulded, the mould were pressed with 3 variations of dies compaction 1.5 MPa, 2 MPa and 2.5 MPa. The tensile and bending test characteristics were carried out on the LBCs. Tensile testing is performed in accordance with ASTM standard D3039 and the bending tests were conducted based on ASTM standard D7264. The results shows at each compacting pressure, the highest tensile and bending strength was achieved by LBCs with a thickness of 1 mm of bamboo laminae and 7 layers of bamboo laminates. The LBCs with thinner bamboo laminae reinforcement and more layers has the highest tensile strength and bending strength, even it has lower mass fraction. The LBCs with laminates oriented 0^o exhibited greater tensile and bending strengths than the LBCs with laminates structured $-45^o/+45^o$ and $0^o/90^o$. The LBCs with 0^o laminates direction is matrix fracture than followed by laminae fracture. In the $0^o/90^o$ direction, matrix fracture followed by delamination in the 90^o laminates and the 0^o direction laminates. Delamination and laminae clefting were observed in LBCs with laminates oriented $+45^o/-45^o$.

Keyword: Laminates Bamboo Composites, Gigantochloa Apus, Tensile Strength, Bending strength.

1. 1. Introduction

In this section of the article the relevance of scientific problems for the present should be justified. That is, it is necessary to answer two main questions:
– why in modern conditions it is necessary to conduct scientific research on this topic?
– what can the results of these studies give to practice?

Bamboo is a group in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. There are more than 1,450 bamboo species are found in cold mountains to hot tropical regions. Bamboo can be harvested in 3–4 years after planting, compared to the traditional timbers that need decades between planting and harvesting [1, 2]. Bamboo has specific mechanical properties that are superior to other types of natural fibers due to the longitudinal arrangement of the fibers. The small microfibrillar angles of the bamboo fibers support high volume stability and excellent mechanical properties [3–5]. The advantages of the mechanical properties of bamboo and the availability of abundant materials have attracted many researchers to use bamboo as reinforcement in composite materials. The use of bamboo fibers as a reinforcing material provide many benefits. Natural fibers that are low in density can be employed as a useful lightweight engineering material compared to synthetic fibers like glass fibers or carbon fibers [6]. Unfortunately, as for the area of bamboo composites characterizations in thermoset setting, only a handful of studies have looked into laminate-based bamboo composites. The use of bamboo as a composite material provides solutions in the development of the materials industry. The tensile strength of bamboo is about twice as high as the tensile strength of lumber, with the compressive strength is approximately 1.5 times stronger than lumber. The strength to weight ratio of bamboo is higher than lumber and plain steel [7]. Bamboo fiber has the potential to replace glass fibers as reinforcing composites. The bamboo fiber has a specific young modulus (Specific E) comparable with the E-glass fiber. It means that the bamboo fiber has a high stiffness with minimum weights [8, 9]. A rather recent study concerning bamboo strips had successfully characterized several imminent properties, for example, tensile, flexural, impact, and hardness of bamboo composite in a comprehensive manner [10].

Indonesia is a tropical country with various species of bamboo plants, including petung bamboo (*dendrocalamus asper*), wulung bamboo (*gigantochloa atroviolacea*), yellow bamboo (*bambusa vulgaris*), spotted bamboo (*bambusa maculata*), apus bamboo (*gigantochloa apus*) and others. Bamboo is widely used for flooring, roof construction, crafts/furniture, and fabrics. Apus bamboo (*gigantochloa apus*) is a type of bamboo that has the advantage of being easy to divide and cut up to the thickness of 1 mm. At this time, apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, ceiling/home asbestos and woven crafts. The Apus bamboo has tensile strength 230 MPa with density is 0.6 gr/cm^3. Strength to weight ratio of Apus bamboo is higher than woods. The abundant availability of apus bamboo and its good mechanical properties can be used to replace wood in various structural applications. The limitation of bamboo for engineering applications is due to its shape.

Bamboo engineering with lamination by develop Laminated Bamboo Composites (LBCs) is a method to increase the application of bamboo as a engineering materials. Laminated bamboo is a processed bamboo based composite manufactured by gluing bamboo strips/laminae under controlled temperature or pressure. The purpose of this article is to develop a LBCs by using epoxy resin reinforced with laminates of Apus bamboo (*gigantochloa apus*). Therefore, studies are being conducted to investigate the effect of the pressure, number, thickness and direction of Apus bamboo laminae on the tensile and bending strengths of LBCs reinforced with apus bamboo laminates.

2. Literature review and problem statement

In this section of the article you have to say about each source of literature: which problems were studied in them, which part of the problem remained unexplored, why this part of the problem has not been studied? Can it be objective reasons, methodological or mathematical difficulties, etc.? You must say this specifically.

The following logic should be followed between this section and section **3. The aim and objectives of the study**:

Section 2 identifies the problem and articulates it at the end of Section 2.

Section 3 sets out a aim that should clearly indicate that achieving it will actually help solve the problem.

Use 7–10 references to the literature, each of the used sources should be accompanied by a comment (at least one sentence)

Bamboo fiber was used as reinforcement of composite. The mechanical behavior of short untreated and treated with NaOH bamboo fiber reinforced epoxy resin composites were studied. Bamboo fibers with various lengths and contents are reinforced with epoxy resin to produce a composite. The results showed that the mechanical properties of the tensile strength, flexural strength, and impact strength of composites were influenced by the NaOH treatment. The tensile strength of composite with three layers of treated fiber is 18.07 Mpa and 16.51 MPa for three layers of untreated fiber [11]. Treating the apus bamboo (*gigantochloa apus*) laminas by soaking it in methanol solution increases the tensile and flexure strength of laminated bamboo composites about 10 % [12]. It is shown that treatment of bamboo by NaOH or methanol solution will enhance the mechanical properties of bamboo composites.

The use of gigantochloa scortechinii woven bamboo fibers as reinforcement in composite materials has been investigated. Bamboo matting is made from sheets of bamboo layers measuring: 0.5 mm thickness and 5.0 mm width. Composites with 2 to 6 bamboo layers were made with a hand lay-up method by using epoxy resin as the matrix. The results of the mechanical properties test (tensile test, bending test, hardness test, and impact test) showed that the composite with two layers of woven reinforcement had high mechanical properties [13]. Bamboo sheets made from thin-wall bamboo culm and isocyanate adhesive have been used to produce laminated bamboo esterilla sheets (LBES). TLBES were fabricated by manual compaction and hydraulic compaction. Manual compaction of laminated bamboo was handled using a hand-tightened bolt without measuring the amount of applied pressure. Hydraulic compaction was conducted on the laboratory-scale Weili MH3848(A) 100 T hydraulic pressing machine. The results show that different compaction methods resulted different properties of LBCs [14]. As a result of these findings, it can be concluded that increasing the layer of bamboo, reduces the mechanical properties of composites. The effect of pressure, thickness and number of laminae are interesting to investigate. Pressure, thickness and number of laminae are important variable on mechanical properties of LBCs.

The laminated composites (LBCs) using four laminas of dendrocalamus strictus cold-pressed using epoxy resin result in maximum stress of LBCs of about 210 MPa. The specimens used had a cross-section of 16 mm x 10 mm. This study reported that compressive strengths of LBCs ranging between 55 MPa and 88 MPa. The fracture mode of LBCs found that the matrix failure occurs followed by fibers failure with metallic sound of anyone layer and subsequently other layers in specimens. There are good agreements between the theoretical values and experiment results for stiffness and strength [15]. Laminated Bamboo Composites (LBCs) of *dendrocalamus strictus* bamboo culms were manufactured from laminas and laminates using an epoxy resin matrix. The mechanical properties of LBCs have been evaluated with different loading conditions. The results show that the mechanical properties of LBCs are better than teak wood, which is one of the strongest woods [16]. The work [17] reported significant differences in strength and behavior between small specimens sourced from different growth portions with the full-size structural members (cross-section 100 mm x 100 mm) constructed from laminated bamboo sourced from different growth portions of the culm. This study found that the bamboo laminate sourced from the middle growth section has the largest elastic modulus. The study of tensile properties of single and two ply laminated bamboo at various off-axis loading angles and laminates configurations has shown that composite laminate theory is applicable to LBCs composite and may be used for design of products and structures [18]. This study fills the gap in existing knowledge of laminated bamboo composites, in order to characterisation of mechanical behaviour of single and multi ply laminates with off-axis loading angle, as well as laminate configuration.

Based on previous studies, it can be concluded that for enhancing the use of bamboo as an engineering materials can be done by developing of Laminated Bamboo Composites (LBCs). Pressure compaction, the number of laminas, the thickness of the laminae, and the orientation of the laminates are critical fabrication variables for achieving a high strength of LBCs. The present study investigates epoxy resin reinforced with bamboo laminates. The type of bamboo studied was Apus bamboo (*Gigantochloa apus*). Apus bamboo was chosen because it has flexible properties and is easy to make into thin sheets. The research was conducted by varying the tickness, number of laminas, direction of laminates and compacting mold pressure. A detailed characterization, including the tensile and bending strength of the LBCs were investigated.

3. The aim and objectives of the study

The aim of the study is the investigation mechanical properties of *gigantochloa apus* laminate reinforced epoxy resin.

The following objectives have been formulated:

- to investigate the effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites (LBCs);

- to investigate the effect of direction of bamboo laminates on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);

- to investigate fracture of tensile and bending photo macrograph of Laminated

Bamboo Composites (LBCs);

4. Materials and Methods

In this section, it is necessary to say only about how the research was carried out: equipment, software (if used), theoretical methods, experimental conditions. That is, this section talks about how exactly the results were obtained.
That is, it is only a research tool.

4. 1. Material

Bamboo's laminae of *gigantochloa apus* was used as primary reinforcement material. The bamboo used is three years old with an average diameter of 150 mm of bamboo. The selected part of the bamboo stem, 1 m to the base to 4 m, was used to make the laminae. The epoxy Bakelite® EPR 174 and resin hardener V-140 were used as a matrix and hardener.

4. 2. Methods

The process of making bamboo lamina begins with cutting the bamboo stalks to obtain a stem length of 40 cm. The bamboo stalks are then split into blades, making the bamboo slats by removing the outer shell. Then the splitting process is carried out to obtain a bamboo blade with a size of 40 cm × 20 mm. The formation of bamboo lamina blades is carried out using the four-side planning tool. This process is carried out to obtain the thickness of 1 mm, 1.5 mm, and 2 mm. Fig. 1 shows the bamboo lamina-making process.

The bamboo laminas is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution. After preservation, the bamboo laminas are dried. The bamboo lamina is dried in an oven until the water content reaches 10 %. A moisturemeter measured the percentage of water content in the bamboo laminas. Drying takes approximately 2–4 weeks in an oven, depending on the weather. Dry bamboo slats are grouped according to their thickness and then sanded to smooth the surface using a sandpaper machine. The photo of bamboo laminae are depicted in Fig. 2.

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The fonts used in figures should match the font Times New Roman 14.

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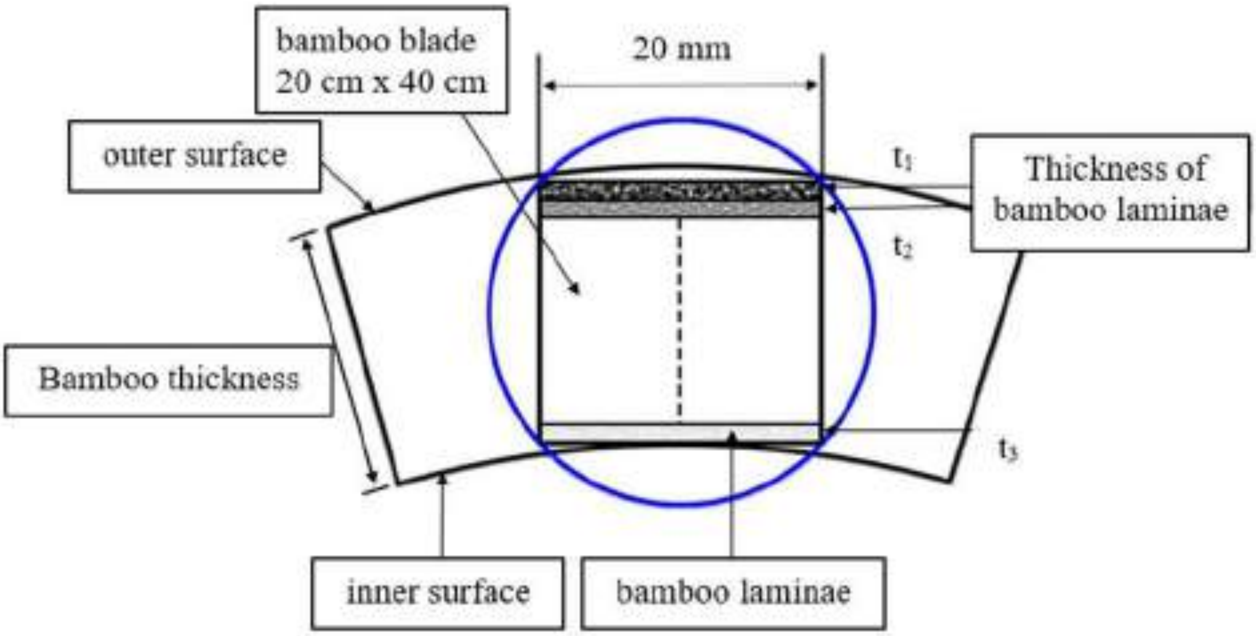

Fig. 1. Formation of the bamboo apus laminae (*gigantochloa apus*)

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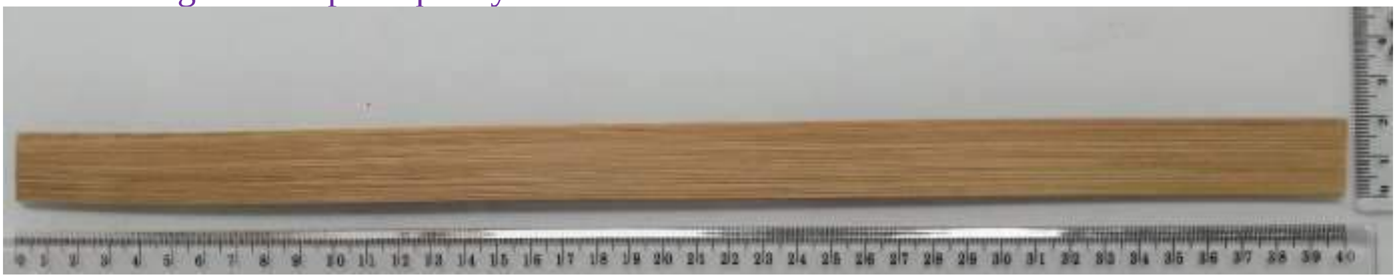

Fig. 2. Bamboo Laminae

The dried bamboo laminas are then used as reinforcing composites to make Laminated Bamboo Composites (LBCs). An epoxy resin polymer is used as a matrix/adhesive material. LBCs were constructed by hand lay up method with three different number of laminas: 3, 5, and 7. Additionally, LBCs are manufactured in a variety of laminates directions: 0, -45º/+45º and 0º/90º. The configuration of the directional arrangement of the laminates in the composite is shown in Table 1. After hand lay up process, LBCs were compacted using a hydraulic pressing machine with variation of compacting pressure: 1.5 MPa; 2.0 MPa; 2.5 MPa. The LBCs were pressed for 24 hours. Table 2 shows the resulting composites with variations in compacting pressure and the number of laminae forming LBCs. This process produces a composite with a size of 400 mm x 250 mm with various thicknesses.

Table 1.

Configuration of laminates direction in Laminated Bamboo Composites

	0º	-45º/+45º	0º/90º
3 layers	0º; 0º; 0º	-45º; +45º; -45º	0º;90º;0º
5 layers	0º; 0º; 0º; 0º; 0º	-45º;+45º;-45º;+45º,-45º	0º;90º;0º;90º;0º
7 layers	0º; 0º; 0º; 0º; 0º; 0º	-45º;+45º;-45º;+45º; -45º;+45º, ;-45º	0º;90º;0º;90º;0º; 90º;0º

Table 2.
The weight fraction of bamboo fibers and the epoxy resin matrix of the composites

No	Pressure compaction (MPa)	Laminae (layer)	Thickness laminae (mm)	Thickness LBCs (mm)	Bamboo Mass fraction (Kg/cm^3)	Epoxy-resin Mass faction (Kg/cm^3)
1	1.5 MPa	3	2.0	7.0	0.70	0.30
2		5	1.5	7.0	0.65	0.35
3		7	1.0	7.0	0.60	0.40
4	2.0 MPa	3	2.0	6.5	0.75	0.25
5		5	1.5	6.5	0.70	0.30
6		7	1.0	6.5	0.65	0.35
7	2.5 MPa	3	2.0	6.0	0.80	0.20
8		5	1.5	6.0	0.75	0.25
9		7	1.0	6.0	0.70	0.30

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Fig. 3. The tensile test specimens

Fig. 4. The bending test specimens

The tensile test refers to the ASTM standard D3039 with a specimen size of 250 mm x 25 mm x t mm. The bending test was carried out using the ASTM standard D7264 with a 130 mm × 13 mm × t mm specimen size. The test specimens were prepared using water jet cutting. Tensile and bending testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1000 KN. For each variation five specimens were tested. Fig. 3-5 present photo of tensile and bending test specimens.

5. Results of research

This section is directly related to the tasks and describes the solution of tasks set in section 3. Each task has its own section: 5.1, 5.2,... It is also important that this section 5 should not be interpreted, the results of each task should be given in the form of "dry residue": formulas, tables, figures.

Structure the "Research results" section according to the task at hand (section 3):

5. 1…. The title should answer the question "What are the results of the research?"

5. 4….. The title should answer the question "What are the results of the research?"

number of tasks (Section 3) = number of subsections Result

5. 1. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites.

Table 3 and graphs in Fig. 5–7 show the results of the tensile test of LBCs for variations in the number of laminates (3, 5, 7), laminates directions (0°, −45°/+45°, 0°/90°) and the compaction pressure (1.5 MPa, 2 MPa, 2.5 MPa) on the tensile strength of LBCs. It can be noticed from Fig. 5-7 that that the tensile strength of LBCs are influenced by number and direction of laminates. It depicted in Fig. 5, that at compacting pressure of 1.5 MPa, direction of laminates 0° (on axis) increasing number of laminates also increase the tensile strength of the LBCs. LBCs with 3 layers laminates has tensile strength about 115 MPa, increase about 7 % (124 MPa) when the layers of laminates are 5 layers. The highest tensile strength of LBCs at 0^0 direction and 1.5 Mpa compaction is 139 MPa at 7 layers laminas.The same phenomenon is obtained in the fiber direction −45°/+45°, 0°/90° that as the number of layers in the LBCs increases from 3 to 7 the tensile strength also increases. LBCs with direction −45°/+45° and 0°/90° gain the highest tensile strength 76 MPa and 107 MPa respectively at 7 layers laminates. Lowest tensile strength of LBCs is 58 MPa (about 41 % of highest value) at 3 layers laminas and −45°/+45° laminates direction.

LBCs with a pressure of 2 MPa produce the highest tensile strength of 185 MPa at 7 laminates with laminates direction 0° (Fig. 6). Besides laminates direction −45°/+45 yied highest tensile strength 88 MPa and LBCs with laminates direction 0°/90° resulted highest tensile strength 156 MPa. LBCs with laminates direction −45°/+45, 3 layers laminas and 2 mm laminae thickness yield lowest tensile strength with the tensile strength value of 76 MPa (41 % from the highest value of tensile strength).

The graph in Fig. 7 shows that at a pressure of 2.5 MPa the highest tensile strength of LBCs is achieved composite with direction of laminates 0° with valued 180 MPa. The highest tensile strength also achieved by LBCs with laminates direction 0° (on axis laminates), 7 layers laminas and 1 mm thicknes of laminae. The increase in number of laminate layers from 3, 5, 7 results in an increase in the tensile strength of 164 MPa, 175 MPa, and 180 MPa, respectively. The lowest value of tensile strength of LBCs is 71 MPa (39 % from the highest value) also find at LBCs with 3 layers laminates and direction laminates −45°/+45.

Table 3.
Tensile strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0°	115	124	139	168	177	185	164	175	180
-45°/+45°	58	64	76	76	81	88	71	78	87
0°/90°	91	99	107	135	149	156	131	141	151

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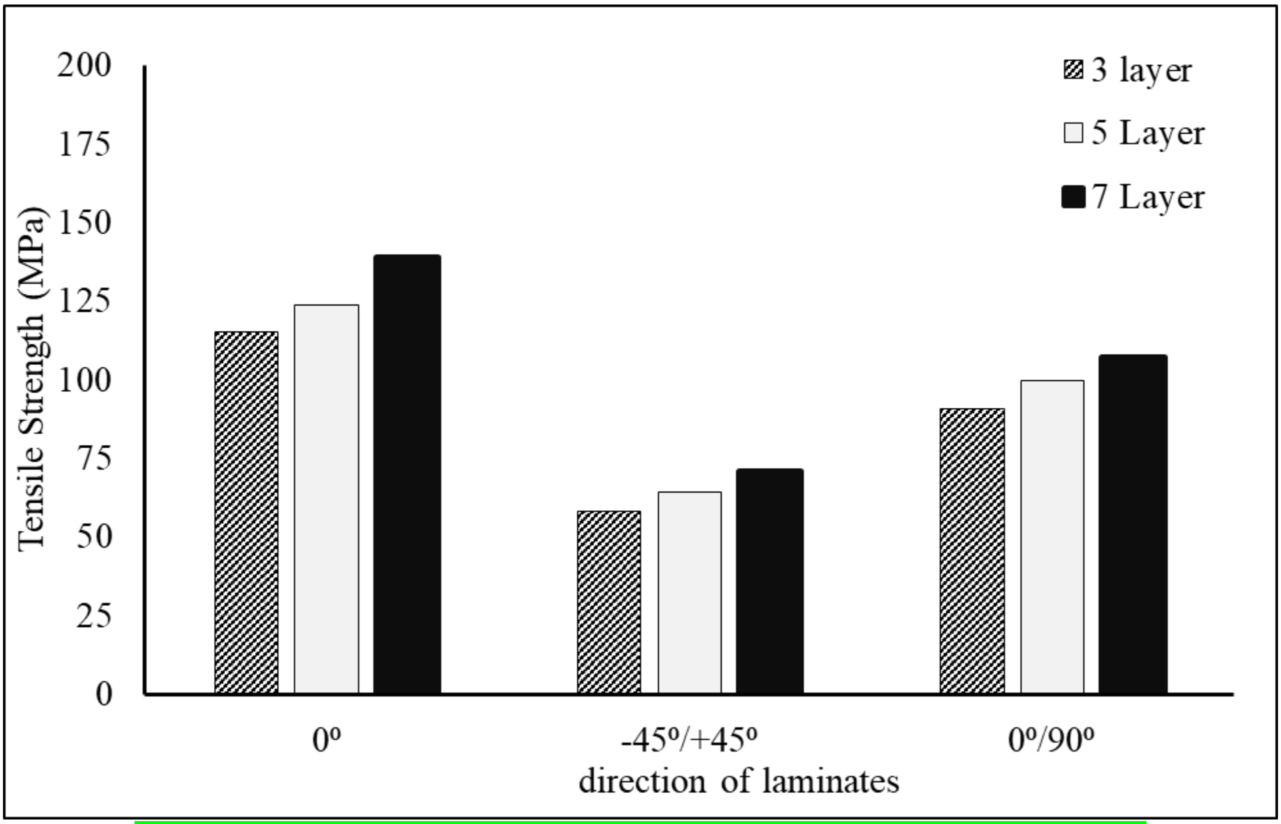

Fig. 5. Tensile strength of LBCs with 1.5 MPa pressure compaction

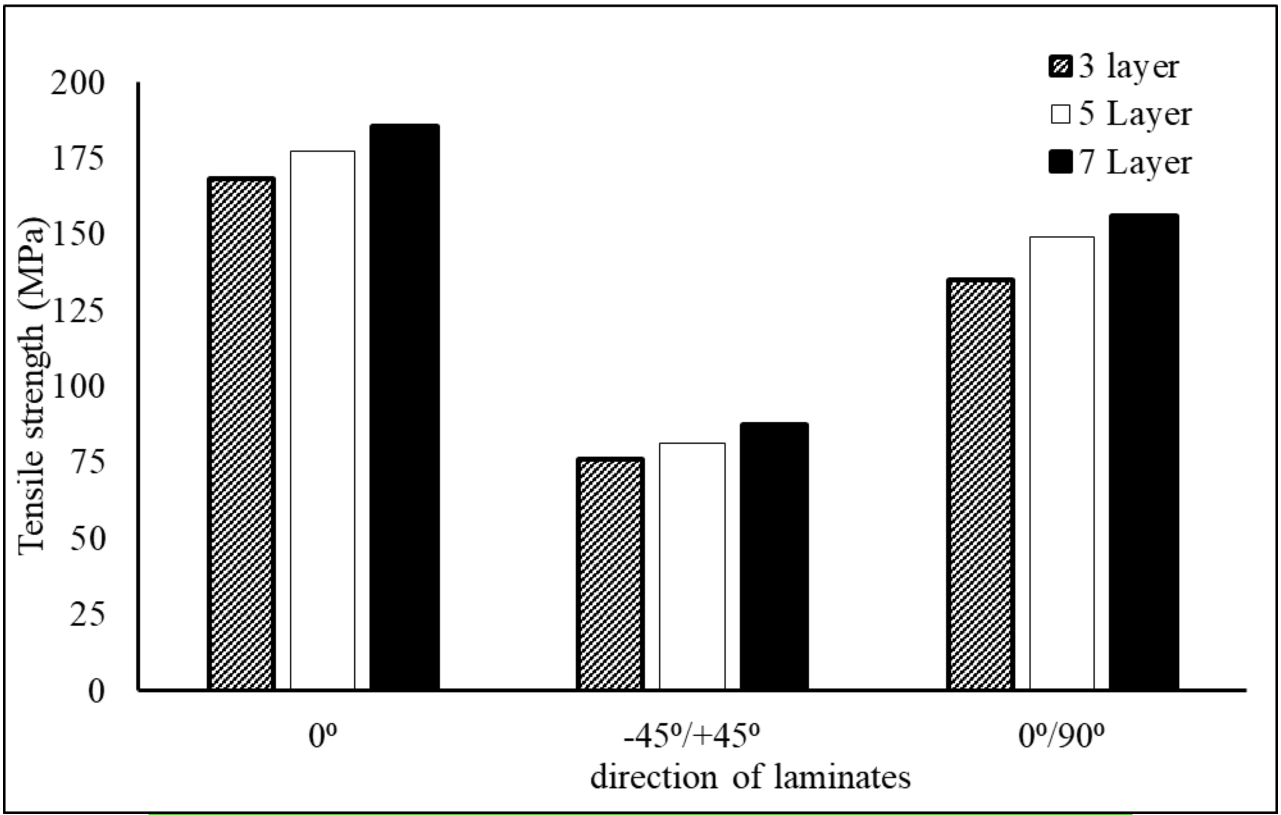

Fig. 6. Tensile strength of LBCs with 2 MPa pressure compaction

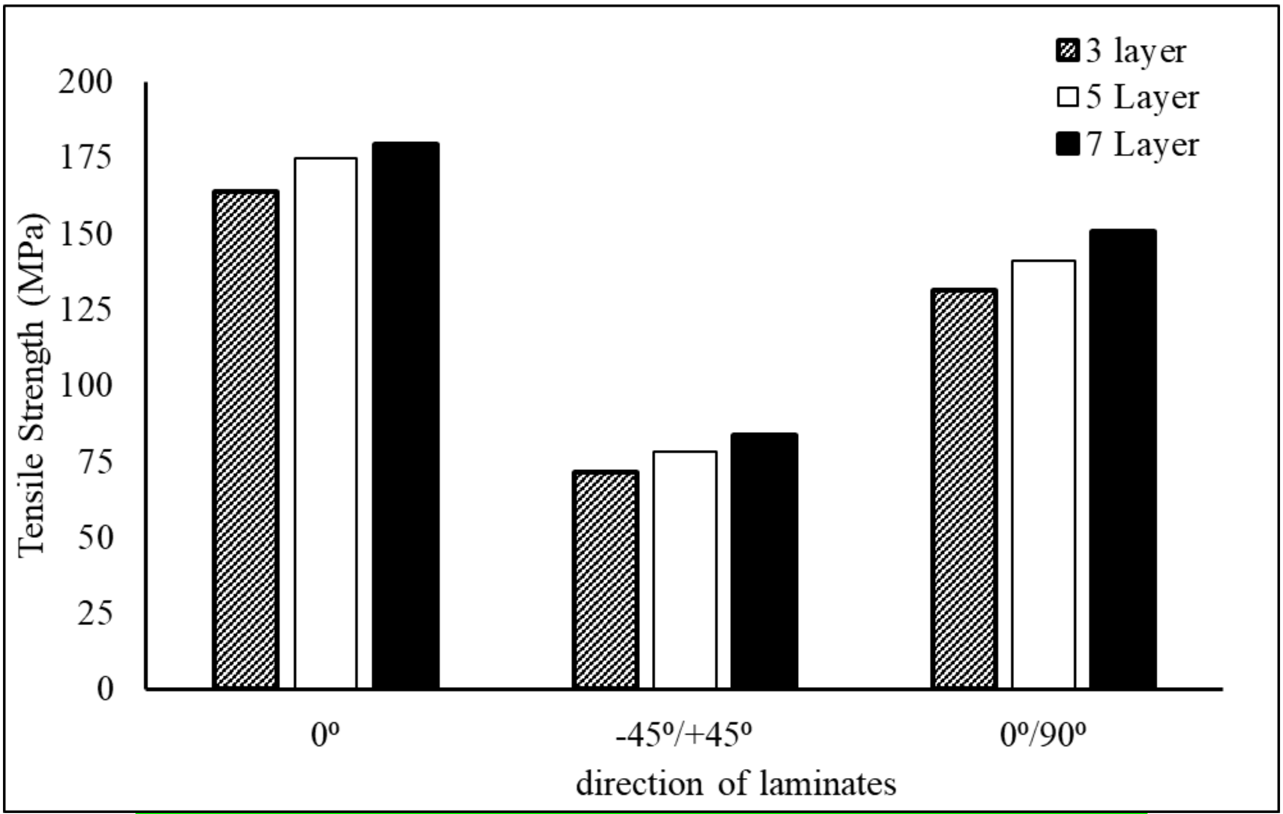

Fig. 7. Tensile strength of LBCs with 2.5 MPa pressure compaction

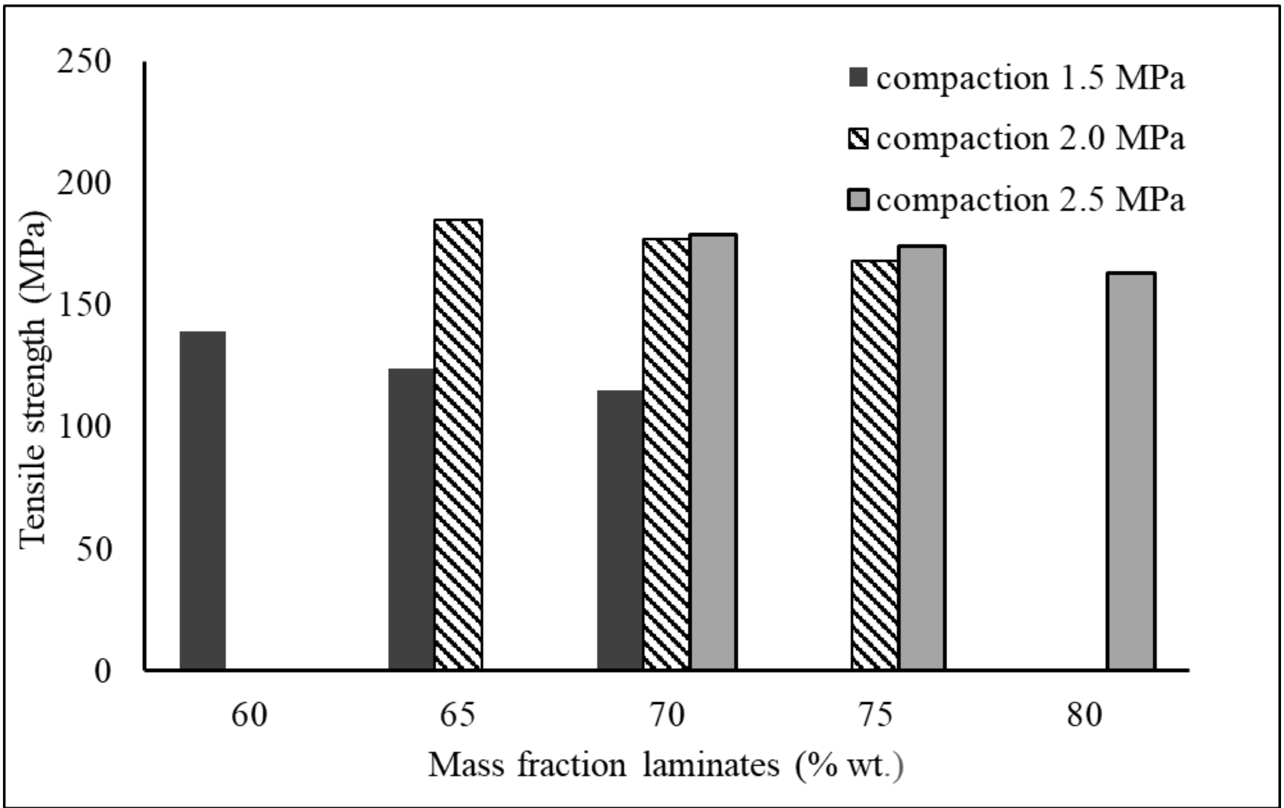

Fig. 8. The effect of mass fraction bamboo laminates on tensile strength of LBCs in composites with direction of 0º

At all pressure variations, LBCs with a 0° laminates direction has a higher tensile strength than LBCs with a direction −45°/+45°and 0°/90°. LBCs with laminates direction -45°/+45° produced lower tensile strength than the others. The effect of mass fraction fraction bamboo laminates and tensile strength of LBCs in composites with direction of 0° is shown in Fig. 8. LBCs with 7 layers laminates 1 mm laminae thickness and compacting pressure 1.5 MPa produces composites with % wt. reinforcement 60 %. At compacting pressure 2.0 MPa and 2.5 MPa, % wt. of LBCs with 7 layers laminates 1 mm laminae thickness are 65% and 70 % respectively. The tensile strengths of LBCs with seven layers are 139 MPa, 185 MPa, and 180 MPa at 1.5 MPa, 2.0 MPa, and 2.5 MPa compaction pressures, respectively. LBCs with 3 layers and 2 mm thickness of laminae yield composite with % wt. reinforcement higher than LBCs with 7 layers and laminae thickness 1 mm. LBCs with three layers and 1.5 MPa, 2.0 MPa, or 2.5 MPa pressure compaction produce LBCs with tensile strengths of 115 MPa, 168 MPa, and 164 MPa, respectively.

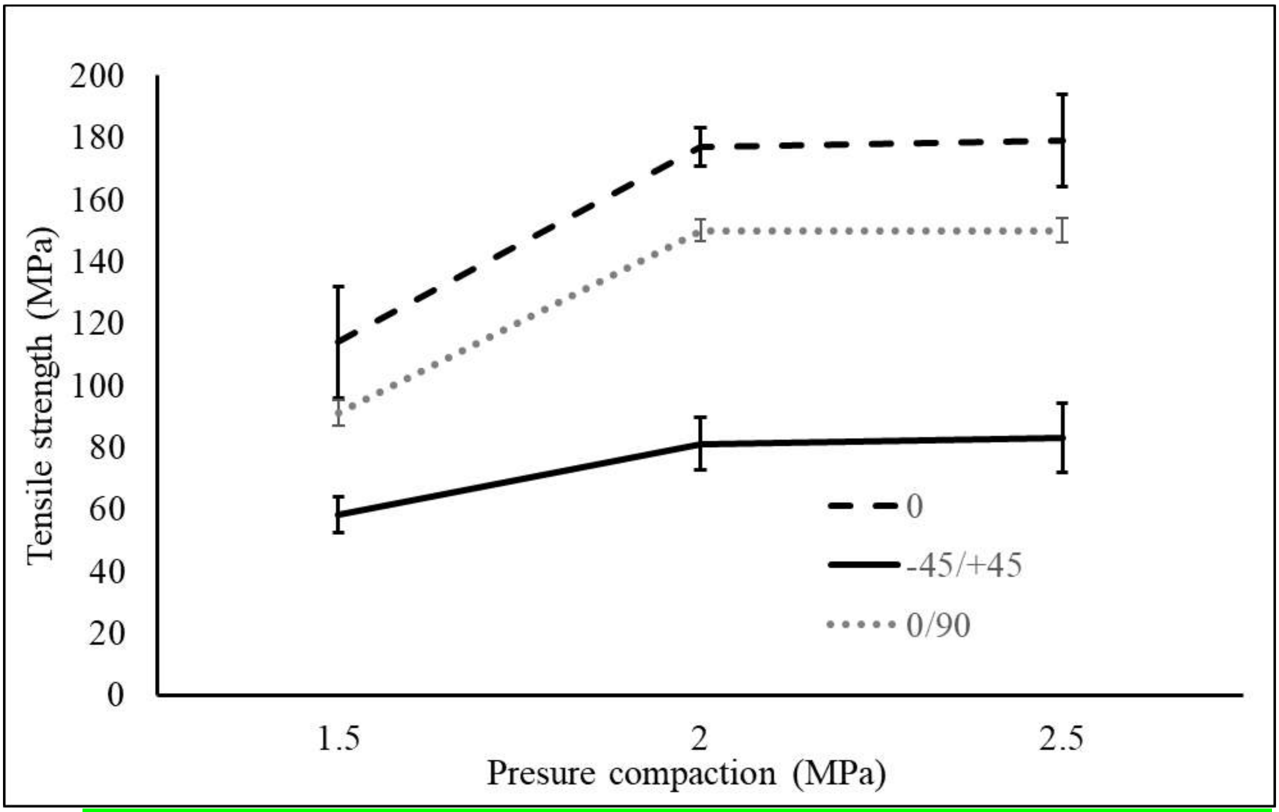

Fig. 9. The effect of Compaction Pressure on Tensile Strength of LBCs at 70 % Mass Fraction

The graph in Fig. 9 also shows the effect of compacting pressure on the tensile strength of LBCs at the mass fraction of 70 %. This analysis selected a mass fraction of 70 % wt because a mass fraction of 70 % wt was generated for all variations studied (Fig. 8). Fig. 9 shows that increasing the compression from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0° laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0°/90° laminates direction. Increasing the compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. The differences of tensile strengths are smaller than the standard deviation of the test. Therefore, it can be concluded the increase in pressure from 2 MPa to 2.5 MPa does not significantly affect the tensile strength of LBCs.

5. 2. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on bending strength Laminated Bamboo Composites.

Table 4 and Fig. 10–12 show the bending strength of LBCs with variations of the direction of laminates: 0°, -45°/+ 45°, 0°/90° and variations in the number (3, 5 and 7) and thickness (1 mm, 1.5 mm and 2 mm) of apus bamboo laminae with variation of compacting pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa. Fig. 10 shows LBCs with direction of laminates 0° resulted higher bending strength than LBCs with laminates direction 0°/90° or -45°/+45°. Bending strength of LBCs with 0° laminates is approximately 8% stronger than either of LBCs with 0°/90° laminates and approximately 12% greater than that of LBCs with -45°/+45° laminates. At pressure compaction 1.5 MPa, highest bending strengtn of LBCs is 265 MPa, lowest bending strength is produced by LBCs with laminates direction -45°/+45° with valued 218 MPa (approximately 82 % form highest bending strength).

Table 4.
Bending strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0°	251	257	265	295	315	321	280	298	306
-45°/+45°	218	229	232	245	266	271	234	239	259
0°/90°	233	241	240	274	284	294	261	268	279

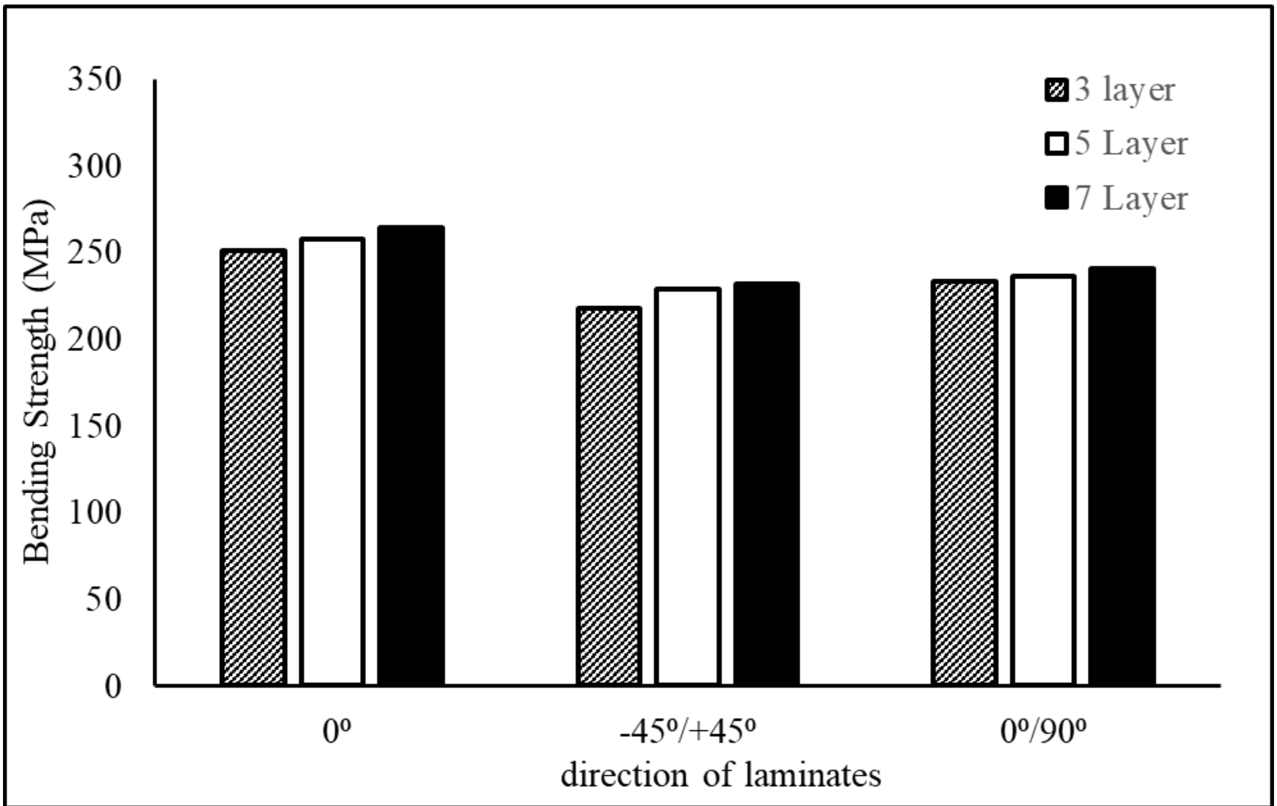

Fig. 10. Bending strength of LBCs with compaction pressure 1.5 MPa

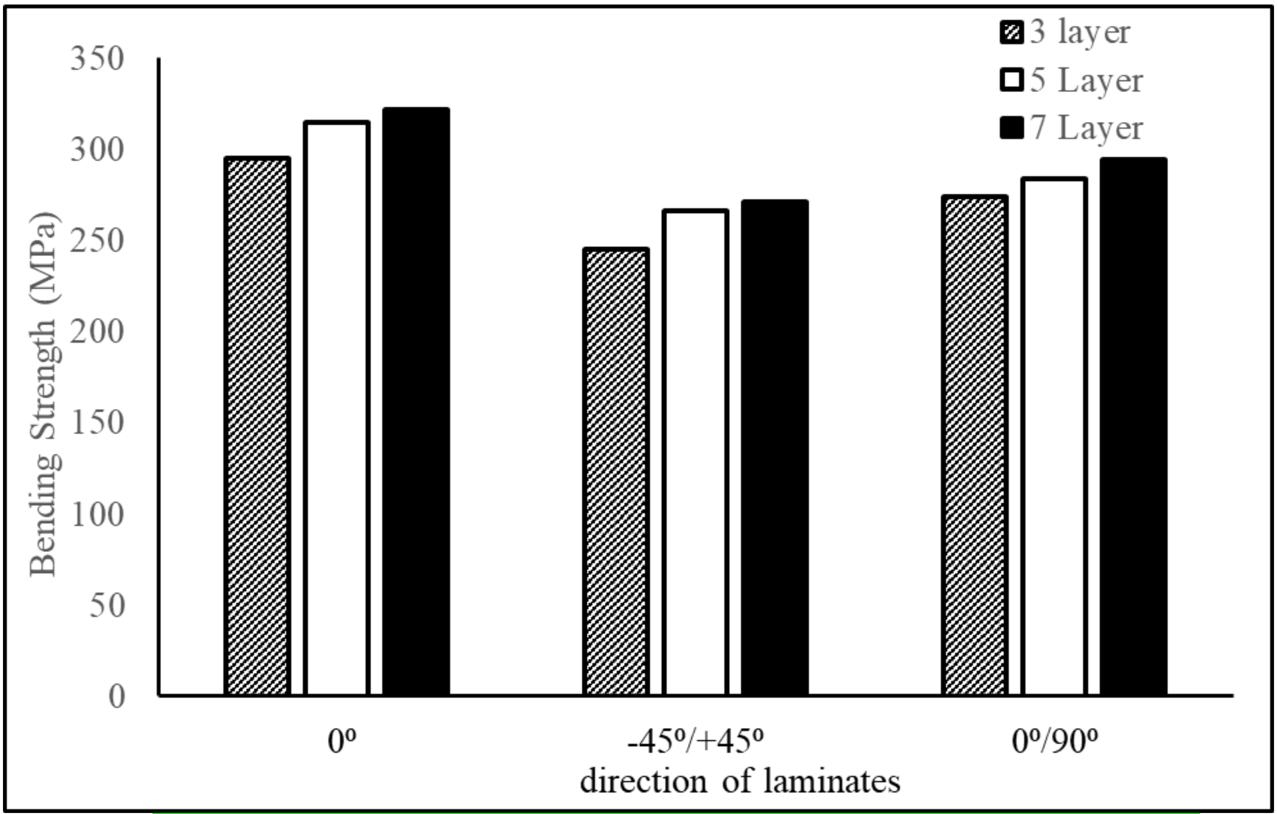

Fig. 11. Bending strength of LBCs with compaction pressure 2.0 MPa

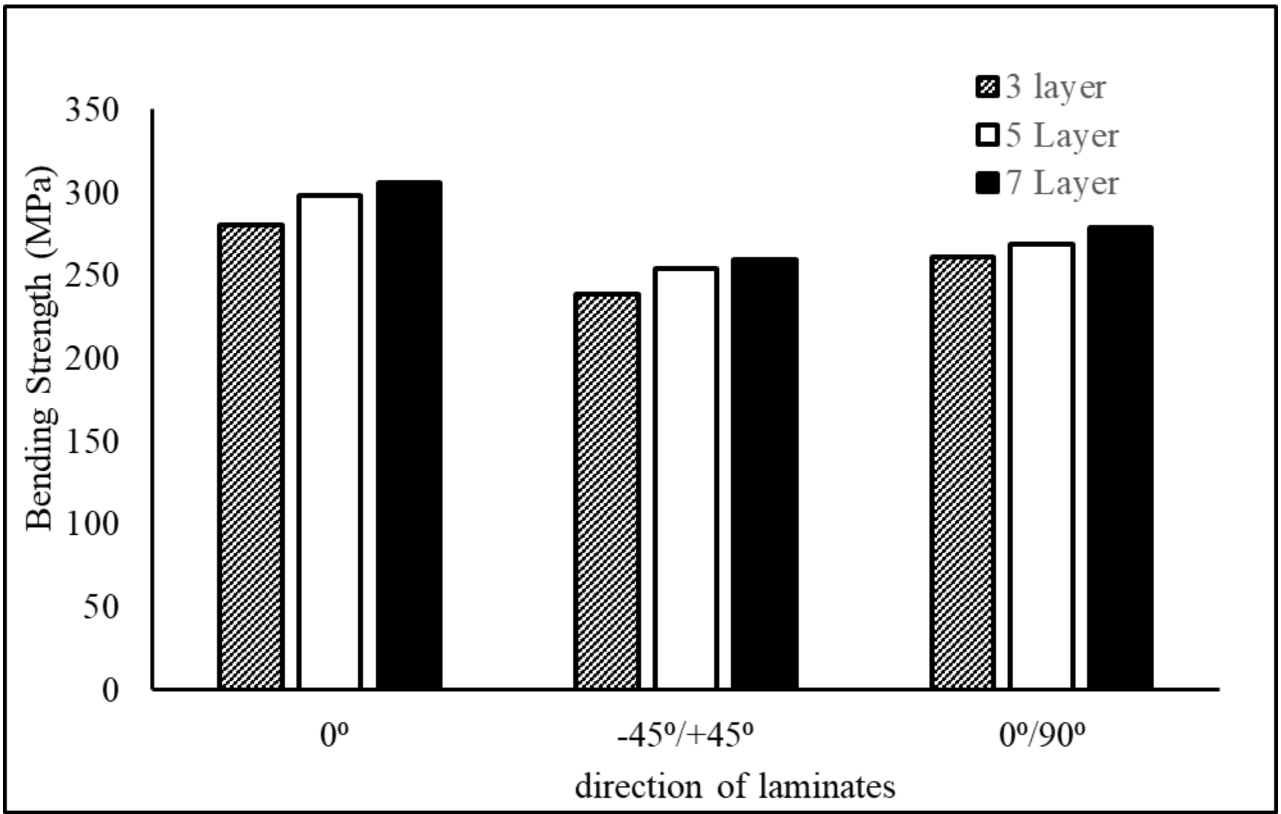

Fig. 12. Bending strength of LBCs with compaction pressure 2.5 MPa

Bending strength of LBCs with compaction pressure 2.0 MPa and 2.5 MPa are depicted in Fig. 11 and Fig. 12, respectively. the value of the bending strength of the composite with a compaction pressure of 2.0 MPa ranged from 245 MPa to 321 MPa.

LBCs have a bending strength of between 234 and 306 MPa when compressed to 2.5 MPa. The composite with a 0° layer direction and 7 layers of laminas produces the highest bending strength

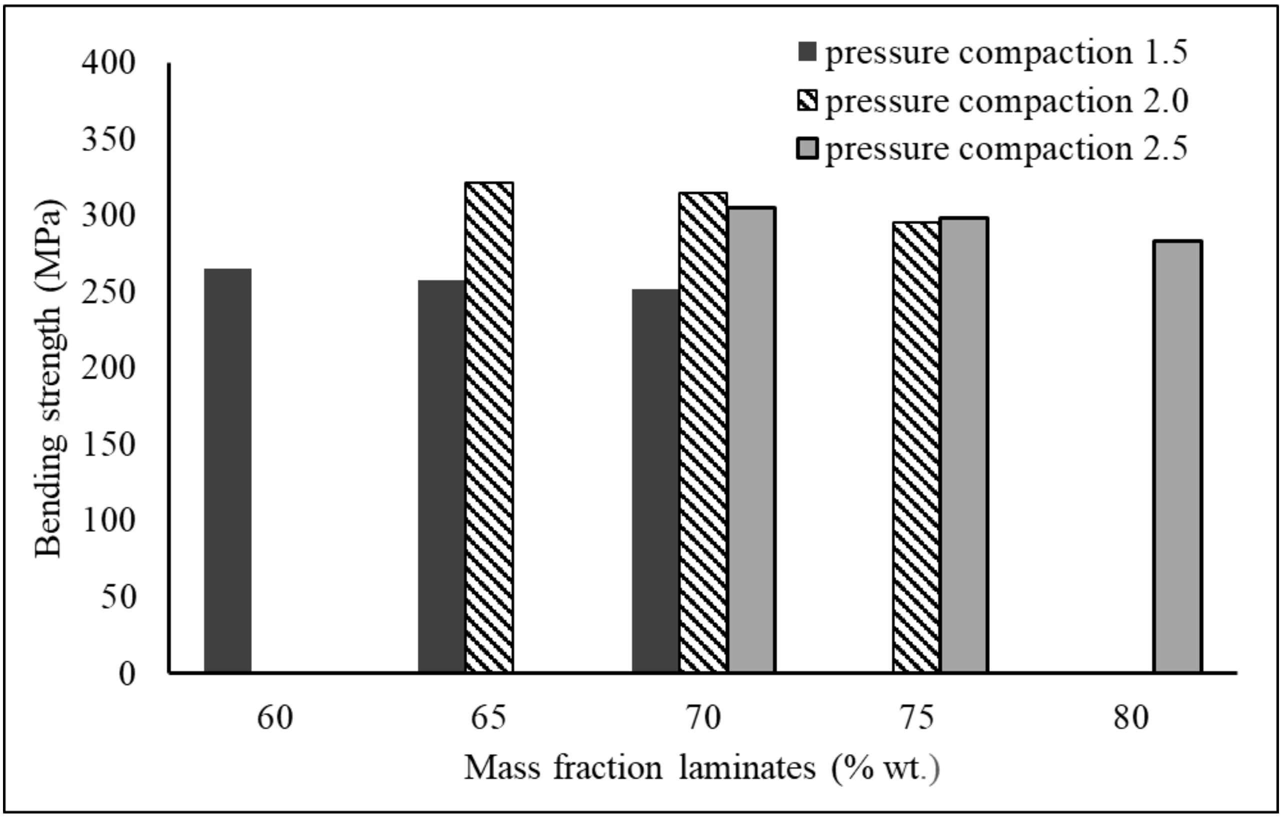

Fig. 13. The effect of mass fraction of laminates on bending strength of LBCs with 0° direction

The relationship between the bending strength of LBCs and their mass fraction with the laminates' on-axis (0°) direction is depicted in Fig. 13. At 1.5 MPa compaction pressure, LBCs with a mass fraction of 60% have stractured 7 layers of laminae with a thickness of 1 mm, yielding the highest bending strength of 265 MPa. At compression pressures of 2.0 MPa and 2.5 MPa, LBCs with 7 layers laminas exhibit the highest bending strength, with values of 321 MPa and 306 MPa, respectively. From the graph in Fig. 13, it can be concluded that the highest bending strength is in the composite with thinner bamboo reinforcement and a higher number of layers even at a lower mass fraction.

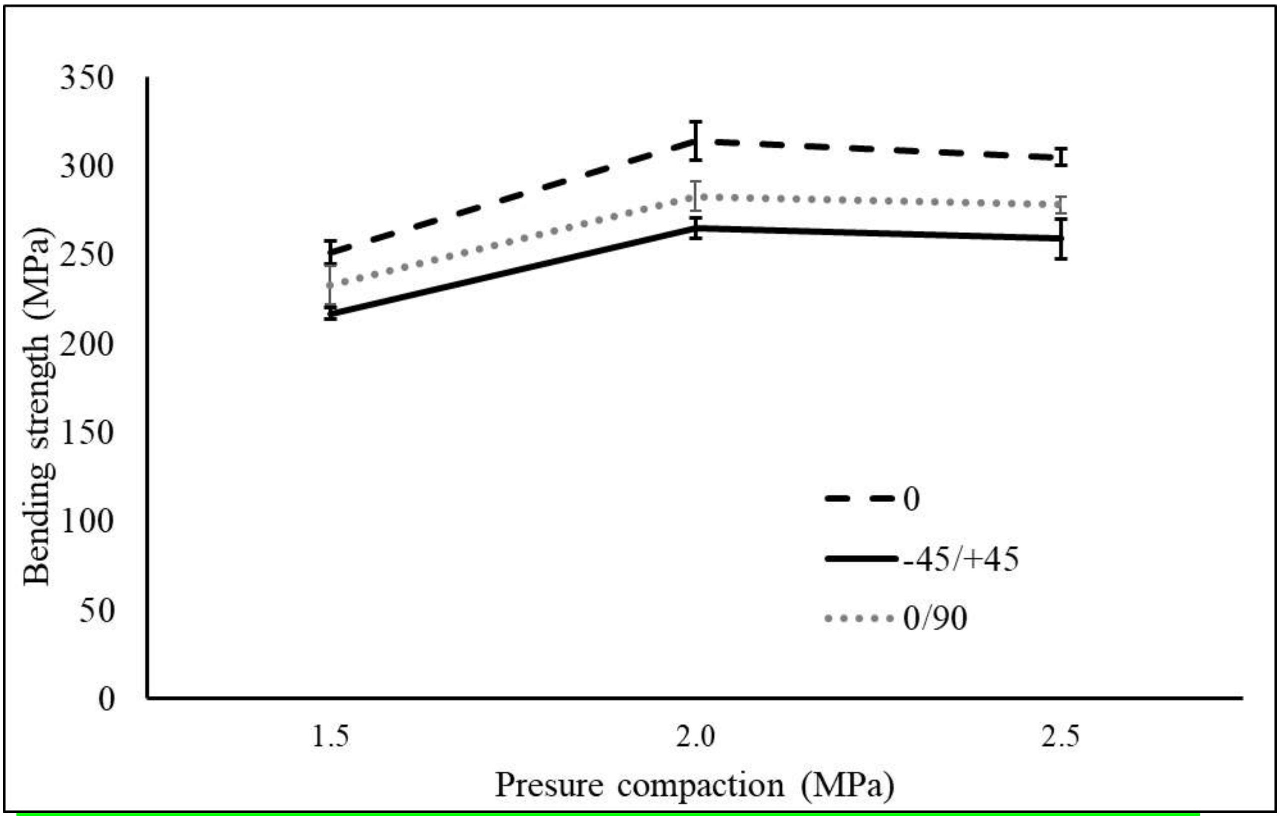

Fig.14. The effect of Compaction Pressure on the Bending Strength of LBCs at 70 % Mass Fraction

The graph in Fig. 14 also shows the effect of compacting pressure on the bending strength of LBCs at the mass fraction of 70 %. By increasing pressure compaction from 1.5 MPa to 2 MPa, the bending strength of LBCs increase by 25% in the 0° laminates direction, 22% in the 45°/+45° laminates direction, and 21% in the 0°/90° laminates direction. As with the tensile tests, increasing the compacting pressure from 2 MPa to 2.5 MPa have no noticeable effect on the bending strength of LBCs.

5. 3. Investigatiom fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs);

Fig. 15 shows a macro photograph of the surface fracture of LBCs after tensile testing. Fig. 15. *a* shows the fracture of LBCs with laminates direction 0°. The fracture surface of the LBCs with the laminates direction -45°/+45° (Fig. 15, *b*) and the fracture surface of the LBCs with the laminates direction -0°/90° (Fig. 15, *c*). The LBCs with 0° direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by load transfer to bamboo laminas and subsequent bamboo laminae fracture. Fig. 15. *b* shows the fracture of matrix followed by delamination of laminae in the 90° direction, and finally fracture of laminae in the 0° direction. In LBCs with laminates orientation +45°/-45°, matrix fracture was followed by delamination and laminae clefting.

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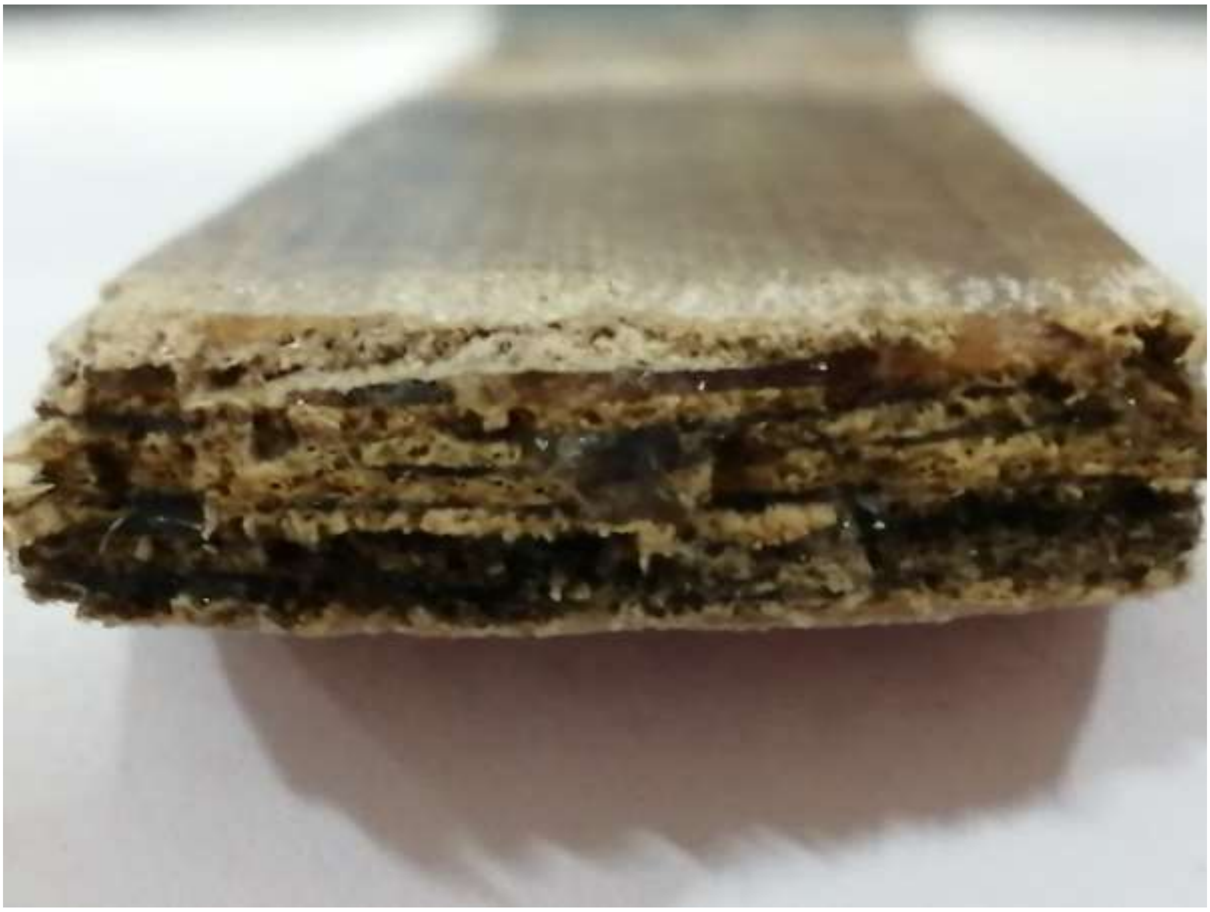
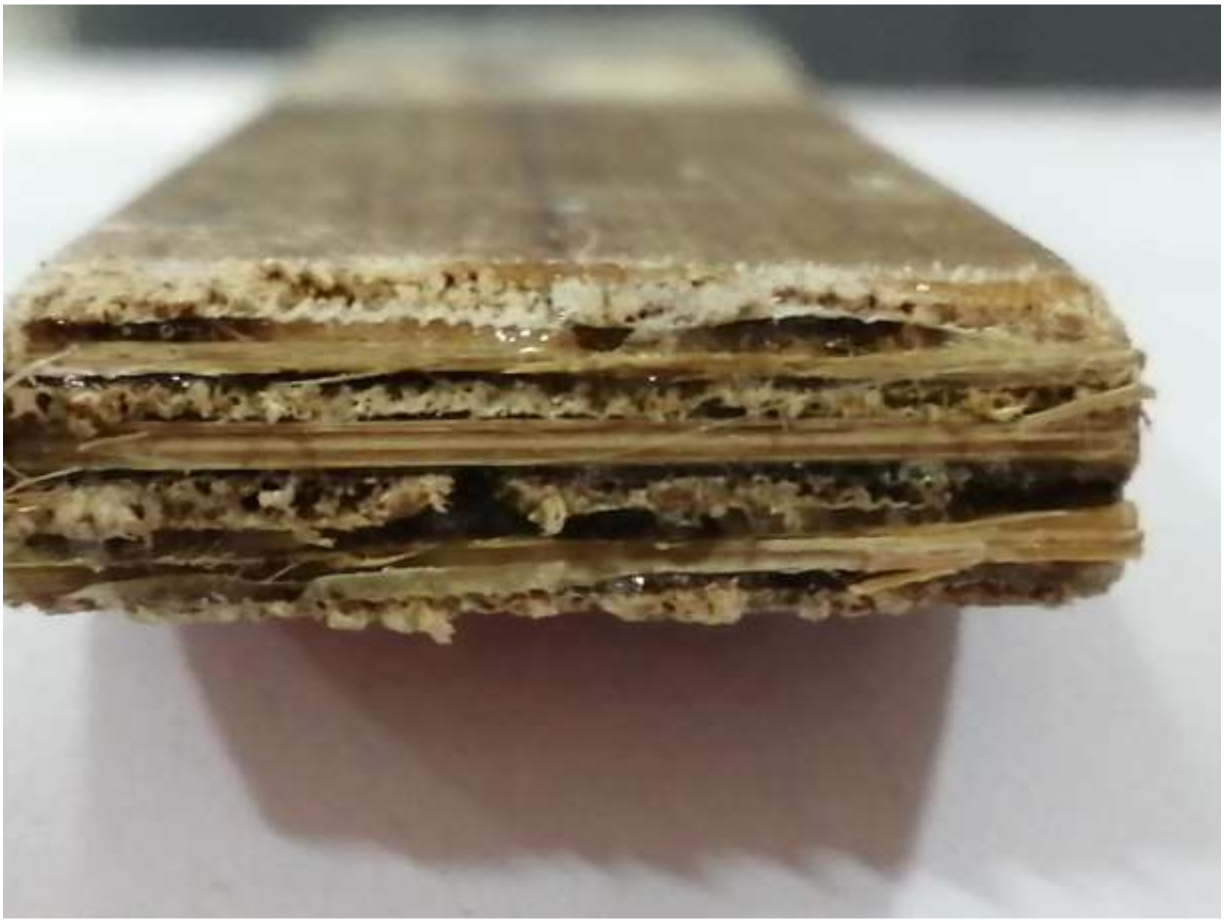


a

b



c

Fig. 15. Photomacrography The Fracture of Cross Section of The Tensile Test of 7 Layers Laminated Bamboo Composites (LBCs)

a. direction of laminates 0^o

b. direction of laminates $-45^o/+45^o$

c. direction of laminates $0^o/90^o$

draw a picture from a hidden table

a

b

c

Fig. 16. Bending Test Result Specimens of Laminated Bamboo Composites (LBCs) from 7 layers.

a. layers direction of 0^{o}

b. layers direction -45^{o}/45^{o}

c. layers direction 0^{o}/90^{o}

The macro photographs of the LBCs after bending tested are shown in Fig. 16. Fig 16.*a* shows that bending tested of LBCs with 0^{o} laminates direction, produced fractured of matrix and followed fracture of laminates. Fracture photographs of LBCs with layers direction -45^{o}/45^{o} (Fig 16. *b*) shows, that at At the bottom of the specimen, fracture occurs due to laminae delamination. Failure continues with delamination and the laminae splits due to shear stress. The failure of the specimen with the direction of the lamina 0^{o}/90^{o} as shown in Fig 16.*c* indicates that the failure due to bending started with matrix fracture and fracture laminae at the bottom (outer) of the specimen. Failure is followed by delamination of the lamina in the 90^{o} direction

6. Discussion of experimental results

Apus bamboo (gigantochloa apus) with a lamina's tensile strength of 230 MPa and an epoxy resin with a tensile strength of 57 MPa after being formed into a composite LBCs was able to produce the highest tensile strength of 185 MPa with a ratio of 70 % lamina bamboo lamina mass fraction and 70 % mass fraction. (wt) epoxy-resin 30 %. This result higher than previous research that reported composites used gigantochloa scortechinii (semantan reed) woven bamboo as reinforcement with a ratio of 33 % of the mass fraction (wt) of bamboo laminates and the mass fraction (wt) of 77 % epoxy matrix was only able to produce a maximum tensile strength of 89 MPa [11].

At each compacting pressure value, the highest tensile strength was achieved by LBCs, with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo lamina. It can be concluded that the highest tensile strength is in the composite with thinner bamboo reinforcement and more layers, even at a lower mass fraction. Increasing the tensile strength properties of LBCs in the thinner bamboo lamina reinforcement with a higher number of composites forming layers is an important concern in this study. This caused by the ability of the epoxy resin to enter the thinner pores of the apus bamboo fiber, thereby increasing the interface strength of the composite-forming bamboo layer. The other works also reported that increasing the number of laminas forming the Layered Laminate Bamboo Composites (LLBCs) will increase tensile and flexural stress [7]. The tensile strength of laminated composites is dependent on the interfacial properties of natural fibers and polymer composites. Additionally, the tensile properties are contingent upon the laminates directions [19]. Study on mechanical properties of laminated bamboo composites with different bamboo and matrices (gigantochloa scortechinii and unsaturated polyester) showed that the thicker the bamboo blades produced the higher the tensile stress and flexural stress [20].

They also mentioned that the direction configuration of the composite laminates also affects the tensile stress and flexural stress of LLBCs. The configuration of the laminates with direction 0º gave the best result of tensile strength compared to the configuration of the direction of the fiber crossed 0°/45° and 0°/90°. Thus, the tensile strength of the LBCs decreases with increasing the angle of the laminates under the tensile stress. According to the Tsai–Hill criterion, the tensile and compressive properties of the composite will continue to decrease due to changes in the fiber orientation angle that increases from 0° [21]. This study's results prove that the direction of the lamina 0° provides the higher tensile strength compared to the direction of the laminates −45°/+45°, 0°/90°.

The compacting pressure applied to the manufacture of LBCs affects the mass fraction (wt) of the epoxy resin matrix contained in the LBCs. The compacting pressure will drive the epoxy resin out of the LBCs mold while the mass fraction of the bamboo laminates steady. Higher compression pressure will reduce the % wt epoxy-resin. The pressure compaction of LBCs from 1.5 MPa to 2.0 MPa can reduce the weight fraction of epoxy resin in LBCs by 5 % of the initial mass fraction, but it can increase the tensile strength of LBCs by 55 % at laminates direction 0°, 40 % in the direction of laminates −45°/+45° and 64 % in the direction of laminates 0°/90°. Another researcher reported that LBCs without compacting pressure could produce a maximum tensile strength of

89 MPa [9]. The optimum tensile stress of Laminated Bamboo Composites (LBCs) was obtained at a 2 MPa compaction pressure variation with a mass fraction (wt) of lamina of 70 % and a mass fraction (wt) of epoxy-resin of 30 %. The application of compacting pressure above 2 MPa on LBCs didn't affect on the value of tensile stress. The anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs each by 5 % for each variation of the tested specimens.

The LBCs with 7 layers of bamboo laminas, 1 mm thickness, 0^o fiber direction and 2 MPa stress yield highest bending strength valued 321 MPa. It's aproximatelly 20 % stronger than LBCs with compacted pressure 1.5 and 5 % higher than LBCs with 2.5 MPa compaction pressure. Apus bamboo (gigantochloa apus) with a bending strength of laminae 348 MPa and epoxy-resin with bending strength of 175 Mpa, after being manufactured into a composite LBCs, this materials yield the highest bending strength of 321 MPa with a ratio of mass fraction (wt) of 70 % and mass fraction (%. wt) epoxy-resin 30 %. Gigantochloa scortechinii (semantan reed) woven bamboo with a ratio of 33 % of the mass fraction (wt) of bamboo laminates and the mass fraction (wt) of 67 % epoxy matrix was only able to produce a maximum bending strength of 120 MPa [11]. The bamboo allowed large flexural deformations because its outer part retains the tensile stress while the softer inner part undergoes large compressive deformation [22]. The configuration of the 0^o direction of the laminates yield the higher bending strength compared to the configuration of $0^o/45^o$ and $0^o/90^o$ crossed laminates [21].

The bending stress of laminated bamboo composites is also influenced by the direction (orientation) of the bamboo laminate and the number of layers. At each variation in the direction of the bamboo laminatesand stress, the bending strength of the LBCs increased with the increasing number of layers of bamboo laminas. In the number of layers, the bending strength of LBCs with the laminates direction of 0^o has the largest bending strength, followed by the crossed fiber direction of 90^o and the lowest bending strength is the LBCs with the -45^o / $+ 45^o$ fiber direction.

The Laminated Bamboo Composites (LBCs) with more layers of laminas produce higher tensile and bending strength compare with LBCs with less number of laminas. The thinner laminae provide a higher adhesive contact surface area than the thicker laminae. Higher adhesive contact area provides better stress transfer to the laminae [23].

Fractuce of LBCs with on axis (0^o) laminates direction, all stress are transfer by matrik to laminates. Bamboo laminates bamboo lamina can fully withstand the load transferred by the matrix. This causes LBCs with laminates 0^o direction (on axis) to be stronger than LBCs with off axis laminated direction. The cross section of fracture photograph demonstrates that the fracture mechanism is a fracture matrix followed by the breaking of the bamboo laminates. LBCs with off axis direction ($-45^o/+45^o$ and $0^o/90^o$) fracture mechanism of LBCs, there delamination of laminae caused by debonding of adhesion between laminae. in the cross-sectional image of the fracture, the laminae delamination behavior is shown.

The structurally-substantive scheme of this section:

- how can the results be explained? This interpretation part is the first main part of the discussion and there are important nuances of its presentation. It is necessary to explain the results obtained for each research objective, referring to those objects in the article that display the discussed results. Such objects in the general case are analytical expressions, figures, tables. That is, it should be seen which result is being discussed at this point in the section.
- how do the proposed solutions/results allow to close the problem area identified by the author, and if so, in which part and due to what exactly? This is the second main part of the discussion, because it is this that closes the research (feedback): the problem is identified – the aim is set – the results are obtained – the results are explained using some kind of evidence base (section "Discussion ...")
- what can be considered the advantages of this study in comparison with those known on this subject. In this case, it is necessary to indicate alternative solutions and say, thanks to which particular features of the proposed solutions, advantages (or, in general, differences) are provided?
- what limitations are inherent in this study? This is the third main part of the discussion.
- what are the disadvantages of the study and in what direction should the study be developed?

7. Conclusions

number of objectives=number of conclusions

1. LBCs with 0° direction of laminas yield higher tensile strength than LBCs with off axis direction of laminates (-45°/45°; 0°/90°). Incresing number of laminate increase tensile strength of LBCs. LBCs with thinner laminae provide a higher adhesive contact surface area than the thicker laminae and yield higher tensile strength of LBCs. The rise of the pressure compation from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0° laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0°/90° laminates direction. Increasing the compacting pressure from 2.0 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. Highest tensile strength of LBCs with value 185 MPa is produced by LBCs with direction 0°, 7 laminas, 1 mm thickness of laminae with pressure compaction 2 MPa.
2. The highest bending strength of LBCs, 321 MPa, is achieved with LBCs in the 0° direction, 7 laminas, 1 mm thickness of laminae, and 2 MPa pressure compaction. LBCs with laminates oriented on axis (0°) have a greater bending strength than composites with orientation of laminates off axis (-45°/45°; 0°/90°). LBCs' bending strength increases as the number of laminates increases. Increases the bending strength of LBCs by 25% in the 0° laminates direction, 22% in the 45°/+45° laminates direction, and 21% in the 0°/90° laminates direction when the pressure compaction is increased from 1.5 MPa to 2.0 MPa. Increased compacting pressure from 2.0 to 2.5 MPa has no perceptible effect on the tensile strength of the LBCs.
3. The LBCs with 0° direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by bamboo laminae fracture. Composites with 0°/90°

laminates direction, the fracture of matrix followed by delamination of laminae in the 90^o direction, and finally fracture of laminae in the 0^o direction. In LBCs with laminates orientation -45^o/+45^o, matrix fracture was followed by delamination and laminae clefting.

Each conclusion should be concretized in accordance with its research objective. Each conclusion should contain the following information: what is the result obtained for this research objective, what are its features and differences from known alternative data, how can this result be explained? Numerical estimates of the result are also recommended. It is these parts of each conclusion that indicate the originality and scientific novelty of the solutions obtained.

1. The number of conclusions should correspond to the number of objectives in section 3.

2. It is desirable to use some numerical estimates of the results in the conclusions

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INVESTIGATION OF MECHANICAL PROPERTIES OF LAMINATED BAMBOO APUS (GIGANTOCHLOA APUS) COMPOSITES WITH EPOXY-RESIN MATRIX

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Parlindungan Manik, Agus Suprihanto, Sri Nugroho, Sulardjaka

This study aims to investigate the mechanical properties of bamboo apus (gigantochloa apus) as a natural reinforced composite material. Bamboo's laminates of gigantochloa apus was used as reinforcement on the epoxy resin matrix. The parameters examined in this study were the variation in the number, thickness and direction of the laminates. The stem of bamboo with a length of 400 mm was split to obtain bamboo laminae with a size of 400 mm x 20 mm. The thickness of bamboo laminae is varied between 1 mm, 1.5 mm, and 2 mm. The bamboo laminas is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution and dried in an oven until the water content reaches 10 %. The Laminated Bamboo Composites (LBCs) were made with a hand lay-up method. After the LBCs are moulded, the mould were pressed with 3 variations of dies compaction

1.5 MPa, 2 MPa and 2.5 MPa. The tensile and bending test characteristics were carried out on the LBCs. Tensile testing is performed in accordance with ASTM standard D3039 and the bending tests were conducted based on ASTM standard D7264. The results shows at each compacting pressure, the highest tensile and bending strength was achieved by LBCs with a thickness of 1 mm of bamboo laminae and 7 layers of bamboo laminates. The LBCs with thinner bamboo laminae reinforcement and more layers has the highest tensile strength and bending strength, even it has lower mass fraction. The LBCs with laminates oriented 0^o exhibited greater tensile and bending strengths than the LBCs with laminates structured -45^o/+45^o and 0^o/90^o. The LBCs with 0^o laminates direction is matrix fracture than followed by laminae fracture. In the 0^o/90^o direction, matrix fracture followed by delamination in the 90^o laminates and the 0^o direction laminates. Delamination and laminae clefting were observed in LBCs with laminates oriented +45^o/-45^o.

Keyword: Laminates Bamboo Composites, Gigantochloa Apus, Tensile Strength, Bending strength.

1. Introduction

Bamboo is a group in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. There are more than 1,450 bamboo species are found in cold mountains to hot tropical regions. Bamboo can be harvested in 3–4 years after planting, compared to the traditional timbers that need decades between planting and harvesting [1, 2]. Bamboo has specific mechanical properties that are superior to other types of natural fibers due to the longitudinal arrangement of the fibers. The small microfibrillar angles of the bamboo fibers support high volume stability and excellent mechanical properties [3–5]. The advantages of the mechanical properties of bamboo and the availability of abundant materials have attracted many researchers to use bamboo as reinforcement in composite materials. The use of bamboo fibers as a reinforcing material provide many benefits. Natural fibers that are low in density can be employed as a useful lightweight engineering material compared to synthetic fibers like glass fibers or carbon fibers [6]. Unfortunately, as for the area of bamboo composites characterizations in thermoset setting, only a handful of studies have looked into laminate-based bamboo composites. The use of bamboo as a composite material provides solutions in the development of the materials industry. The tensile strength of bamboo is about twice as high as the tensile strength of lumber, with the compressive strength is approximately 1.5 times stronger than lumber. The strength to weight ratio of bamboo is higher than lumber and plain steel [7]. Bamboo fiber has the potential to replace glass fibers as reinforcing composites. The bamboo fiber has a specific young modulus (Specific E) comparable with the E-glass fiber. It means that the bamboo fiber has a high stiffness with minimum weights [8, 9]. A rather recent study concerning bamboo strips had successfully characterized several imminent properties, for example, tensile, flexural, impact, and hardness of bamboo composite in a comprehensive manner [10].

Indonesia is a tropical country with various species of bamboo plants, including petung bamboo (*dendrocalamus asper*), wulung bamboo (*gigantochloa atroviolacea*), yellow bamboo (*bambusa vulgaris*), spotted bamboo (*bambusa* *maculata*), apus bamboo (*gigantochloa apus*) and others. Bamboo is widely used for flooring, roof construction, crafts/furniture, and fabrics. Apus bamboo (*gigantochloa apus*) is a type of bamboo that has the advantage of being easy to divide and cut up to the thickness of 1 mm. At this time, apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, ceiling/home asbestos and woven crafts. The Apus bamboo has tensile strength 230 MPa with density is 0.6 gr/cm^3. Strength to weight ratio of Apus bamboo is higher than woods. The abundant availability of apus bamboo and its good mechanical properties can be used to replace wood in various structural applications. The limitation of bamboo for engineering applications is due to its shape.

Bamboo engineering with lamination by develop Laminated Bamboo Composites (LBCs) is a method to increase the application of bamboo as a engineering materials. Laminated bamboo is a processed bamboo based composite manufactured by gluing bamboo strips/laminae under controlled temperature or pressure. The purpose of this article is to develop a LBCs by using epoxy resin reinforced with laminates of Apus bamboo (*gigantochloa apus*). Therefore, studies are being conducted to investigate the effect of the pressure, number, thickness and direction of Apus bamboo laminae on the tensile and bending strengths of LBCs reinforced with apus bamboo laminates. This is superfluous, because this section of the article did not need to annotate the article. It was necessary to justify the relevance of this problem in modern times. Therefore, you can remove this part of the text.

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2. Literature review and problem statement

Bamboo fiber was used as reinforcement of composite. The mechanical behavior of short untreated and treated with NaOH bamboo fiber reinforced epoxy resin composites were studied. Bamboo fibers with various lengths and contents are reinforced with epoxy resin to produce a composite. The results showed that the mechanical properties of the tensile strength, flexural strength, and impact strength of composites were influenced by the NaOH treatment. The tensile strength of composite with three layers of treated fiber is 18.07 MPa and 16.51 MPa for three layers of untreated fiber [11]. Treating the apus bamboo (*gigantochloa apus*) laminas by soaking it in methanol solution increases the tensile and flexure strength of laminated bamboo composites about 10 % [12]. It is shown that treatment of bamboo by NaOH or methanol solution will enhance the mechanical properties of bamboo composites.

The use of gigantochloa scortechinii woven bamboo fibers as reinforcement in composite materials has been investigated. Bamboo matting is made from sheets of bamboo layers measuring: 0.5 mm thickness and 5.0 mm width. Composites with 2 to 6 bamboo layers were made with a hand lay-up method by using epoxy resin as the matrix. The results of the mechanical properties test (tensile test, bending test, hardness test, and impact test) showed that the composite with two layers of woven reinforcement had high mechanical properties [13]. Bamboo sheets made from thin-wall bamboo culm and isocyanate adhesive have been used to produce laminated bamboo esterilla sheets (LBES). TLBES were fabricated by manual compaction and hydraulic compaction. Manual compaction of laminated bamboo was handled using a hand-tightened bolt without measuring the amount of applied pressure. Hydraulic compaction was conducted on the laboratory-scale Weili MH3848(A) 100 T hydraulic pressing machine. The results show that different compaction methods resulted different properties of LBCs [14]. As a result of these findings, it can be concluded that increasing the layer of bamboo, reduces the mechanical properties of composites. The effect of pressure, thickness and number of laminae are interesting to investigate. Pressure, thickness and number of laminae are important variable on mechanical properties of LBCs.

The laminated composites (LBCs) using four laminas of dendrocalamus strictus cold-pressed using epoxy resin result in maximum stress of LBCs of about 210 MPa. The specimens used had a cross-section of 16 mm x 10 mm. This study reported that compressive strengths of LBCs ranging between 55 MPa and 88 MPa. The fracture mode of LBCs found that the matrix failure occurs followed by fibers failure with metallic sound of anyone layer and subsequently other layers in specimens. There are good agreements between the theoretical values and experiment results for stiffness and strength [15]. Laminated Bamboo Composites (LBCs) of *dendrocalamus strictus* bamboo culms were manufactured from laminas and laminates using an epoxy resin matrix. The mechanical properties of LBCs have been evaluated with different loading conditions. The results show that the mechanical properties of LBCs are better than teak wood, which is one of the strongest woods [16]. The work [17] reported significant differences in strength and behavior between small specimens sourced from different growth portions with the full-size structural members (cross-section 100 mm x 100 mm) constructed from laminated bamboo sourced from different growth portions of the culm. This study found that the bamboo laminate sourced from the middle growth section has the largest elastic modulus. The study of tensile properties of single and two ply laminated bamboo at various off-axis loading angles and laminates configurations has shown that composite laminate theory is applicable to LBCs composite and may be used for design of products and structures [18]. This study fills the gap in existing knowledge of laminated bamboo composites, in order to characterisation of mechanical behaviour of single and multi ply laminates with off-axis loading angle, as well as laminate configuration.

Based on previous studies, it can be concluded that for enhancing the use of bamboo as an engineering materials can be done by developing of Laminated Bamboo Composites (LBCs). Pressure compaction, the number of laminas, the thickness of the laminae, and the orientation of the laminates are critical fabrication variables for achieving a high strength of LBCs. The present study investigates epoxy resin reinforced with bamboo laminates. The type of bamboo studied was Apus bamboo (*Gigantochloa apus*). Apus bamboo was chosen because it has flexible properties and is easy to make into thin sheets. The research was conducted by varying the tickness, number of laminas, direction of laminates and compacting mold pressure. A detailed characterization, including the tensile and bending strength of the LBCs were investigated.

The review is interesting. However, this version of the review has a drawback. It was necessary to make a critical analysis based on the cited sources. That is, it was necessary not only to describe the issues considered in the mentioned works, but to point out those parts of the problem that are not covered in them. It is necessary to refine the section in this direction. You have to say about each source of literature: which problems were studied in them, which part of the problem remained unexplored, why this part of the problem has not been studied? Can it be objective reasons, methodological or mathematical difficulties, etc.? You must say this specifically.

The last paragraph as a conclusion to the review should also be corrected. You do not just have to say that something is being done in the article. It is necessary to justify why the aim of the research, stated in section 3, is promising. And this should be justified by a critical analysis of the cited sources.

3. The aim and objectives of the study

The aim of the study is the investigation mechanical properties of *gigantochloa apus* laminate reinforced epoxy resin. see the remark to the title of the article. Maybe so: *The aim of the study is the revealing the patterns* (or *features*) *of formation of mechanical properties of gigantochloa apus laminate reinforced epoxy resin*

The following objectives have been formulated:

– to investigate the effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites (LBCs);

– to investigate the effect of direction of bamboo laminates on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);

– to investigate fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs);

4. Materials and Methods

4. 1. Material

Bamboo's laminae of *gigantochloa apus* was used as primary reinforcement material. The bamboo used is three years old with an average diameter of 150 mm of bamboo. The selected part of the bamboo stem, 1 m to the base to 4 m, was used to make the laminae. The epoxy Bakelite® EPR 174 and resin hardener V-140 were used as a matrix and hardener.

4. 2. Methods

The process of making bamboo lamina begins with cutting the bamboo stalks to obtain a stem length of 40 cm. The bamboo stalks are then split into blades, making the bamboo slats by removing the outer shell. Then the splitting process is carried out to obtain a bamboo blade with a size of 40 cm × 20 mm. The formation of bamboo lamina blades is carried out using the four-side planning tool. This process is carried out to obtain the thickness of 1 mm, 1.5 mm, and 2 mm. Fig. 1 shows the bamboo lamina-making process.

The bamboo laminas is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution. After preservation, the bamboo laminas are dried. The bamboo lamina is dried in an oven until the water content reaches 10 %. A moisturemeter measured the percentage of water content in the bamboo laminas. Drying takes approximately 2–4 weeks in an oven, depending on the weather. Dry bamboo slats are grouped according to their thickness and then sanded to smooth the surface using a sandpaper machine. The photo of bamboo laminae are depicted in Fig. 2.

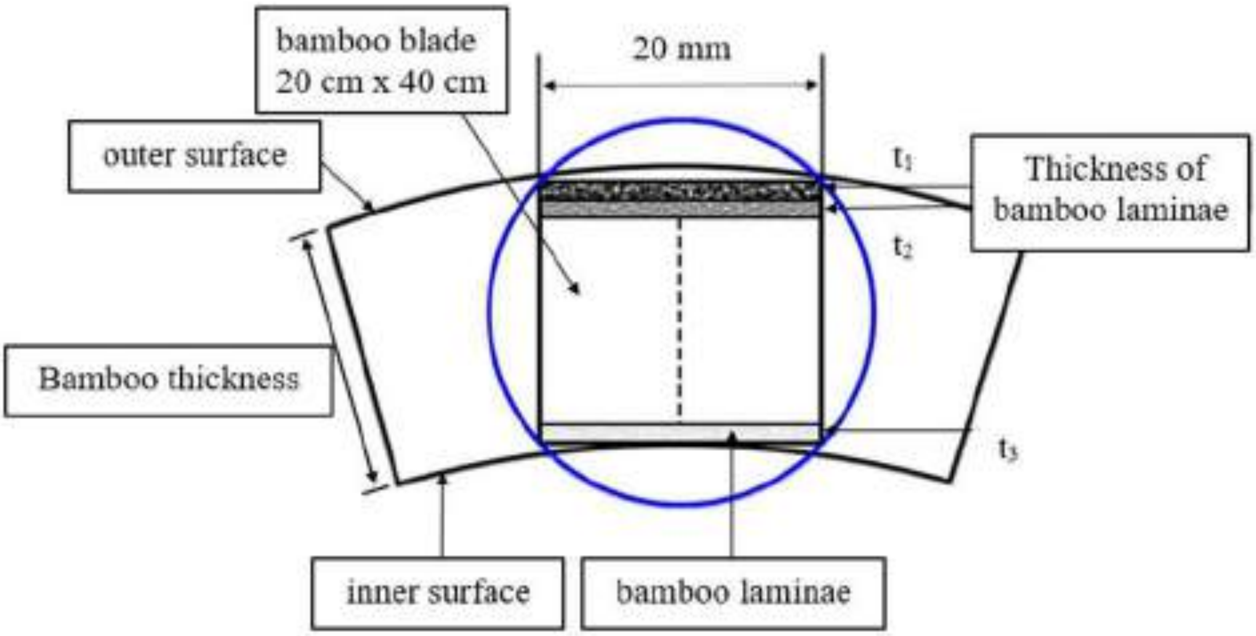


Fig. 1. Formation of the bamboo apus laminae (*gigantochloa apus*)

Fig. 2. Bamboo Laminae

The dried bamboo laminas are then used as reinforcing composites to make Laminated Bamboo Composites (LBCs). An epoxy resin polymer is used as a matrix/adhesive material. LBCs were constructed by hand lay up method with three different number of laminas: 3, 5, and 7. Additionally, LBCs are manufactured in a variety of laminates directions: 0, -45^{o}/+45^{o} and 0^{o}/90^{o}. The configuration of the directional arrangement of the laminates in the composite is shown in Table 1. After hand lay up process, LBCs were compacted using a hydraulic pressing machine with variation of compacting pressure: 1.5 MPa; 2.0 MPa; 2.5 MPa. The LBCs were pressed for 24 hours. Table 2 shows the resulting composites with variations in compacting pressure and the number of laminae forming LBCs. This process produces a composite with a size of 400 mm x 250 mm with various thicknesses.

Table 1
Configuration of laminates direction in Laminated Bamboo Composites

-	0^o	$-45^o/+45^o$	$0^o/90^o$
3 layers	0^o; 0^o; 0^o	-45^o; $+45^o$; -45^o	0^o;90^o;0^o
5 layers	0^o; 0^o; 0^o; 0^o; 0^o	-45^o;$+45^o$;-45^o;$+45^o$,-45^o	0^o;90^o;0^o;90^o;0^o
7 layers	0^o; 0^o; 0^o; 0^o; 0^o; 0^o	-45^o;$+45^o$;-45^o;$+45^o$; -45^o;$+45^o$, ;-45^o	0^o;90^o;0^o;90^o;0^o; 90^o;0^o

Table 2
The weight fraction of bamboo fibers and the epoxy resin matrix of the composites

No	Pressure compaction (MPa)	Laminae (layer)	Thickness laminae (mm)	Thickness LBCs (mm)	Bamboo Mass fraction (Kg/cm^3)	Epoxy-resin Mass faction (Kg/cm^3)
1	1.5 MPa	3	2.0	7.0	0.70	0.30
2		5	1.5	7.0	0.65	0.35
3		7	1.0	7.0	0.60	0.40
4	2.0 MPa	3	2.0	6.5	0.75	0.25
5		5	1.5	6.5	0.70	0.30
6		7	1.0	6.5	0.65	0.35
7	2.5 MPa	3	2.0	6.0	0.80	0.20
8		5	1.5	6.0	0.75	0.25
9		7	1.0	6.0	0.70	0.30

Fig. 3. The tensile test specimens

Fig. 4. The bending test specimens

The tensile test refers to the ASTM standard D3039 with a specimen size of 250 mm x 25 mm x t mm. The bending test was carried out using the ASTM standard D7264 with a 130 mm × 13 mm × t mm specimen size. The test specimens were prepared using water jet cutting. Tensile and bending testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1000 KN. For each variation five specimens were tested. Fig. 3-5 present photo of tensile and bending test specimens.

5. Results of research….??? This section title should be clarified. The title should answer the question "What are the results of the research?"

5. 1. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites

Table 3 and graphs in Fig. 5–7 show the results of the tensile test of LBCs for variations in the number of laminates (3, 5, 7), laminates directions (0°, −45°/+45°, 0°/90°) and the compaction pressure (1.5 MPa, 2 MPa, 2.5 MPa) on the tensile strength of LBCs. It can be noticed from Fig. 5–7 that that the tensile strength of LBCs are influenced by number and direction of laminates. It depicted in Fig. 5, that at compacting pressure of 1.5 MPa, direction of laminates 0^o (on axis) increasing number of laminates also increase the tensile strength of the LBCs. LBCs with 3 layers laminates has tensile strength about 115 MPa, increase about 7 % (124 MPa) when the layers of laminates are 5 layers. The highest tensile strength of LBCs at 0^0 direction and 1.5 Mpa compaction is 139 MPa at 7 layers laminas.The same phenomenon is obtained in the fiber direction −45°/+45°, 0°/90° that as the number of layers in the LBCs increases from 3 to 7 the tensile strength also increases. LBCs with direction −45°/+45° and 0°/90° gain the highest tensile strength 76 MPa and 107 MPa respectively at 7 layers laminates. Lowest tensile strength of LBCs is 58 MPa (about 41 % of highest value) at 3 layers laminas and −45°/+45° laminates direction.

LBCs with a pressure of 2 MPa produce the highest tensile strength of 185 MPa at 7 laminates with laminates direction 0^o (Fig. 6). Besides laminates direction −45°/+45 yied highest tensile strength 88 MPa and LBCs with laminates direction $0^o/90^o$ resulted highest tensile strength 156 MPa. LBCs with laminates direction −45°/+45, 3 layers laminas and 2 mm laminae thickness yield lowest tensile strength with the tensile strength value of 76 MPa (41 % from the highest value of tensile strength).

The graph in Fig. 7 shows that at a pressure of 2.5 MPa the highest tensile strength of LBCs is achieved composite with direction of laminates 0^o with valued 180 MPa. The highest tensile strength also achieved by LBCs with laminates direction 0^o (on axis laminates), 7 layers laminas and 1 mm thicknes of laminae. The increase in number of laminate layers from 3, 5, 7 results in an increase in the tensile strength of 164 MPa, 175 MPa, and 180 MPa, respectively. The lowest value of tensile strength of LBCs is 71 MPa (39 % from the highest value) also find at LBCs with 3 layers laminates and direction laminates −45°/+45.

Table 3
Tensile strength of LBCs

Pressure	1.5 MPa	2.0 MPa	2.5 MPa

Layers	3	5	7	3	5	7	3	5	7
0^o	115	124	139	168	177	185	164	175	180
$-45^o/+45^o$	58	64	76	76	81	88	71	78	87
$0^o/90^o$	91	99	107	135	149	156	131	141	151

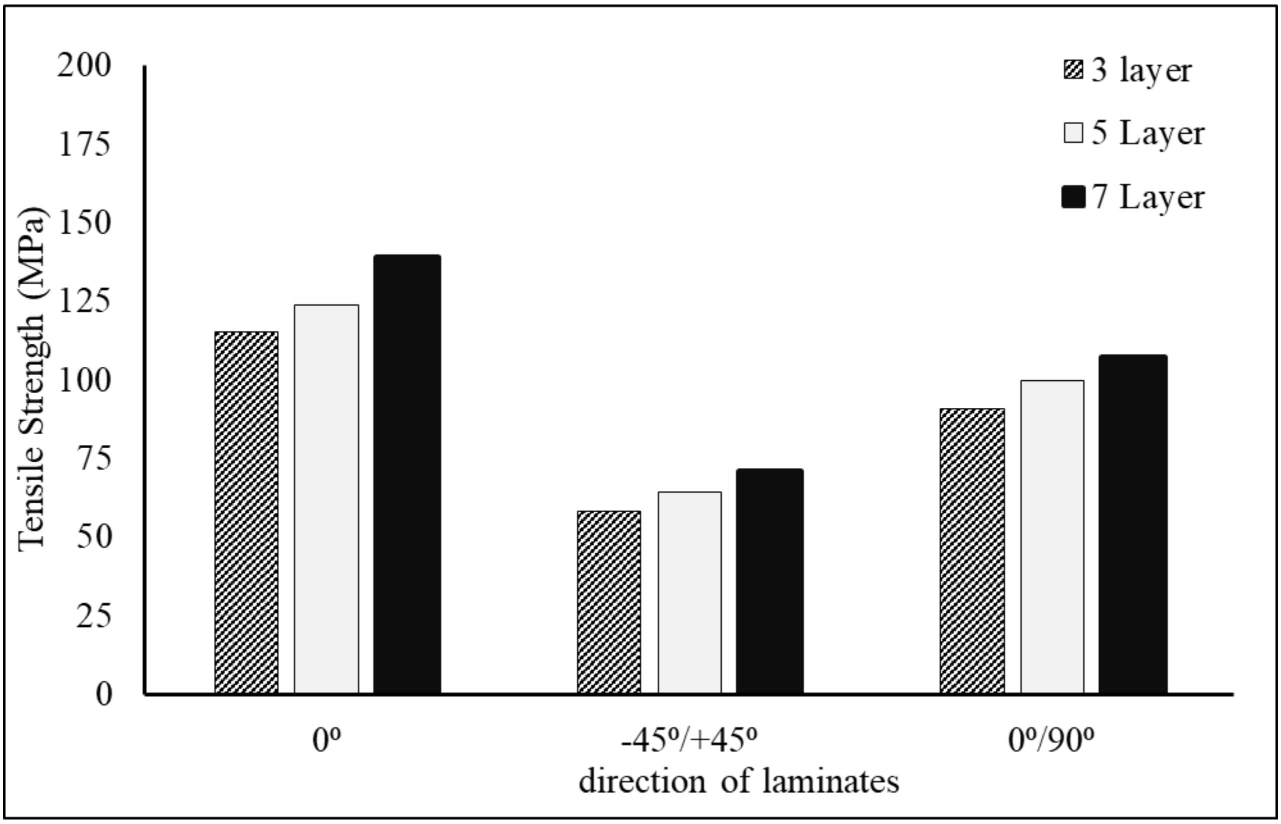


Fig. 5. Tensile strength of LBCs with 1.5 MPa pressure compaction

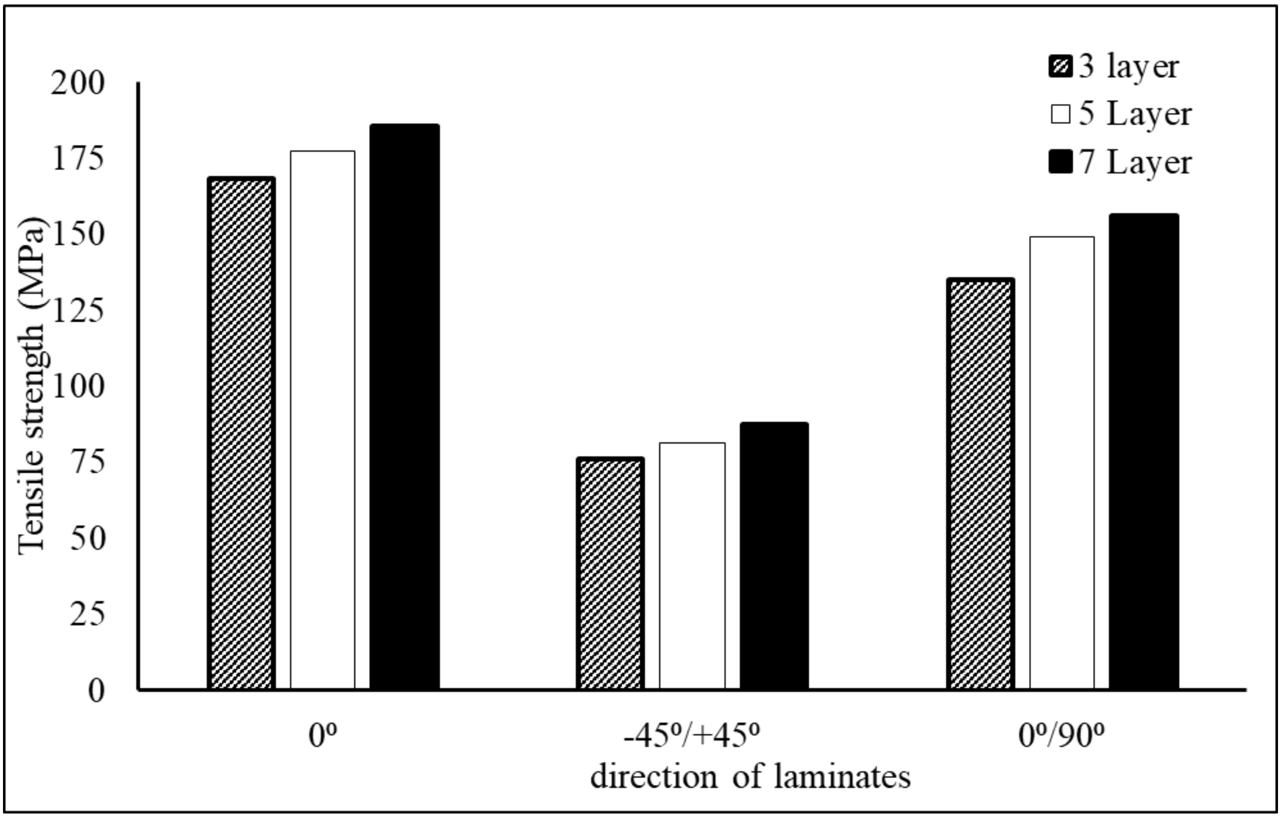


Fig. 6. Tensile strength of LBCs with 2 MPa pressure compaction

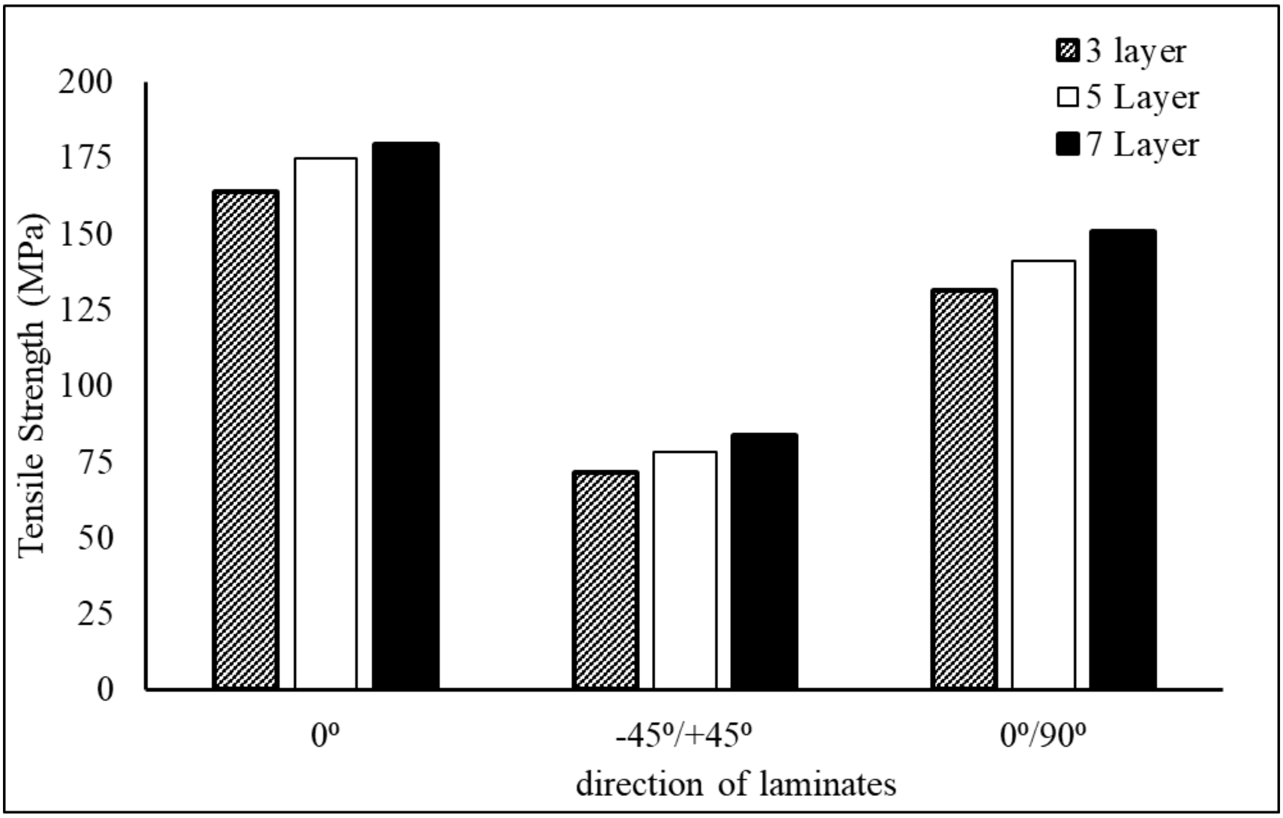


Fig. 7. Tensile strength of LBCs with 2.5 MPa pressure compaction

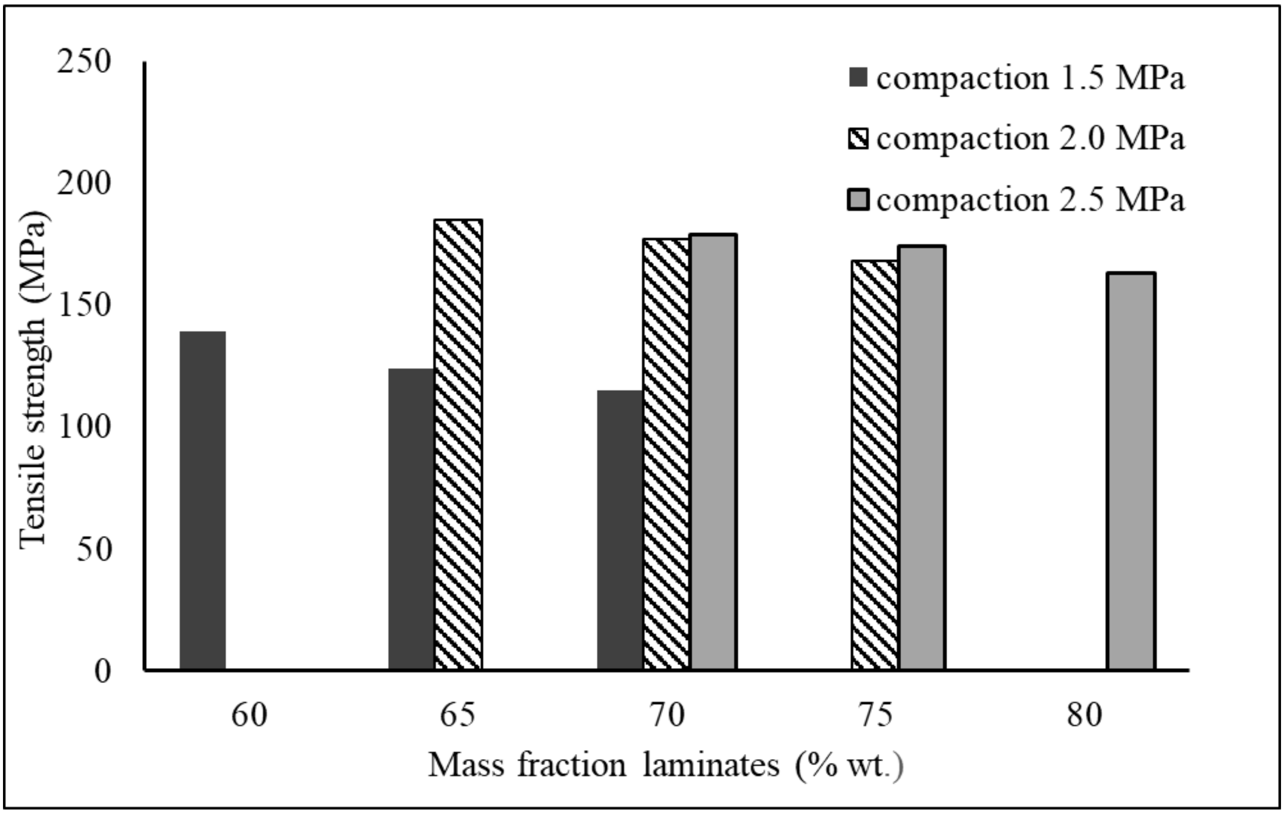


Fig. 8. The effect of mass fraction bamboo laminates on tensile strength of LBCs in composites with direction of 0^o

At all pressure variations, LBCs with a 0^o laminates direction has a higher tensile strength than LBCs with a direction −45°/+45°and 0°/90°. LBCs with laminates direction $-45^o/+45^o$ produced lower tensile strength than the others. The effect of mass fraction fraction bamboo laminates and tensile strength of LBCs in composites with direction of 0^o is shown in Fig. 8. LBCs with 7 layers laminates 1 mm laminae thickness and compacting pressure 1.5 MPa produces composites with % wt. reinforcement 60 %. At compacting pressure 2.0 MPa and 2.5 MPa, % wt. of LBCs with 7 layers laminates 1 mm laminae thickness are 65% and 70 % respectively. The tensile strengths of LBCs with seven layers are 139 MPa, 185 MPa, and 180 MPa at 1.5 MPa, 2.0 MPa, and 2.5 MPa compaction pressures, respectively. LBCs with 3 layers and 2 mm thickness of laminae yield composite with % wt. reinforcement higher than LBCs with 7 layers and laminae thickness 1 mm. LBCs with three layers and 1.5 MPa, 2.0 MPa, or 2.5 MPa pressure compaction produce LBCs with tensile strengths of 115 MPa, 168 MPa, and 164 MPa, respectively.

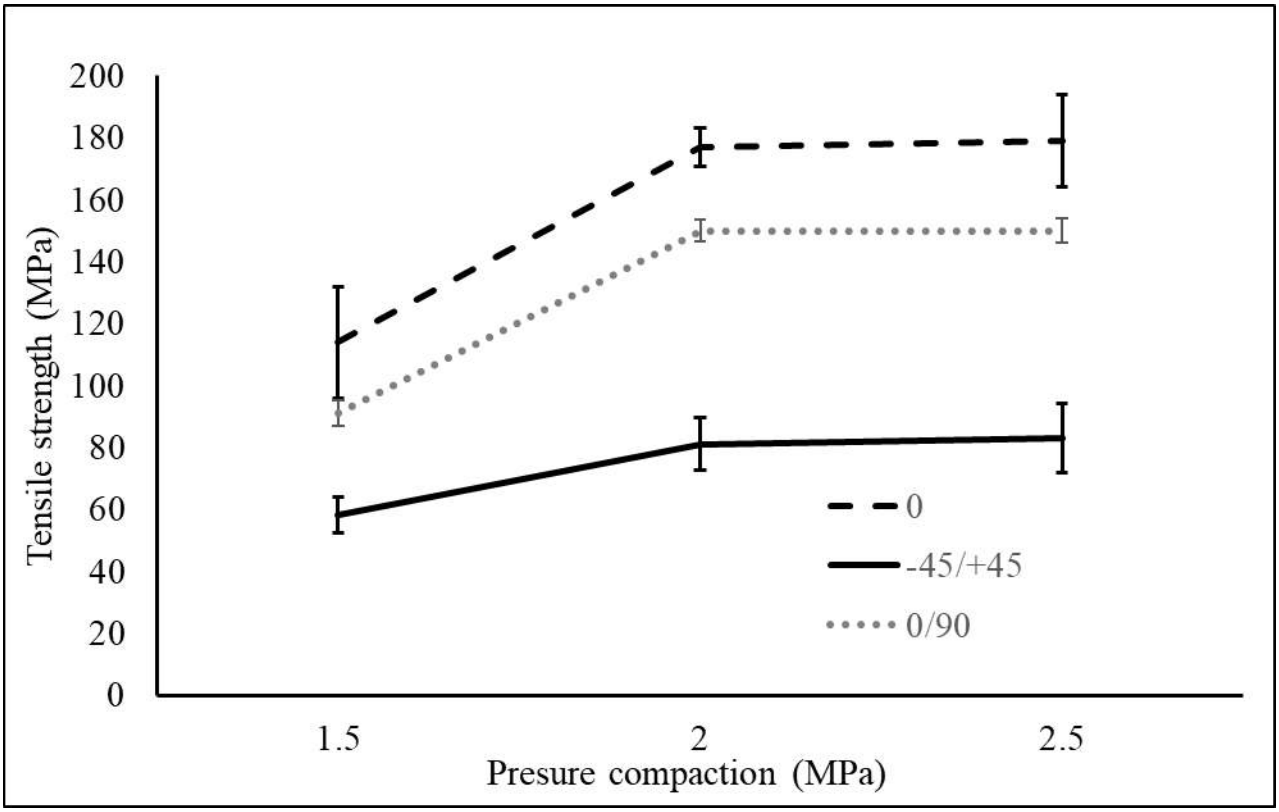


Fig. 9. The effect of Compaction Pressure on Tensile Strength of LBCs at 70 % Mass Fraction

The graph in Fig. 9 also shows the effect of compacting pressure on the tensile strength of LBCs at the mass fraction of 70 %. This analysis selected a mass fraction of 70 % wt because a mass fraction of 70 % wt was generated for all variations studied (Fig. 8). Fig. 9 shows that increasing the compression from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0^o laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0^o/90^o laminates direction. Increasing the compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. The differences of tensile strengths are smaller than the standard deviation of the test. Therefore, it can be concluded the increase in pressure from 2 MPa to 2.5 MPa does not significantly affect the tensile strength of LBCs.

5. 2. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on bending strength Laminated Bamboo Composites

Table 4 and Fig. 10–12 show the bending strength of LBCs with variations of the direction of laminates: 0^o, -45^o/+ 45^o, 0^o/90^o and variations in the number (3, 5 and 7) and thickness (1 mm, 1.5 mm and 2 mm) of apus bamboo laminae with variation of compacting pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa. Fig. 10 shows LBCs with direction of laminates 0^o resulted higher bending strength than LBCs with laminates direction 0^o/90^o or -45^o/+45^o. Bending strength of LBCs with 0^o laminates is approximately 8 % stronger than either of LBCs with 0^o/90^o laminates and approximately 12 % greater than that of LBCs with -45^o/+45^o laminates. At pressure compaction 1.5 MPa, highest bending strengtn of LBCs is 265 MPa, lowest bending strength is produced by LBCs with laminates direction -45°/+45° with valued 218 MPa (approximately 82 % form highest bending strength).

Table 4
Bending strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0°	251	257	265	295	315	321	280	298	306
-45°/+45°	218	229	232	245	266	271	234	239	259
0°/90°	233	241	240	274	284	294	261	268	279

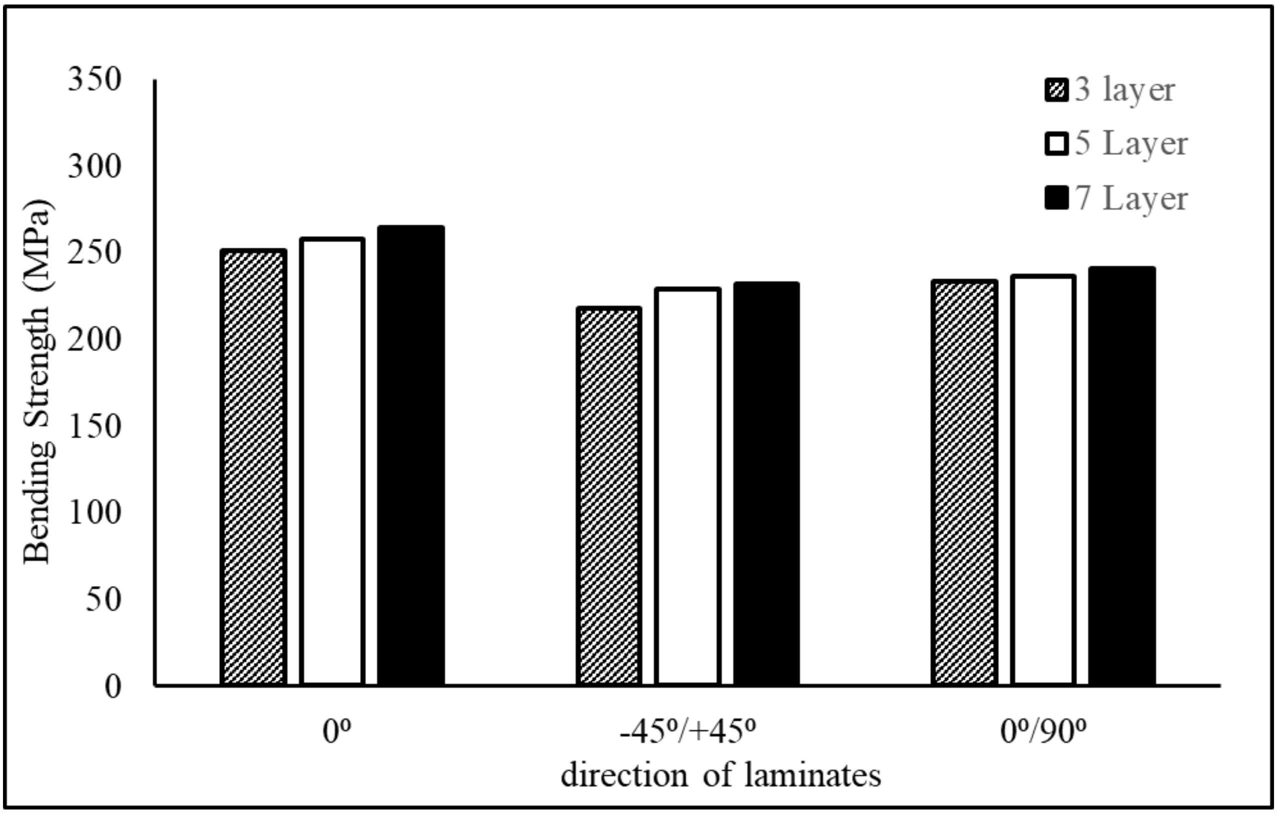


Fig. 10. Bending strength of LBCs with compaction pressure 1.5 MPa

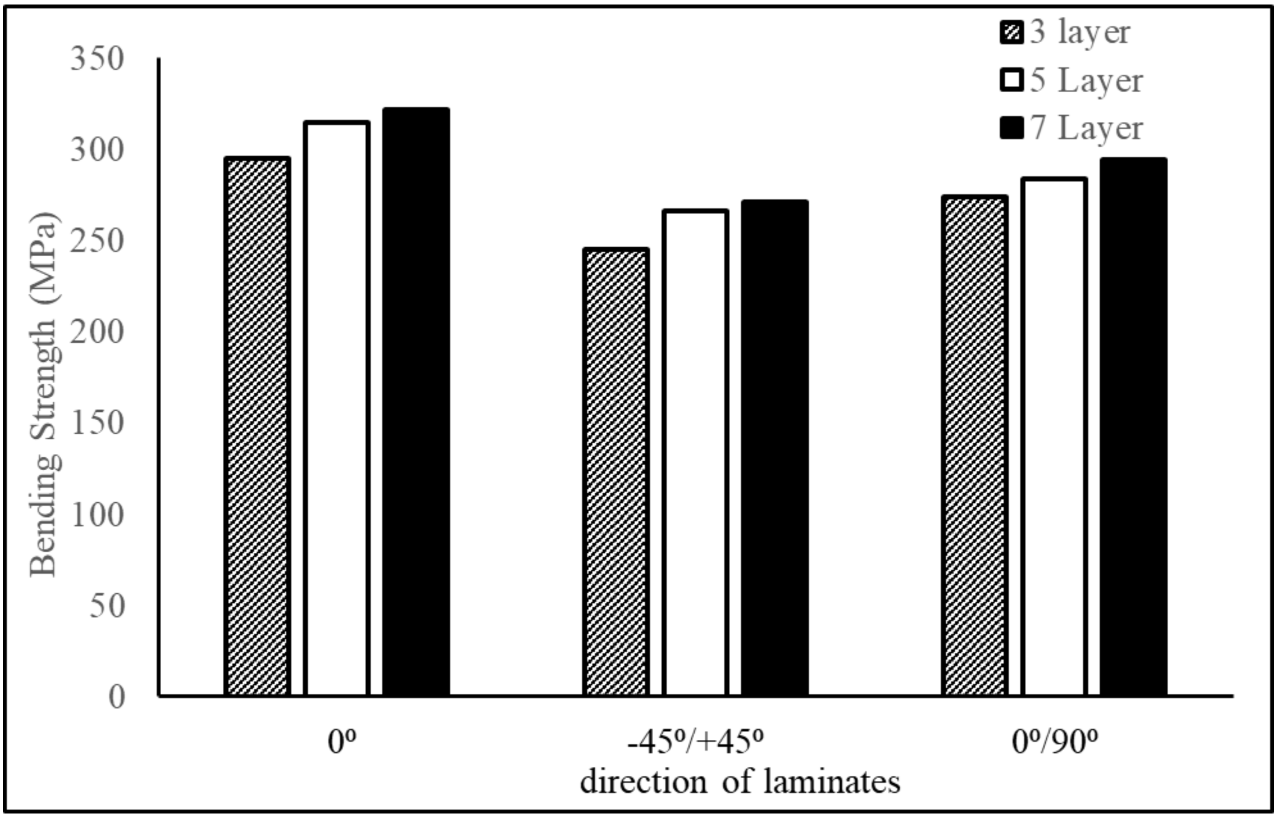


Fig. 11. Bending strength of LBCs with compaction pressure 2.0 MPa

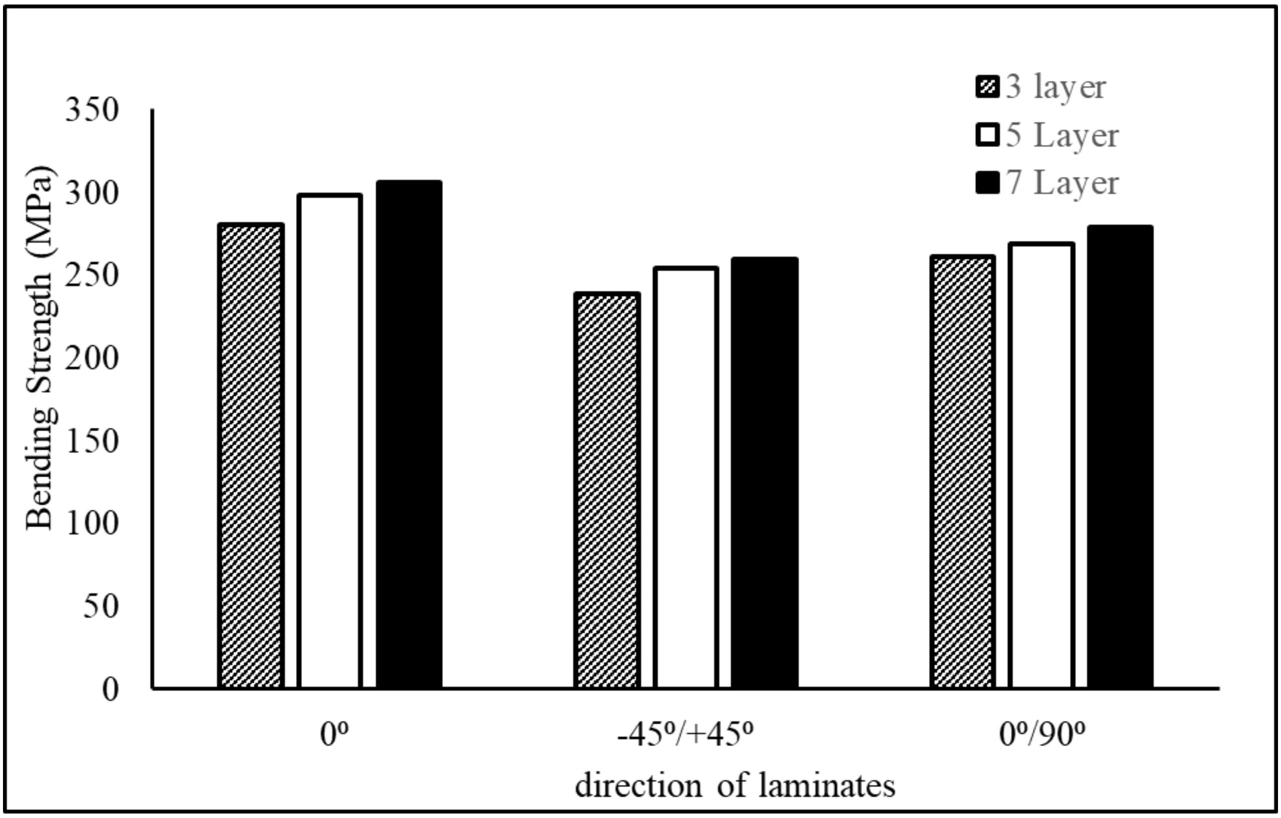


Fig. 12. Bending strength of LBCs with compaction pressure 2.5 MPa

Bending strength of LBCs with compaction pressure 2.0 MPa and 2.5 MPa are depicted in Fig. 11, 12, respectively. the value of the bending strength of the composite with a compaction pressure of 2.0 MPa ranged from 245 MPa to 321 MPa. LBCs have a bending strength of between 234 and 306 MPa when compressed to 2.5 MPa. The composite with a 0° layer direction and 7 layers of laminas produces the highest bending strength

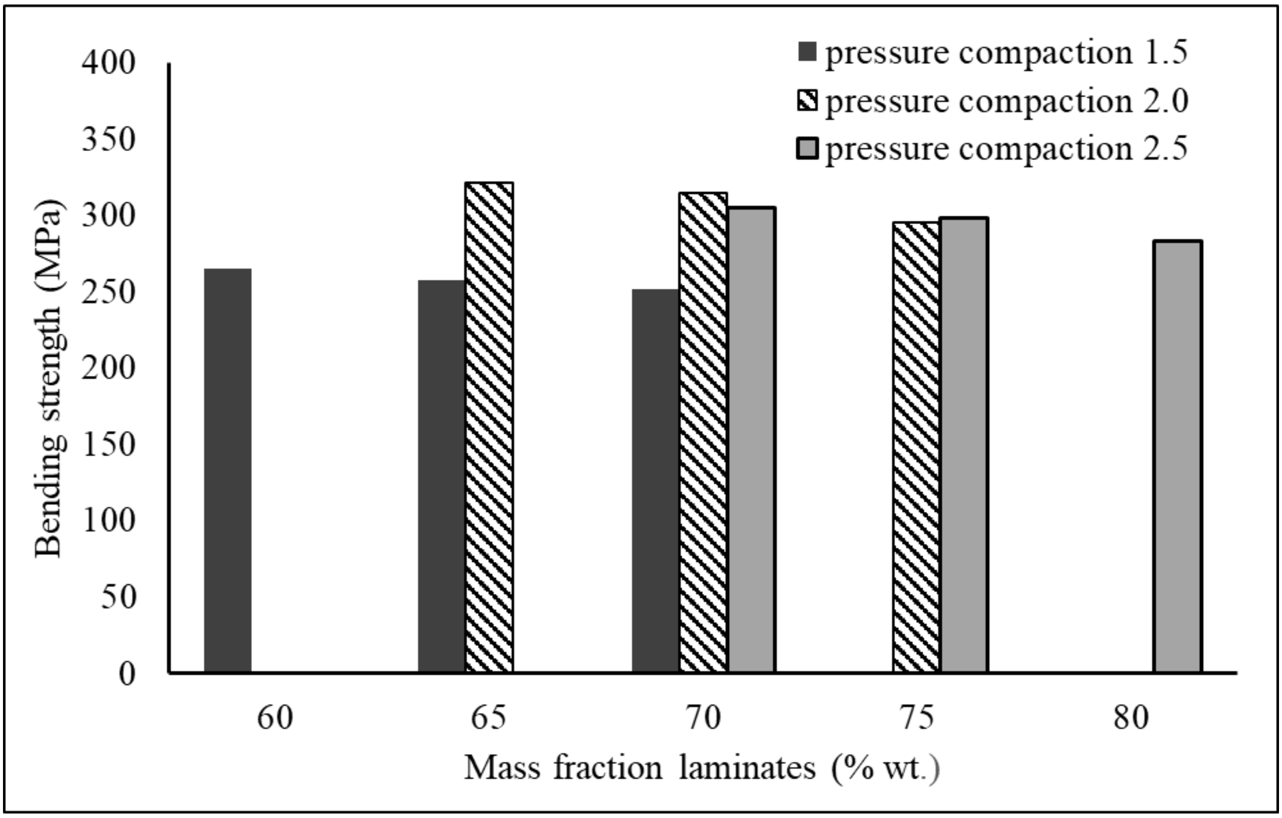


Fig. 13. The effect of mass fraction of laminates on bending strength of LBCs with 0° direction

The relationship between the bending strength of LBCs and their mass fraction with the laminates' on-axis (0°) direction is depicted in Fig. 13. At 1.5 MPa compaction pressure, LBCs with a mass fraction of 60% have stractured 7 layers of laminae with a thickness of 1 mm, yielding the highest bending strength of 265 MPa. At compression pressures of 2.0 MPa and 2.5 MPa, LBCs with 7 layers laminas exhibit the highest bending strength, with values of 321 MPa and 306 MPa, respectively. From the graph in Fig. 13, it can be concluded that the highest bending strength is in the composite with thinner bamboo reinforcement and a higher number of layers even at a lower mass fraction.

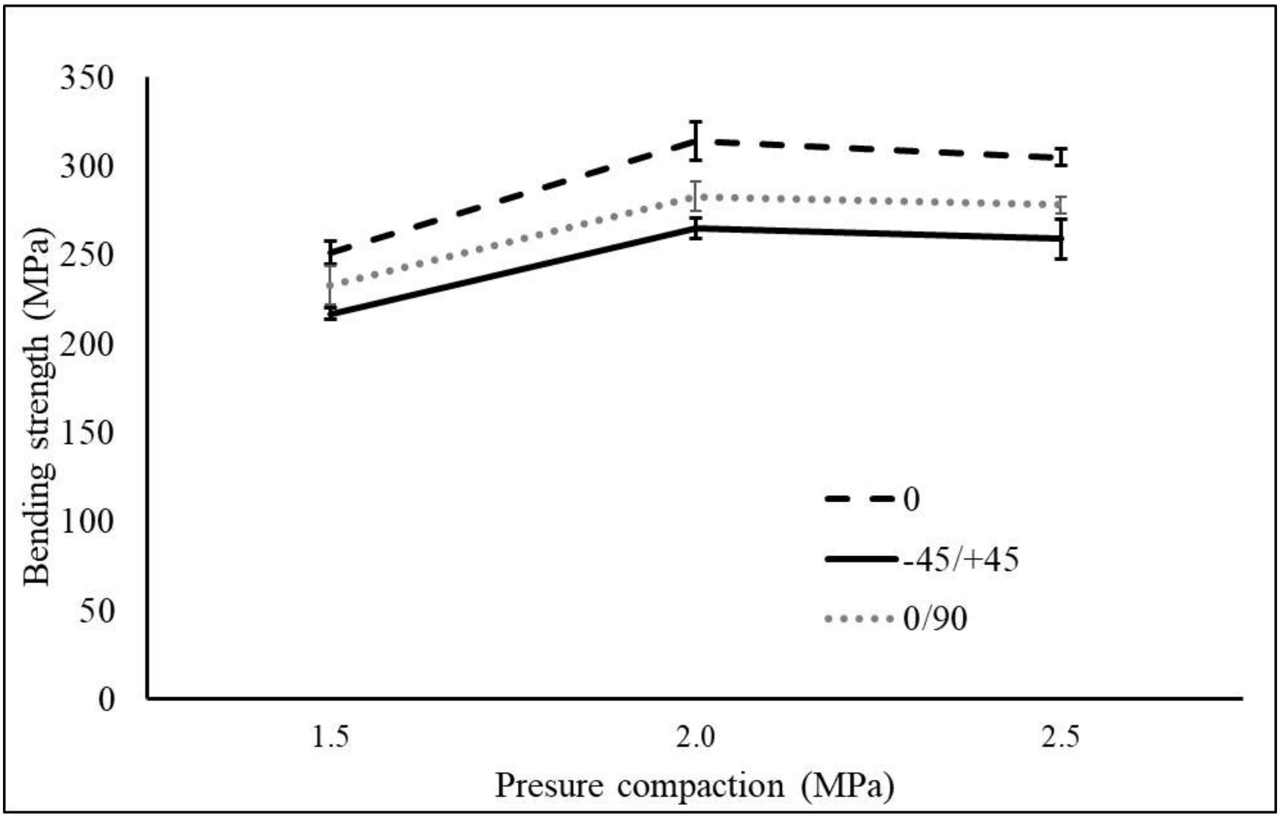
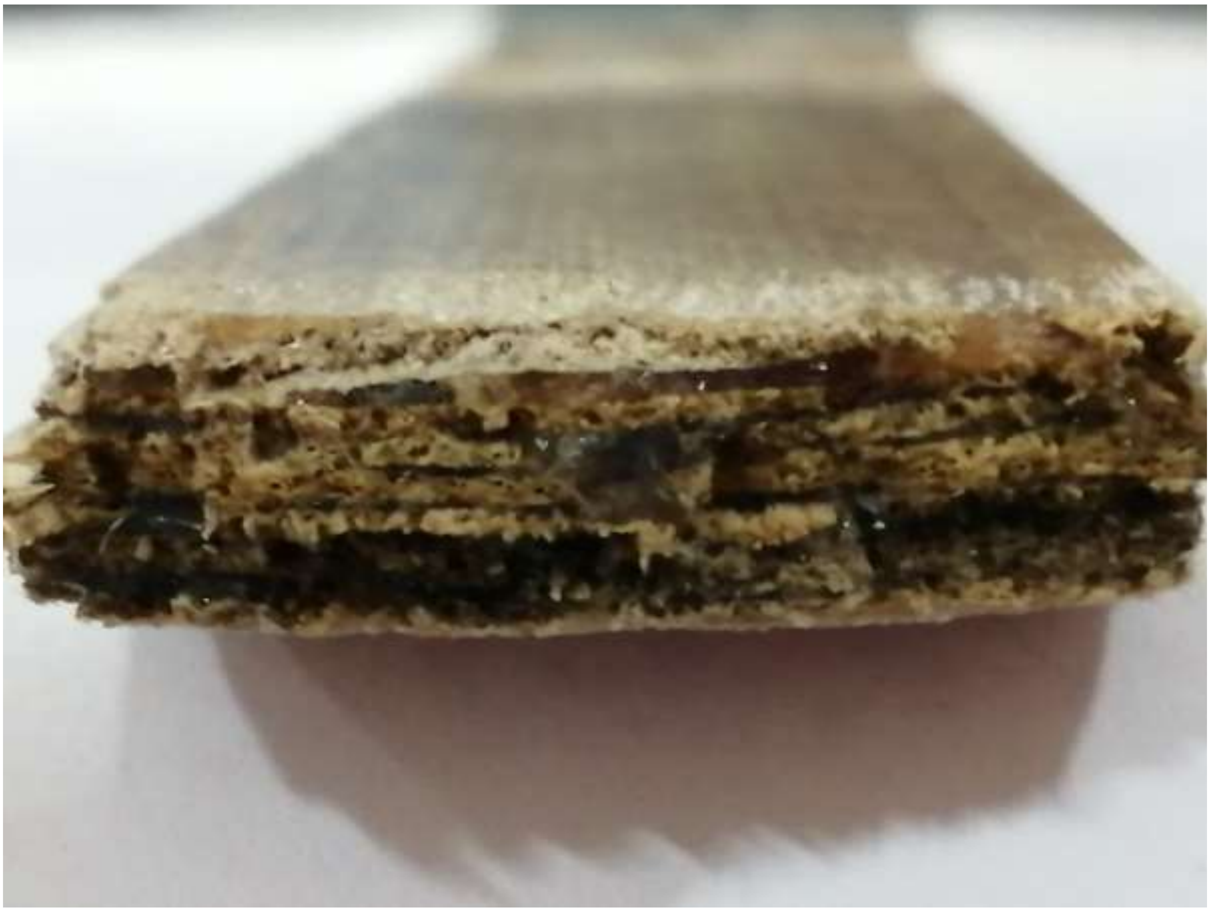


Fig. 14. The effect of Compaction Pressure on the Bending Strength of LBCs at 70 % Mass Fraction

The graph in Fig. 14 also shows the effect of compacting pressure on the bending strength of LBCs at the mass fraction of 70 %. By increasing pressure compaction from 1.5 MPa to 2 MPa, the bending strength of LBCs increase by 25% in the 0^o laminates direction, 22% in the 45°/+45° laminates direction, and 21% in the 0^o/90^o laminates direction. As with the tensile tests, increasing the compacting pressure from 2 MPa to 2.5 MPa have no noticeable effect on the bending strength of LBCs.

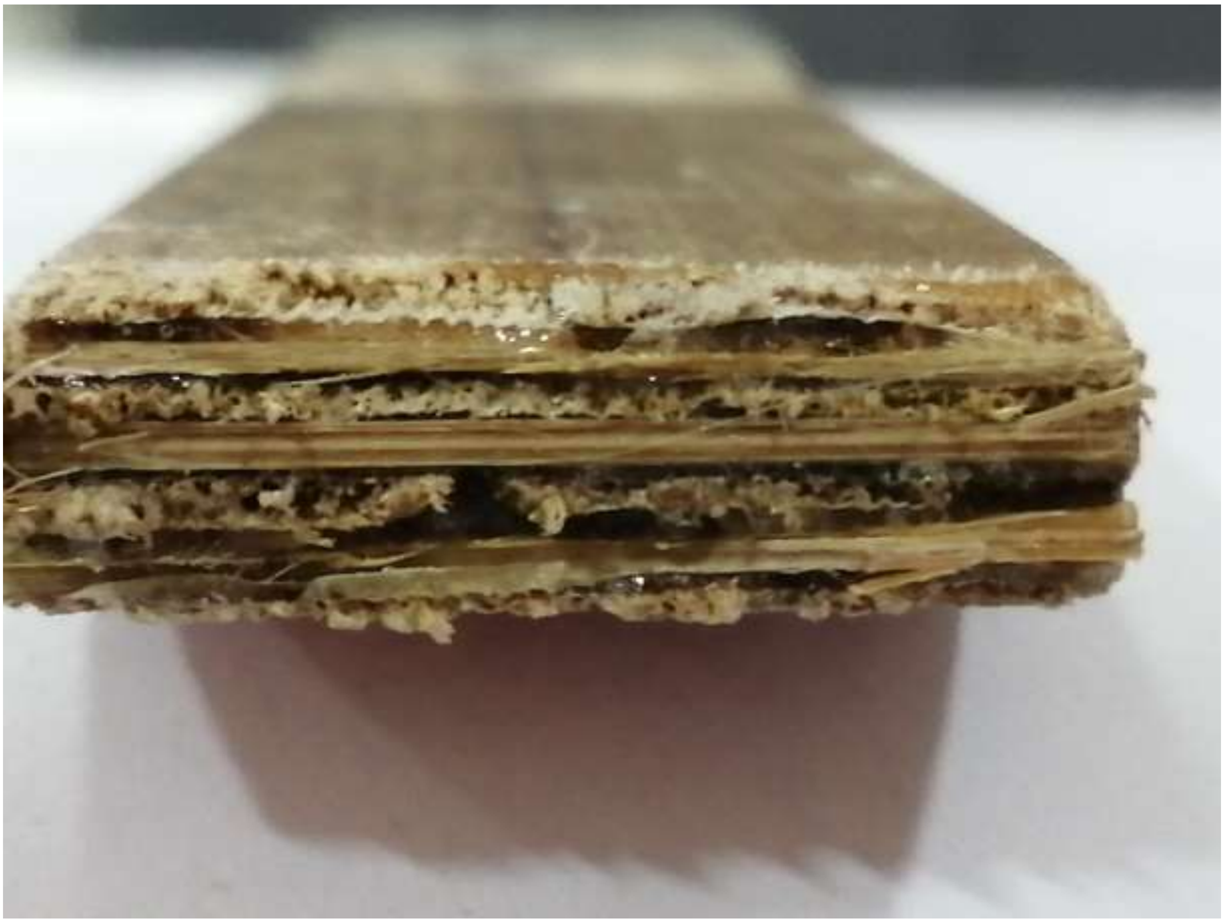
5. 3. Investigatiom fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs)

Fig. 15 shows a macro photograph of the surface fracture of LBCs after tensile testing. Fig. 15, *a* shows the fracture of LBCs with laminates direction 0^o. The fracture surface of the LBCs with the laminates direction -45^o/+45^o (Fig. 15, *b*) and the fracture surface of the LBCs with the laminates direction -0^o/90^o (Fig. 15, *c*). The LBCs with 0^o direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by load transfer to bamboo laminas and subsequent bamboo laminae fracture. Fig. 15, *b* shows the fracture of matrix followed by delamination of laminae in the 90^o direction, and finally fracture of laminae in the 0^o direction. In LBCs with laminates orientation +45^o/-45^o, matrix fracture was followed by delamination and laminae clefting.



a

b



c

Fig. 15. Photomacrography The Fracture of Cross Section of The Tensile Test of 7 Layers Laminated Bamboo Composites (LBCs): *a* – direction of laminates 0^{o}; *b* – direction of laminates -45^{o}/+45^{o}; *c* – direction of laminates 0^{o}/90^{o}

a

b

c

Fig. 16. Bending Test Result Specimens of Laminated Bamboo Composites (LBCs) from 7 layers: *a* – layers direction of 0^o; *b* – layers direction $-45^o/45^o$; *c* – layers direction $0^o/90^o$

The macro photographs of the LBCs after bending tested are shown in Fig. 16. Fig 16, *a* shows that bending tested of LBCs with 0^o laminates direction, produced fractured of matrix and followed fracture of laminates. Fracture photographs of LBCs with layers direction $-45^o/45^o$ (Fig. 16, *b*) shows, that at At the bottom of the specimen, fracture occurs due to laminae delamination. Failure continues with delamination and the laminae splits due to shear stress. The failure of the specimen with the direction of the lamina $0^o/90^o$ as shown in Fig 16.*c* indicates that the failure due to bending started with matrix fracture and fracture laminae at the bottom (outer) of the specimen. Failure is followed by delamination of the lamina in the 90^o direction

6. Discussion of experimental results **of....????? This section title should be clarified. The title should answer the question "Discussion of the results of the study of what?"**

Apus bamboo (gigantochloa apus) with a lamina's tensile strength of 230 MPa and an epoxy resin with a tensile strength of 57 MPa after being formed into a composite LBCs was able to produce the highest tensile strength of 185 MPa with a ratio of 70 % lamina bamboo lamina mass fraction and 70 % mass fraction. (wt) epoxy-resin 30 %. This result higher than previous research that reported composites used gigantochloa scortechinii (semantan reed) woven bamboo as reinforcement with a ratio of 33 % of the mass fraction (wt) of bamboo laminates and the mass fraction (wt) of 77 % epoxy matrix was only able to produce a maximum tensile strength of 89 MPa [11].

At each compacting pressure value, the highest tensile strength was achieved by LBCs, with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo lamina. It can be concluded that the highest tensile strength is in the composite with thinner bamboo reinforcement and more layers, even at a lower mass fraction. Increasing the tensile strength properties of LBCs in the thinner bamboo lamina reinforcement with a higher number of composites forming layers is an important concern in this study. This caused by the ability of the epoxy resin to enter the thinner pores of the apus bamboo fiber, thereby increasing the interface strength of the composite-forming bamboo layer. The other works also reported that increasing the number of laminas forming the Layered Laminate Bamboo Composites (LLBCs) will increase tensile and flexural stress [7]. The tensile strength of laminated composites is dependent on the interfacial properties of natural fibers and polymer composites. Additionally, the tensile properties are contingent upon the laminates directions [19]. Study on mechanical properties of laminated bamboo composites with different bamboo and matrices (gigantochloa scortechinii and unsaturated polyester) showed that the thicker the bamboo blades produced the higher the tensile stress and flexural stress [20].

They also mentioned that the direction configuration of the composite laminates also affects the tensile stress and flexural stress of LLBCs. The configuration of the laminates with direction 0° gave the best result of tensile strength compared to the configuration of the direction of the fiber crossed 0°/45° and 0°/90°. Thus, the tensile strength of the LBCs decreases with increasing the angle of the laminates under the tensile stress. According to the Tsai–Hill criterion, the tensile and compressive properties of the composite will continue to decrease due to changes in the fiber orientation angle that increases from 0° [21]. This study's results prove that the direction of the lamina 0° provides the higher tensile strength compared to the direction of the laminates −45°/+45°, 0°/90°.

The compacting pressure applied to the manufacture of LBCs affects the mass fraction (wt) of the epoxy resin matrix contained in the LBCs. The compacting pressure will drive the epoxy resin out of the LBCs mold while the mass fraction of the bamboo laminates steady. Higher compression pressure will reduce the % wt epoxy-resin. The pressure compaction of LBCs from 1.5 MPa to 2.0 MPa can reduce the weight fraction of epoxy resin in LBCs by 5 % of the initial mass fraction, but it can increase the tensile strength of LBCs by 55 % at laminates direction 0°, 40 % in the direction of laminates −45°/+45° and 64 % in the direction of laminates 0°/90°. Another researcher reported that LBCs without compacting pressure could produce a maximum tensile strength of 89 MPa [9]. The optimum tensile stress of Laminated Bamboo Composites (LBCs) was obtained at a 2 MPa compaction pressure variation with a mass fraction (wt) of lamina of 70 % and a mass fraction (wt) of epoxy-resin of 30 %. The application of compacting pressure above 2 MPa on LBCs didn't affect on the value of tensile stress. The anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs each by 5 % for each variation of the tested specimens.

The LBCs with 7 layers of bamboo laminas, 1 mm thickness, 0^o fiber direction and 2 MPa stress yield highest bending strength valued 321 MPa. It's aproximatelly 20 % stronger than LBCs with compacted pressure 1.5 and 5 % higher than LBCs with 2.5 MPa compaction pressure. Apus bamboo (gigantochloa apus) with a bending strength of laminae 348 MPa and epoxy-resin with bending strength of 175 Mpa, after being manufactured into a composite LBCs, this materials yield the highest bending strength of 321 MPa with a ratio of mass fraction (wt) of 70 % and mass fraction (%. wt) epoxy-resin 30 %. Gigantochloa scortechinii (semantan reed) woven bamboo with a ratio of 33 % of the mass fraction (wt) of bamboo laminates and the mass fraction (wt) of 67 % epoxy matrix was only able to produce a maximum bending strength of 120 MPa [11]. The bamboo allowed large flexural deformations because its outer part retains the tensile stress while the softer inner part undergoes large compressive deformation [22]. The configuration of the 0^o direction of the laminates yield the higher bending strength compared to the configuration of $0^o/45^o$ and $0^o/90^o$ crossed laminates [21].

The bending stress of laminated bamboo composites is also influenced by the direction (orientation) of the bamboo laminate and the number of layers. At each variation in the direction of the bamboo laminatesand stress, the bending strength of the LBCs increased with the increasing number of layers of bamboo laminas. In the number of layers, the bending strength of LBCs with the laminates direction of 0^o has the largest bending strength, followed by the crossed fiber direction of 90^o and the lowest bending strength is the LBCs with the -45^o / $+ 45^o$ fiber direction.

The Laminated Bamboo Composites (LBCs) with more layers of laminas produce higher tensile and bending strength compare with LBCs with less number of laminas. The thinner laminae provide a higher adhesive contact surface area than the thicker laminae. Higher adhesive contact area provides better stress transfer to the laminae [23].

Fractuce of LBCs with on axis (0^o) laminates direction, all stress are transfer by matrik to laminates. Bamboo laminates bamboo lamina can fully withstand the load transferred by the matrix. This causes LBCs with laminates 0^o direction (on axis) to be stronger than LBCs with off axis laminated direction. The cross section of fracture photograph demonstrates that the fracture mechanism is a fracture matrix followed by the breaking of the bamboo laminates. LBCs with off axis direction ($-45^o/+45^o$ and $0^o/90^o$) fracture mechanism of LBCs, there delamination of laminae caused by debonding of adhesion between laminae. in the cross-sectional image of the fracture, the laminae delamination behavior is shown.

In this version of the article, the Discussion section is not specific, so it is difficult to imagine what exactly the author interprets as the main scientific results and how exactly it explains them. To remove this problem, it is necessary to revise the section, bringing it into line with such a structurally-substantive scheme:

– how can the results be explained? This interpretation part is the first main part of the discussion and there are important nuances of its presentation. It is necessary to explain the results obtained for each research objective, referring to those objects in the article that display the discussed results. Such objects in the general case are figures and tables. That is, it should be seen which result is being discussed at this point in the section.

– how do the proposed solutions/results allow to close the problem area identified by the author, and if so, in which part and due to what exactly? This is the second main part of the discussion, because it is this that closes the research (feedback): the problem is identified – the aim is set – the results are obtained – the results are explained using some kind of evidence base (section "Discussion ...")

– what can be considered the advantages of this study in comparison with those known on this subject. In this case, it is necessary to indicate alternative solutions and say, thanks to which particular features of the proposed solutions, advantages (or, in general, differences) are provided?

– what limitations are inherent in this study? This is the third main part of the discussion.

– what are the disadvantages of the study and in what direction should the study be developed?

7. Conclusions

1. LBCs with 0o direction of laminas yield higher tensile strength than LBCs with off axis direction of laminates (-45o/45o; 0o/90o). Incresing number of laminate increase tensile strength of LBCs. LBCs with thinner laminae provide a higher adhesive contact surface area than the thicker laminae and yield higher tensile strength of LBCs. The rise of the pressure compation from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0o laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0o/90o laminates direction. Increasing the compacting pressure from 2.0 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. Highest tensile strength of LBCs with value 185 MPa is produced by LBCs with direction 0o, 7 laminas, 1 mm thickness of laminae with pressure compaction 2 MPa.

2. The highest bending strength of LBCs, 321 MPa, is achieved with LBCs in the 0o direction, 7 laminas, 1 mm thickness of laminae, and 2 MPa pressure compaction. LBCs with laminates oriented on axis (0o) have a greater bending strength than composites with orientation of laminates off axis (-45o/45o; 0o/90o). LBCs' bending strength increases as the number of laminates increases. Increases the bending strength of LBCs by 25% in the 0o laminates direction, 22% in the 45°/+45° laminates direction, and 21% in the 0o/90o laminates direction when the pressure

compaction is increased from 1.5 MPa to 2.0 MPa. Increased compacting pressure from 2.0 to 2.5 MPa has no perceptible effect on the tensile strength of the LBCs.

3. The LBCs with 0o direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by bamboo laminae fracture. Composites with 0o/90o laminates direction, the fracture of matrix followed by delamination of laminae in the 90o direction, and finally fracture of laminae in the 0o direction. In LBCs with laminates orientation -45o/+45o, matrix fracture was followed by delamination and laminae clefting.

Acknowledgments

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THE EFFECT OF CONFIGURATION OF LAMINA AND PRESSURE COMPACTION ON MECHANICAL PROPERTIES OF LAMINATED GIGANTOCHLOA APUS COMPOSITES

"INVESTIGATION" is a process. And the title of the article should show the result. This can be, for example, *Revealing the patterns of formation ... as a result of the influence of such and such factors, identifying some regularities, identifying the influence of something on something, identifying the mechanism of such and such a process, developing a model (method, etc.), developing application techniques such and such methods for ...* etc.

Parlindungan Manik, Agus Suprihanto, Sri Nugroho, Sulardjaka*

This study aims to investigate the mechanical properties of bamboo apus (gigantochloa apus) as a natural reinforced composite material. Bamboo's laminates of gigantochloa apus was used as reinforcement on the epoxy resin matrix. The parameters examined in this study configuration of lamina and pressure compaction. Laminate configuration varies in the number, thickness and direction of the lamina. Variant compaction pressures of 1.5 MPa, 2 MPa, and 2.5 MPa were used to fabricate the Laminated Bamboo Composites (LBCs). The stem of bamboo with a length of 400 mm was split to obtain bamboo lamina with a size of 400 mm x 20 mm. The thickness of bamboo lamina is varied between 1 mm, 1.5 mm, and 2 mm. The bamboo laminas is then preserved by watering it with a preser vative solution in the form of 2.5 % sodium tetraborate solution and dried in an oven until the water content reaches 10 %. LBCs *were made with a hand lay-up method. After the LBCs were moulded then were pressed with 3 variations of dies compaction 1.5 MPa, 2 MPa and 2.5 MPa. The tensile and bending test characteristics were carried out on the LBCs. Tensile testing is performed in accordance with ASTM standard D3039 and the bending tests were conducted based on ASTM standard D7264. The results shows at each compacting pressure, the highest tensile and bending strength was achieved by LBCs with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo laminates. The LBCs with thinner bamboo lamina reinforcement and more layers has the highest tensile strength and bending strength, even it has lower mass fraction. The LBCs with laminates oriented 0^o exhibited greater tensile and bending strengths than the LBCs with laminates structured $-45^o/+45^o$ and $0^o/90^o$. The LBCs with 0^o laminates direction is matrix fracture than followed by lamina fracture. In the $0^o/90^o$ direction, matrix fracture followed by delamination in the 90^o laminates and the 0^o direction laminates. Delamination and lamina clefting were observed in LBCs with laminates oriented $+45^o/-45^o$.*

Keyword: Laminates Bamboo Composites, Gigantochloa Apus, Tensile Strength, Bending strength.

1. Introduction

Bamboo is a group in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. There are more than 1,450 bamboo species are found in cold mountains to hot tropical regions. Bamboo can be harvested in 3–4 years after planting, compared to the traditional timbers that need decades between planting and harvesting [1, 2]. Bamboo has specific mechanical properties that are superior to other types of natural fibers due to the longitudinal arrangement of the fibers. The small microfibrillar angles of the bamboo fibers support high volume stability and excellent mechanical properties [3–5]. The advantages of the mechanical properties of bamboo and the availability of abundant materials have attracted many researchers to use bamboo as reinforcement in composite materials. The use of bamboo fibers as a reinforcing material provide many benefits. Natural fibers that are low in density can be employed as a useful lightweight engineering material compared to synthetic fibers like glass fibers or carbon fibers [6]. Unfortunately, as for the area of bamboo composites characterizations in thermoset setting, only a handful of studies have looked into laminate-based bamboo composites. The use of bamboo as a composite material provides solutions in the development of the materials industry. The tensile strength of bamboo is about twice as high as the tensile strength of lumber, with the compressive strength is approximately 1.5 times stronger than lumber. The strength to weight ratio of bamboo is higher than lumber and plain steel [7]. Bamboo fiber has the potential to replace glass fibers as reinforcing composites. The bamboo fiber has a specific young modulus (Specific E) comparable with the E-glass fiber. It means that the bamboo fiber has a high stiffness with minimum weights [8, 9]. A rather recent study concerning bamboo strips had successfully characterized several imminent properties, for example, tensile, flexural, impact, and hardness of bamboo composite in a comprehensive manner [10].

Indonesia is a tropical country with various species of bamboo plants, including petung bamboo (*dendrocalamus asper*), wulung bamboo (*gigantochloa atroviolacea*), yellow bamboo (*bambusa vulgaris*), spotted bamboo (*bambusa maculata*), apus bamboo (*gigantochloa apus*) and others. Bamboo is widely used for flooring, roof construction, crafts/furniture, and fabrics. Apus bamboo (*gigantochloa apus*) is a type of bamboo that has the advantage of being easy to divide and cut up to the thickness of 1 mm. At this time, apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, ceiling/home asbestos and woven crafts. The Apus bamboo has tensile strength 230 MPa with density is 0.6 gr/cm^3. Strength to weight ratio of Apus bamboo is higher than woods. The abundant availability of apus bamboo and its good mechanical properties can be used to replace wood in various structural applications. The limitation of bamboo for engineering applications is due to its shape.

Bamboo engineering with lamination by develop Laminated Bamboo Composites (LBCs) is a method to increase the application of bamboo as a engineering materials. Laminated bamboo is a processed bamboo based composite manufactured by gluing bamboo strips/lamina under controlled temperature or pressure. Therefore, the development and improvement of manufacture of LBCs by study the effect of the pressure, number, thickness and direction of Apus bamboo lamina with improved characteristics is the number one priority of researchers in this field.

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2. Literature review and problem statement

Bamboo fiber was used as reinforcement of composite. The mechanical behavior of short untreated and treated with NaOH bamboo fiber reinforced epoxy resin composites were studied. Bamboo fibers with various lengths and contents are reinforced with epoxy resin to produce a composite. The results showed that the mechanical properties of the tensile strength, flexural strength, and impact strength of composites were influenced by the NaOH treatment. The tensile strength of composite with three layers of treated fiber is 18.07 MPa and 16.51 MPa for three layers of untreated fiber [11]. Treating the apus bamboo (*gigantochloa apus*) laminas by soaking it in methanol solution increases the tensile and flexure strength of laminated bamboo composites about 10 % [12]. The results have shown that treatment of bamboo by NaOH or methanol solution will enhance the mechanical properties of bamboo composites. However the effect number, thickness, direction of the lamina and pressures compaction have not been investigated in the study.

The use of gigantochloa scortechinii woven bamboo fibers as reinforcement in composite materials has been investigated. Bamboo matting is made from sheets of bamboo layers measuring: 0.5 mm thickness and 5.0 mm width. Composites with 2 to 6 bamboo layers were made with a hand lay-up method by using unsaturated polyester [UP] as the matrix. The results indicate that increasing the thickness of the bamboo strips increases the tensile stress and modulus of the laminated UP/BF. This is attributed to the bamboo's increased physical interaction with an unsaturated polyester matrix [13]. Bamboo sheets made from thin-wall bamboo culm and isocyanate adhesive have been used to produce laminated bamboo esterilla sheets (LBES). LBES were fabricated by manual compaction and hydraulic compaction. Manual compaction of laminated bamboo was handled using a hand-tightened bolt without measuring the amount of applied pressure. Hydraulic compaction was conducted on the laboratory-scale Weili MH3848(A) 100 T hydraulic pressing machine. The results show that different compaction methods resulted different properties of LBCs. The manual compaction yield lower MOR than the hydraulic presses [14]. The results of this study indicate that in composites with a single laminate, increasing lamina thickness increase the mechanical properties of the composite. The method and amount of compaction in the manufacture of LBCs affect the tensile and bending strength of LBCs. Research to examine the effect of the interaction between the matrix and the bamboo lamina in composites with more than one layer needs to be investigated. A study is required to investigate the characteristics of the effect of the amount of compaction pressure used as a parameter in the manufacture of LBCs.

The laminated composites (LBCs) using four laminas of dendrocalamus strictus cold-pressed using epoxy resin result in maximum stress of LBCs of about 210 MPa. The specimens used had a cross-section of 16 mm x 10 mm. This study reported that compressive strengths of LBCs ranging between 55 MPa and 88 MPa. The fracture mode of LBCs found that the matrix failure occurs followed by fibers failure with metallic sound of anyone layer and subsequently other layers in specimens. There are good agreements between the theoretical values and experiment results for stiffness and strength [15]. Laminated Bamboo Composites (LBCs) of *dendrocalamus strictus* bamboo culms were manufactured from laminas and laminates using an epoxy resin matrix. The mechanical properties of LBCs have been evaluated with different loading conditions. The results show that the mechanical properties of LBCs are better than teak wood, which is one of the strongest woods [16]. The work [17] reported significant differences in strength and behavior between small specimens sourced from different growth portions with the full-size structural members (cross-section 100 mm x 100 mm) constructed from laminated bamboo sourced from different growth portions of the culm. This study found that the bamboo laminate sourced from the middle growth section has the largest elastic modulus. The study of tensile properties of single and two ply laminated bamboo at various off-axis loading angles and laminates configurations has shown that composite laminate theory is applicable to LBCs composite and may be used for design of products and structures [18]. Researchs are needed for fill the gap in existing knowledge of laminated bamboo composites, in order to characterisation of mechanical behaviour of single and multi ply laminates with off-axis loading angle, as well as laminate configuration.

Based on previous studies, it can be concluded that for enhancing the use of bamboo as an engineering materials can be done by developing of Laminated Bamboo Composites (LBCs). Pressure compaction, the number of laminas, the thickness of the lamina, and the orientation of the laminates are critical fabrication variables for achieving a high strength of LBCs. The present study investigates epoxy resin reinforced with bamboo laminates. The type of bamboo studied was Apus bamboo

(*Gigantochloa apus*). Apus bamboo was chosen because it has flexible properties and is easy to make into thin sheets. The research was conducted by varying the tickness, number of laminas, direction of laminates and compacting mold pressure. A detailed characterization, including the tensile and bending strength of the LBCs were investigated.

The review is interesting. However, this version of the review has a drawback. It was necessary to make a critical analysis based on the cited sources. That is, it was necessary not only to describe the issues considered in the mentioned works, but to point out those parts of the problem that are not covered in them. It is necessary to refine the section in this direction. You have to say about each source of literature: which problems were studied in them, which part of the problem remained unexplored, why this part of the problem has not been studied? Can it be objective reasons, methodological or mathematical difficulties, etc.? You must say this specifically.

The last paragraph as a conclusion to the review should also be corrected. You do not just have to say that something is being done in the article. It is necessary to justify why the aim of the research, stated in section 3, is promising. And this should be justified by a critical analysis of the cited sources.

3. The aim and objectives of the study

The aim of this study is to determine the effect of configuration of lamina and pressure compaction on tensile and bending strength of laminated gigantochloa apus (Apus bamboo) composites. see the remark to the title of the article. Maybe so: *The aim of the study is the revealing the patterns* (or *features*) *of formation of mechanical properties of gigantochloa apus laminate reinforced epoxy resin*

The following objectives have been formulated:

– to investigate the effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites (LBCs);

– to investigate the effect of direction of bamboo laminates on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);

– to investigate fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs);

4. Materials and Methods

4. 1. Material

Bamboo's lamina of *gigantochloa apus* was used as primary reinforcement material. The bamboo used is three years old with an average diameter of 150 mm of bamboo. The selected part of the bamboo stem, 1 m to the base to 4 m, was used to make the lamina. The epoxy Bakelite® EPR 174 and resin hardener V-140 were used as a matrix and hardener.

4. 2. Methods

The process of making bamboo lamina begins with cutting the bamboo stalks to obtain a stem length of 40 cm. The bamboo stalks are then split into blades, making the bamboo slats by removing the outer shell. Then the splitting process is carried out to obtain a bamboo blade with a size of 40 cm × 20 mm. The formation of bamboo lamina blades is carried out using the four-side planning tool. This process is carried out to obtain the thickness of 1 mm, 1.5 mm, and 2 mm. Fig. 1 shows the bamboo lamina-making process.

The bamboo laminas is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution. After preservation, the bamboo laminas are dried. The bamboo lamina is dried in an oven until the water content reaches 10 %. A moisturemeter measured the percentage of water content in the bamboo laminas. Drying takes approximately 2–4 weeks in an oven, depending on the weather. Dry bamboo slats are grouped according to their thickness and then sanded to smooth the surface using a sandpaper machine. The photo of bamboo lamina are depicted in Fig. 2.

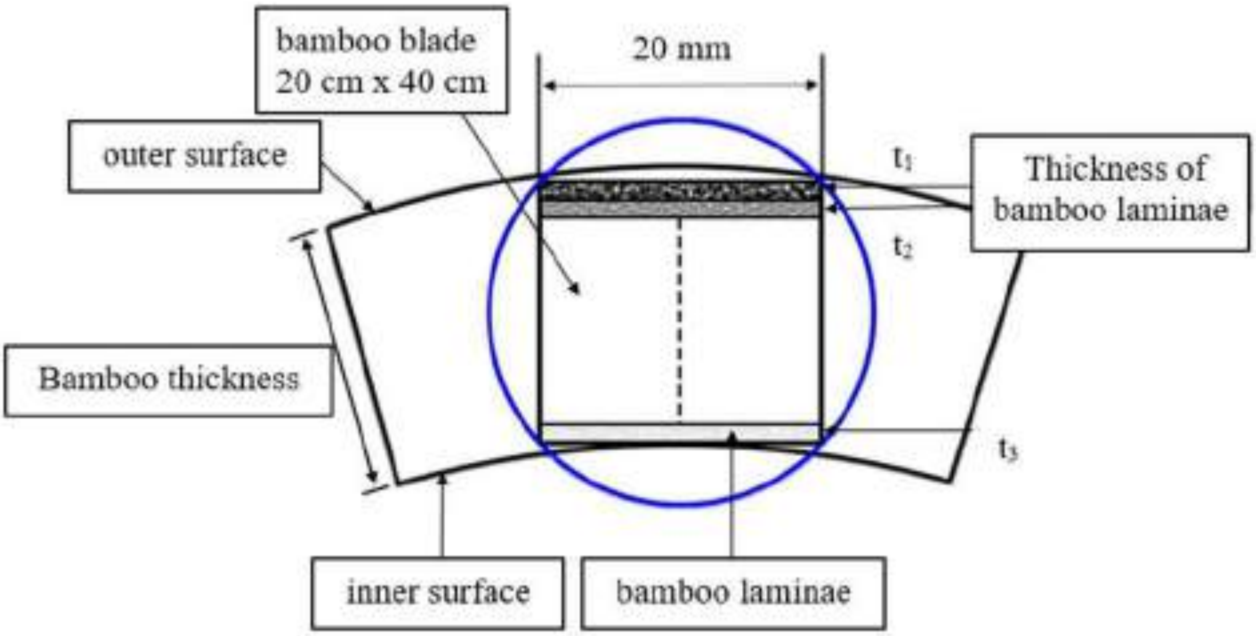


Fig. 1. Formation of the bamboo apus lamina (*gigantochloa apus*)

Fig. 2. Bamboo Lamina

The dried bamboo laminas are then used as reinforcing composites to make Laminated Bamboo Composites (LBCs). An epoxy resin polymer is used as a matrix/adhesive material. LBCs were constructed by hand lay up method with three different number of laminas: 3, 5, and 7. Additionally, LBCs are manufactured in a variety of laminates directions: 0, -45°/+45° and 0°/90°. The configuration of the directional arrangement of the laminates in the composite is shown in Table 1. After hand lay up process, LBCs were compacted using a hydraulic pressing machine with variation of compacting pressure: 1.5 MPa; 2.0 MPa; 2.5 MPa. The LBCs were pressed for 24 hours. Table 2 shows the resulting composites with variations in compacting pressure and the number of lamina forming LBCs. This process produces a composite with a size of 400 mm x 250 mm with various thicknesses.

Table 1
Configuration of laminates direction in Laminated Bamboo Composites

	0°	-45°/+45°	0°/90°
3 layers	0°; 0°; 0°	-45°; +45°; -45°	0°;90°;0°
5 layers	0°; 0°; 0°; 0°; 0°	-45°;+45°;-45°;+45°,-45°	0°;90°;0°;90°;0°
7 layers	0°; 0°; 0°; 0°; 0°; 0°	-45°;+45°;-45°;+45°; -45°;+45°, ;-45°	0°;90°;0°;90°;0°; 90°;0°

Table 2
The weight fraction of bamboo fibers and the epoxy resin matrix of the composites

No	Pressure compaction (MPa)	Lamina (layer)	Thickness lamina (mm)	Thickness LBCs (mm)	Bamboo Mass fraction (Kg/cm^3)	Epoxy-resin Mass faction (Kg/cm^3)
1	1.5 MPa	3	2.0	7.0	0.70	0.30
2		5	1.5	7.0	0.65	0.35
3		7	1.0	7.0	0.60	0.40
4	2.0 MPa	3	2.0	6.5	0.75	0.25
5		5	1.5	6.5	0.70	0.30
6		7	1.0	6.5	0.65	0.35
7	2.5 MPa	3	2.0	6.0	0.80	0.20
8		5	1.5	6.0	0.75	0.25
9		7	1.0	6.0	0.70	0.30

Fig. 3. The tensile test specimens

Fig. 4. The bending test specimens

The tensile test refers to the ASTM standard D3039 with a specimen size of 250 mm x 25 mm x t mm. The bending test was carried out using the ASTM standard D7264 with a 130 mm × 13 mm × t mm specimen size. The test specimens were prepared using water jet cutting. Tensile and bending testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1000 KN. For each variation five specimens were tested. Fig. 3-5 present photo of tensile and bending test specimens.

5. Results of the effect of configuration of lamina and pressure compaction on mechanical properties of laminated gigantochloa apus composites ….??? This section title should be clarified. The title should answer the question "What are the results of the research?"

5. 1. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites

Table 3 and graphs in Fig. 5–7 show the results of the tensile test of LBCs for variations in the number of laminates (3, 5, 7), laminates directions (0°, −45°/+45°, 0°/90°) and the compaction pressure (1.5 MPa, 2 MPa, 2.5 MPa) on the tensile strength of LBCs. It can be noticed from Fig. 5–7 that that the tensile strength of LBCs are influenced by number and direction of laminates. It depicted in Fig. 5, that at compacting pressure of 1.5 MPa, direction of laminates 0^o (on axis) increasing number of laminates also increase the tensile strength of the LBCs. LBCs with 3 layers laminates has tensile strength about 115 MPa, increase about 7 % (124 MPa) when the layers of laminates are 5 layers. The highest tensile strength of LBCs at 0^0 direction and 1.5 Mpa compaction is 139 MPa at 7 layers laminas.The same phenomenon is obtained in the fiber direction −45°/+45°, 0°/90° that as the number of layers in the LBCs increases from 3 to 7 the tensile strength also increases. LBCs with direction −45°/+45° and 0°/90° gain the highest tensile strength 76 MPa and 107 MPa respectively at 7 layers laminates. Lowest tensile strength of LBCs is 58 MPa (about 41 % of highest value) at 3 layers laminas and −45°/+45° laminates direction.

LBCs with a pressure of 2 MPa produce the highest tensile strength of 185 MPa at 7 laminates with laminates direction 0^o (Fig. 6). Besides laminates direction −45°/+45 yied highest tensile strength 88 MPa and LBCs with laminates direction $0^o/90^o$ resulted highest tensile strength 156 MPa. LBCs with laminates direction −45°/+45, 3 layers laminas and 2 mm lamina thickness yield lowest tensile strength with the tensile strength value of 76 MPa (41 % from the highest value of tensile strength).

The graph in Fig. 7 shows that at a pressure of 2.5 MPa the highest tensile strength of LBCs is achieved composite with direction of laminates 0^o with valued 180 MPa. The highest tensile strength also achieved by LBCs with laminates direction 0^o (on axis laminates), 7 layers laminas and 1 mm thicknes of lamina. The increase in number of laminate layers from 3, 5, 7 results in an increase in the tensile strength of 164 MPa, 175 MPa, and 180 MPa, respectively. The lowest value of tensile strength of LBCs is 71 MPa (39 % from the highest value) also find at LBCs with 3 layers laminates and direction laminates −45°/+45.

Table 3

Tensile strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0º	115	124	139	168	177	185	164	175	180
-45º/+45º	58	64	76	76	81	88	71	78	87
0º/90º	91	99	107	135	149	156	131	141	151

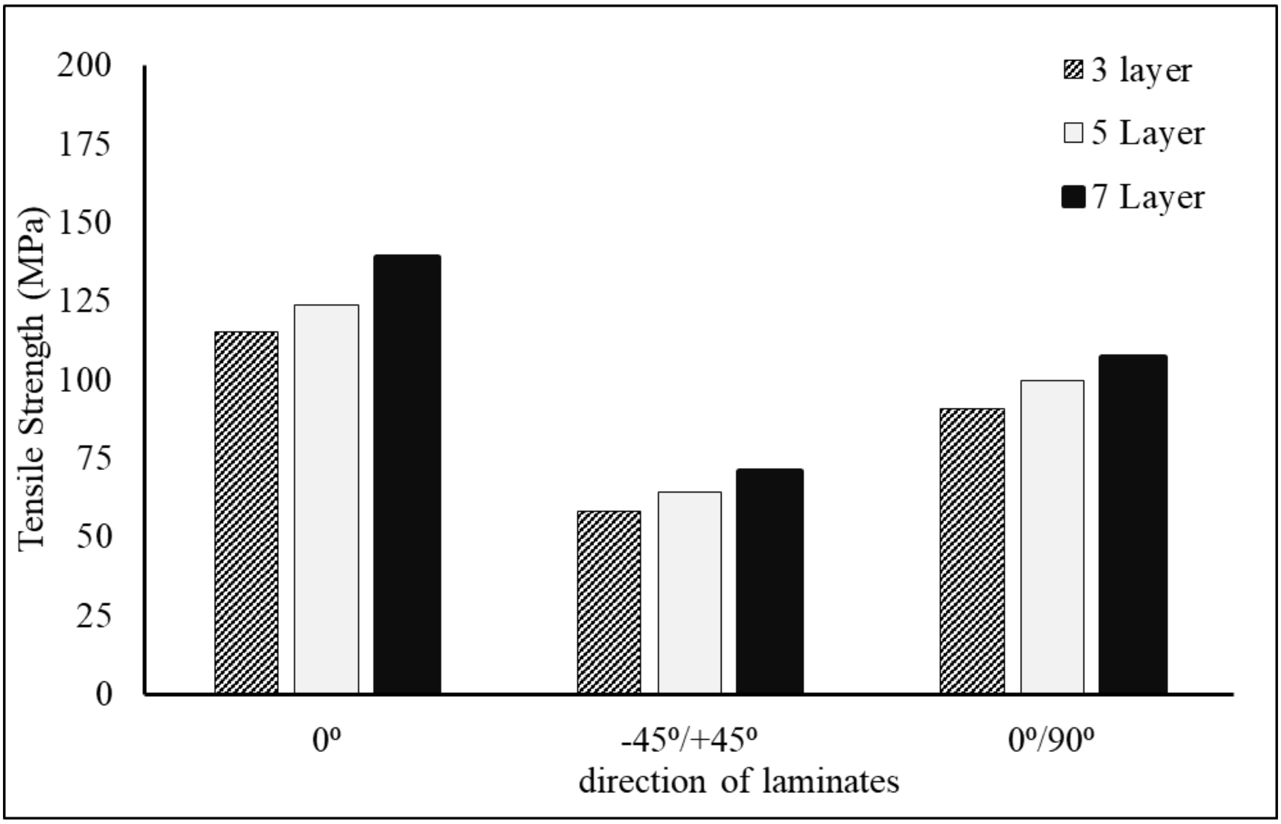


Fig. 5. Tensile strength of LBCs with 1.5 MPa pressure compaction

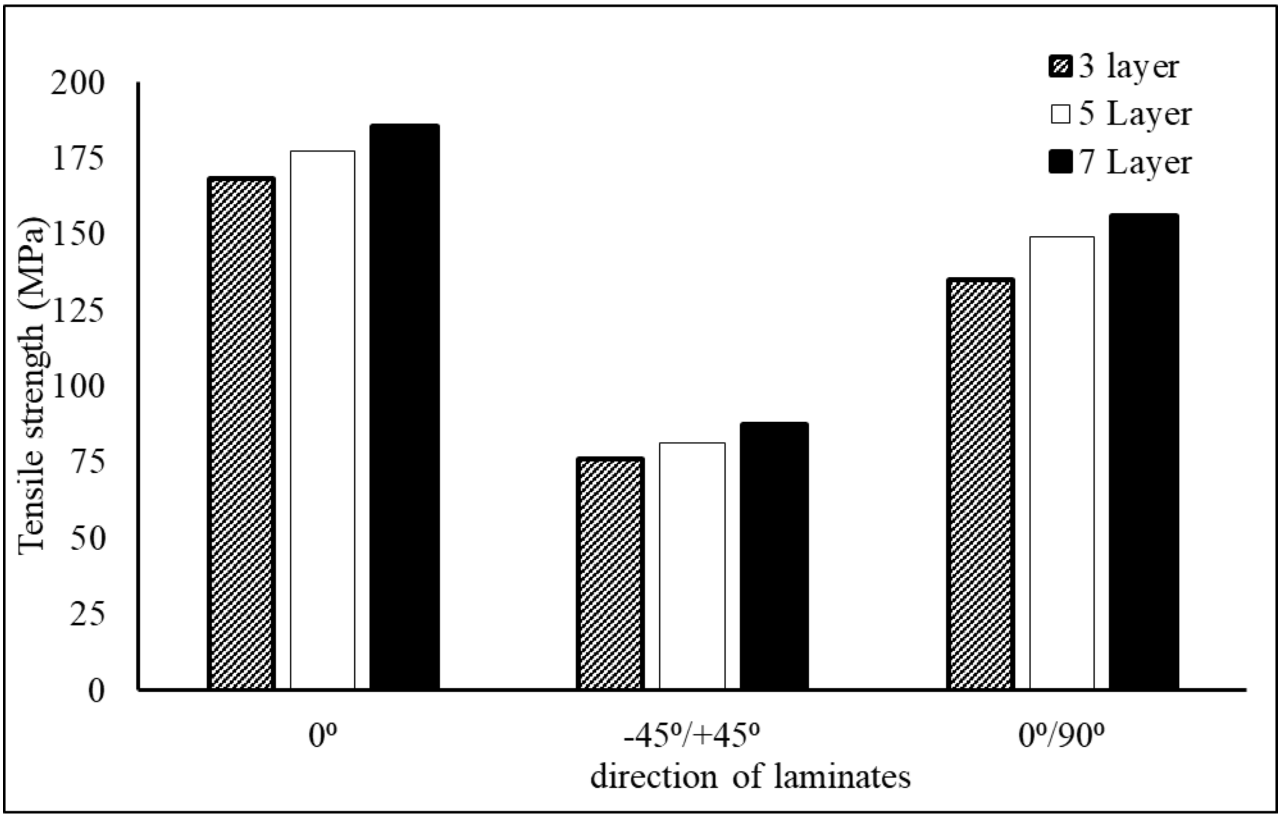


Fig. 6. Tensile strength of LBCs with 2 MPa pressure compaction

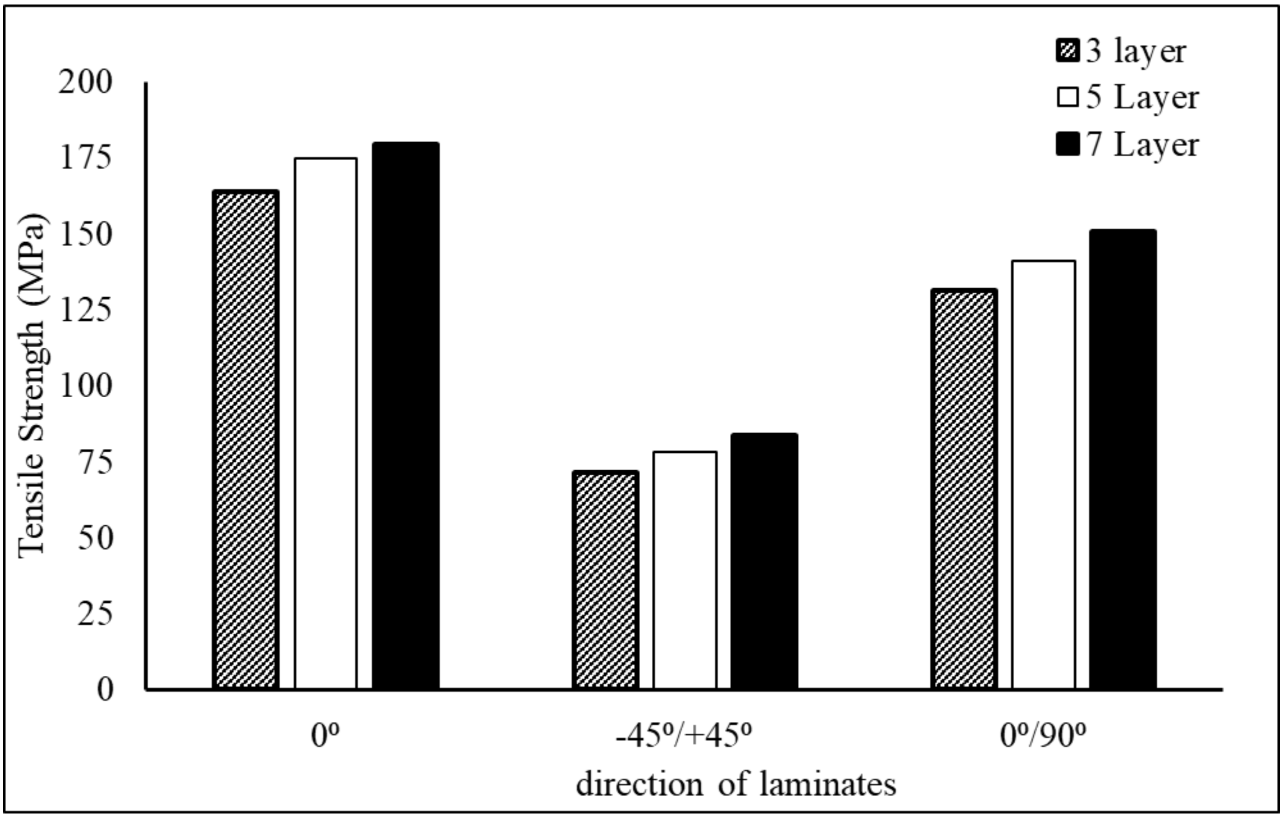


Fig. 7. Tensile strength of LBCs with 2.5 MPa pressure compaction

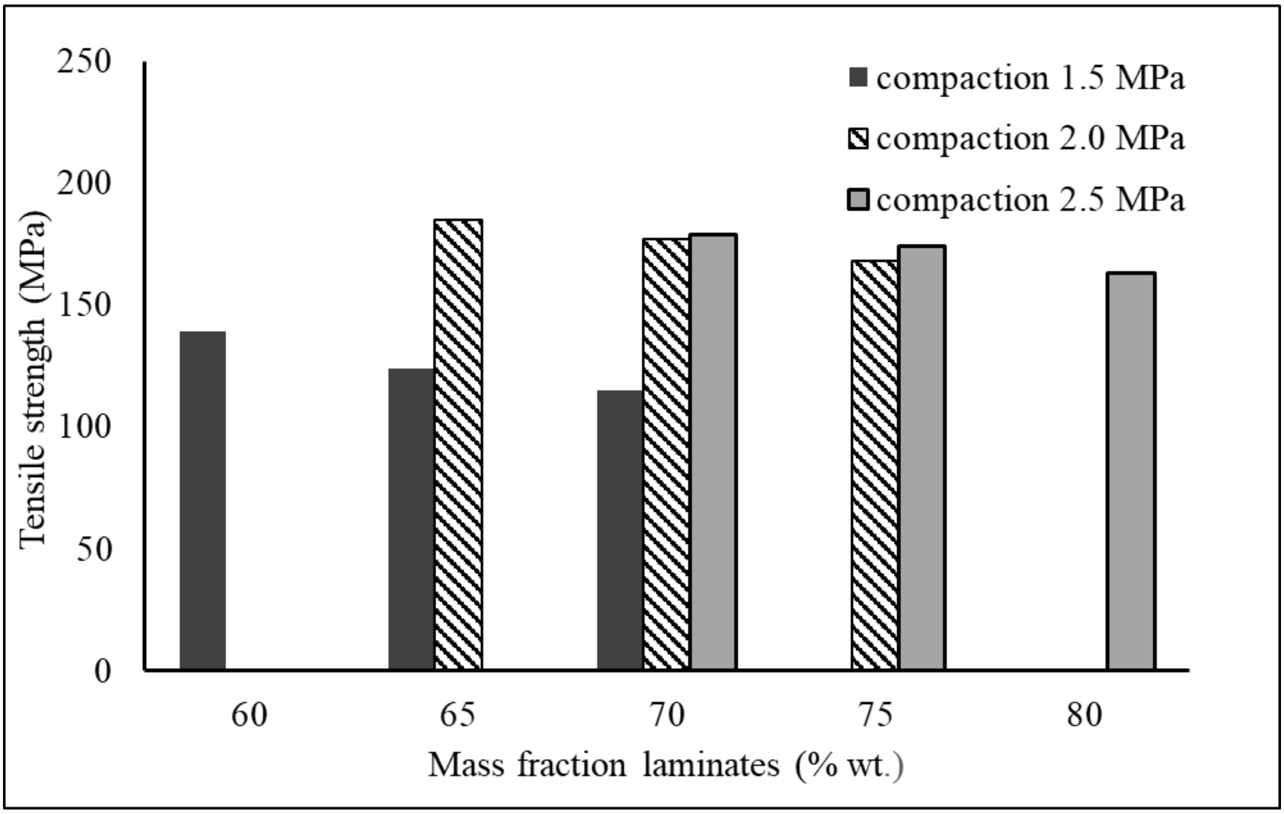


Fig. 8. The effect of mass fraction bamboo laminates on tensile strength of LBCs in composites with direction of 0°

At all pressure variations, LBCs with a 0° laminates direction has a higher tensile strength than LBCs with a direction −45°/+45°and 0°/90°. LBCs with laminates direction -45°/+45° produced lower tensile strength than the others. The effect of mass fraction fraction bamboo laminates and tensile strength of LBCs in composites with direction of 0° is shown in Fig. 8. LBCs with 7 layers laminates 1 mm lamina thickness and compacting pressure 1.5 MPa produces composites with % wt. reinforcement 60 %. At compacting pressure 2.0 MPa and 2.5 MPa, % wt. of LBCs with 7 layers laminates 1 mm lamina thickness are 65% and 70 % respectively. The tensile strengths of LBCs with seven layers are 139 MPa, 185 MPa, and 180 MPa at 1.5 MPa, 2.0 MPa, and 2.5 MPa compaction pressures, respectively. LBCs with 3 layers and 2 mm thickness of lamina yield composite with % wt. reinforcement higher than LBCs with 7 layers and lamina thickness 1 mm. LBCs with three layers and 1.5 MPa, 2.0 MPa, or 2.5 MPa pressure compaction produce LBCs with tensile strengths of 115 MPa, 168 MPa, and 164 MPa, respectively.

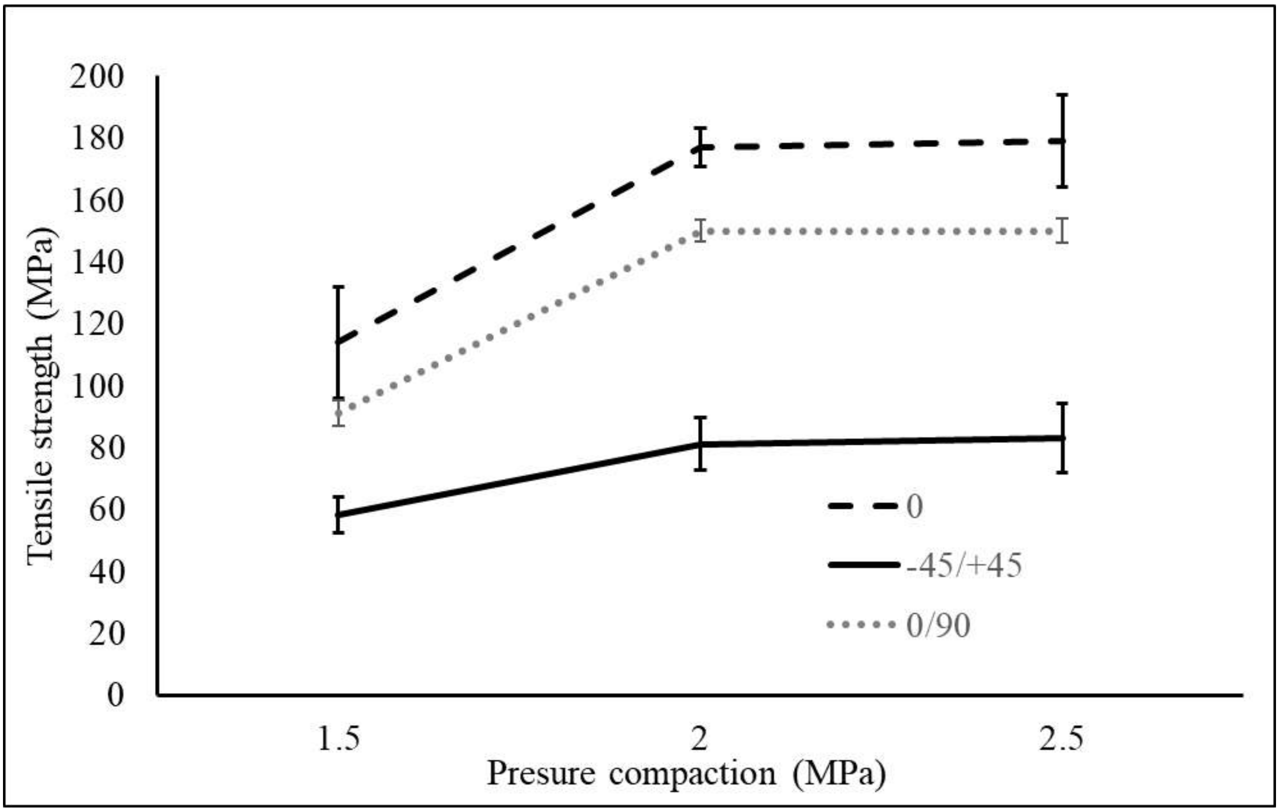


Fig. 9. The effect of Compaction Pressure on Tensile Strength of LBCs at 70 % Mass Fraction

The graph in Fig. 9 also shows the effect of compacting pressure on the tensile strength of LBCs at the mass fraction of 70 %. This analysis selected a mass fraction of 70 % wt because a mass fraction of 70 % wt was generated for all variations studied (Fig. 8). Fig. 9 shows that increasing the compression from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0^o laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0^o/90^o laminates direction. Increasing the compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. The differences of tensile strengths are smaller than the standard deviation of the test. Therefore, it can be concluded the increase in pressure from 2 MPa to 2.5 MPa does not significantly affect the tensile strength of LBCs.

5. 2. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on bending strength Laminated Bamboo Composites

Table 4 and Fig. 10–12 show the bending strength of LBCs with variations of the direction of laminates: 0^o, -45^o/+ 45^o, 0^o/90^o and variations in the number (3, 5 and 7) and thickness (1 mm, 1.5 mm and 2 mm) of apus bamboo lamina with variation of compacting pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa. Fig. 10 shows LBCs with direction of laminates 0^o resulted higher bending strength than LBCs with laminates direction 0^o/90^o or -45^o/+45^o. Bending strength of LBCs with 0^o laminates is approximately 8 % stronger than either of LBCs with 0^o/90^o laminates and approximately 12 % greater than that of LBCs with -45^o/+45^o laminates. At pressure compaction 1.5 MPa, highest bending strengtn of LBCs is 265 MPa, lowest bending strength is produced by LBCs with laminates direction -45º/+45º with valued 218 MPa (approximately 82 % form highest bending strength).

Table 4
Bending strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0º	251	257	265	295	315	321	280	298	306
-45º/+45º	218	229	232	245	266	271	234	239	259
0º/90º	233	241	240	274	284	294	261	268	279

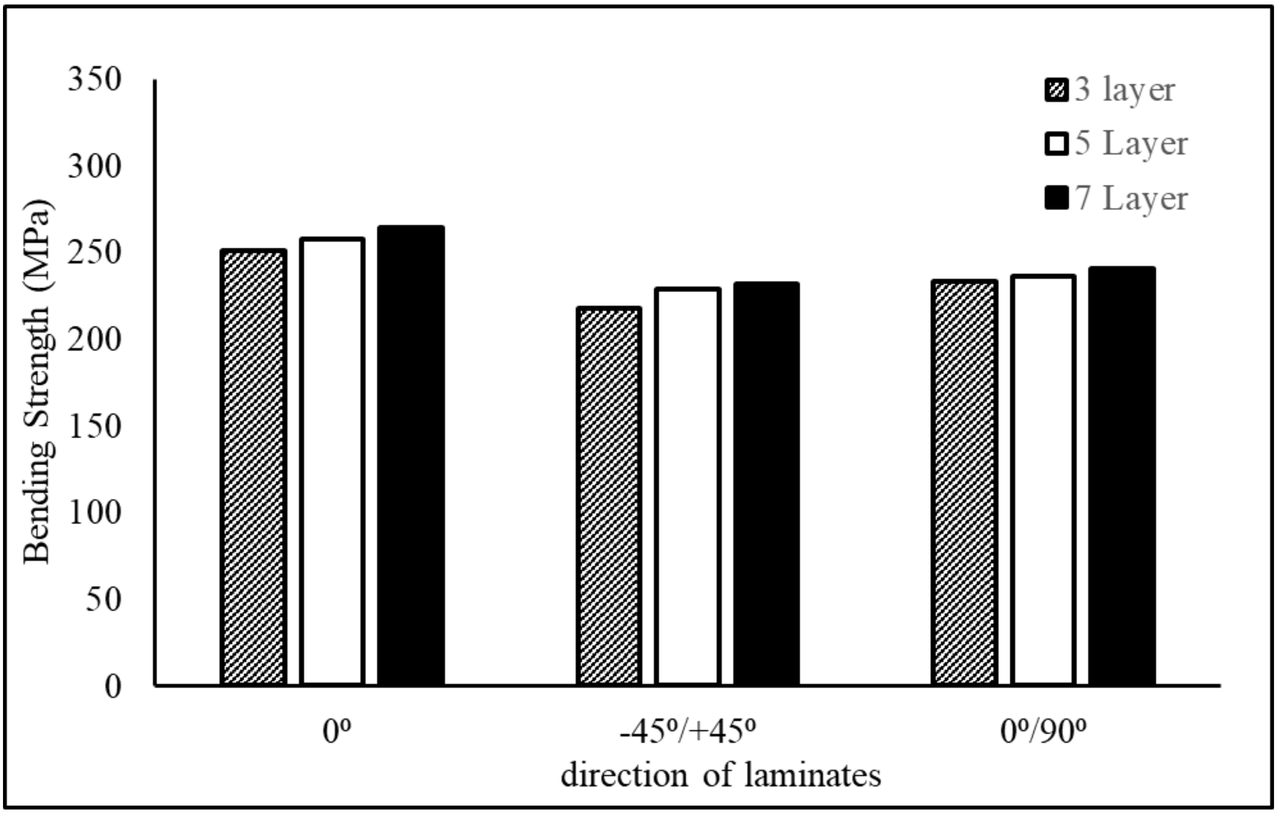


Fig. 10. Bending strength of LBCs with compaction pressure 1.5 MPa

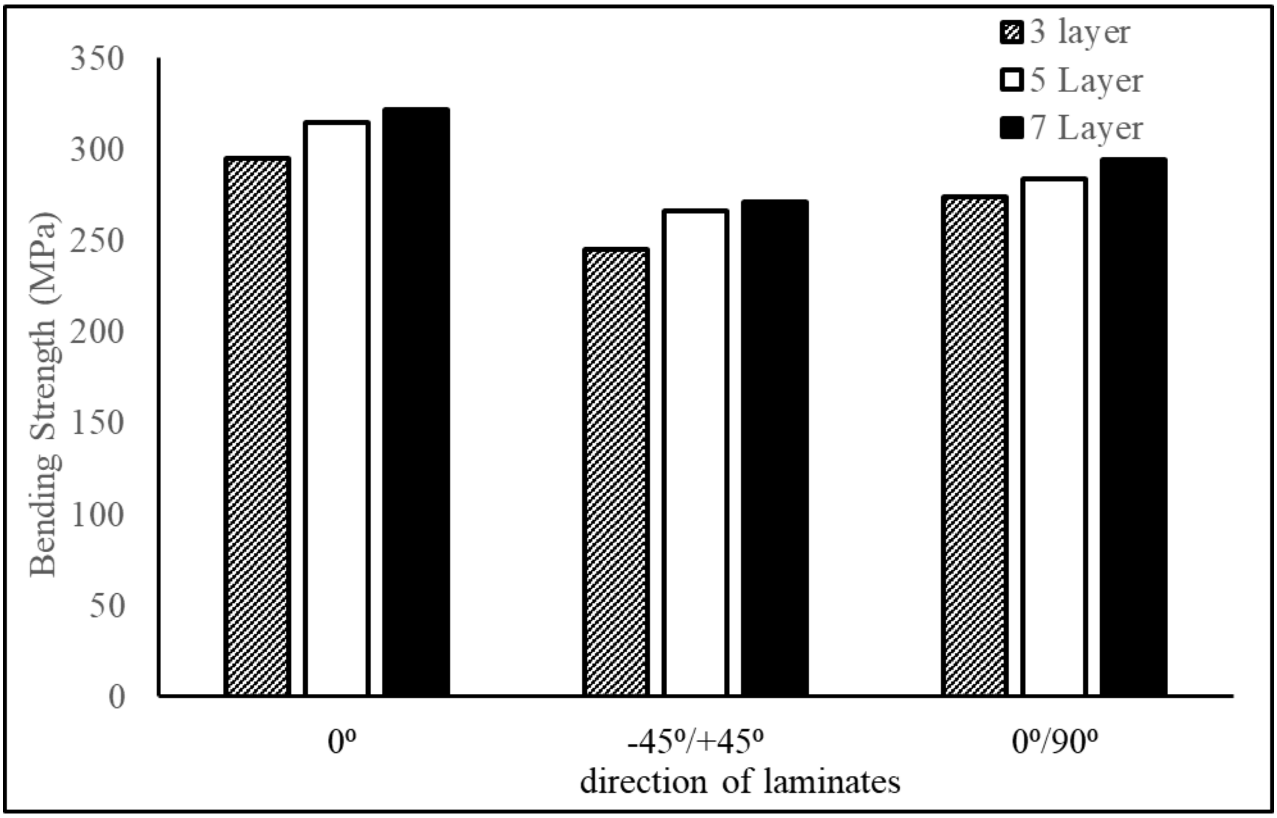


Fig. 11. Bending strength of LBCs with compaction pressure 2.0 MPa

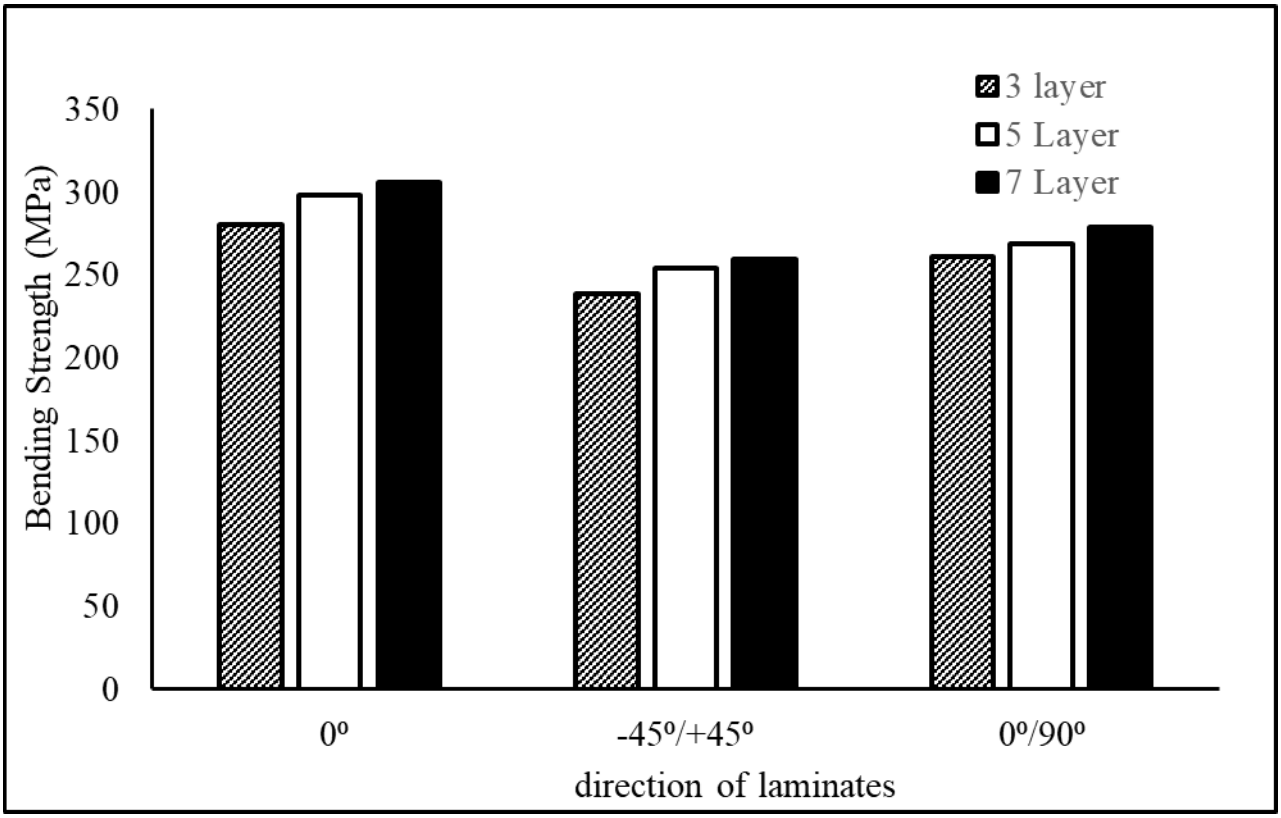


Fig. 12. Bending strength of LBCs with compaction pressure 2.5 MPa

Bending strength of LBCs with compaction pressure 2.0 MPa and 2.5 MPa are depicted in Fig. 11, 12, respectively. the value of the bending strength of the composite with a compaction pressure of 2.0 MPa ranged from 245 MPa to 321 MPa. LBCs have a bending strength of between 234 and 306 MPa when compressed to 2.5 MPa. The composite with a 0^o layer direction and 7 layers of laminas produces the highest bending strength

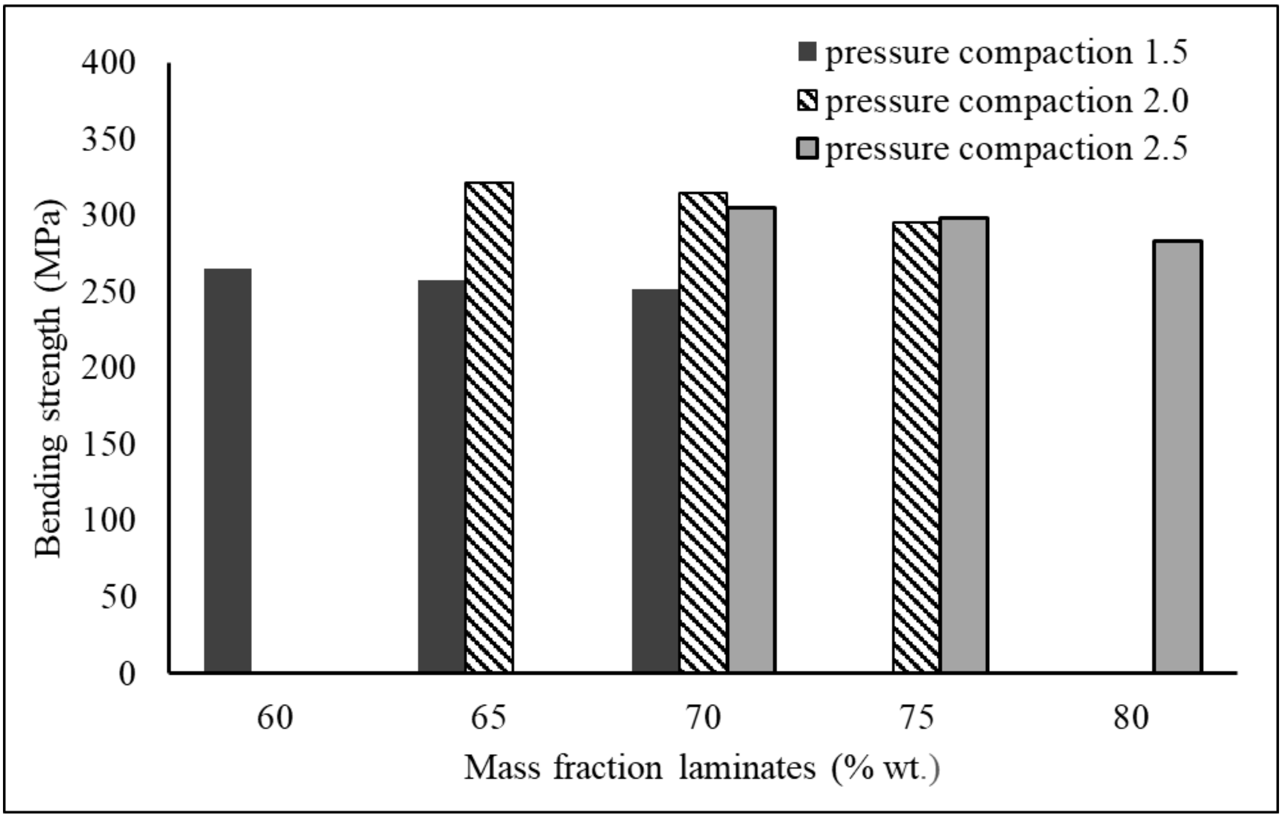


Fig. 13. The effect of mass fraction of laminates on bending strength of LBCs with 0^o direction

The relationship between the bending strength of LBCs and their mass fraction with the laminates' on-axis (0^o) direction is depicted in Fig. 13. At 1.5 MPa compaction pressure, LBCs with a mass fraction of 60% have stractured 7 layers of lamina with a thickness of 1 mm, yielding the highest bending strength of 265 MPa. At compression pressures of 2.0 MPa and 2.5 MPa, LBCs with 7 layers laminas exhibit the highest bending strength, with values of 321 MPa and 306 MPa, respectively. From the graph in Fig. 13, it can be concluded that the highest bending strength is in the composite with thinner bamboo reinforcement and a higher number of layers even at a lower mass fraction.

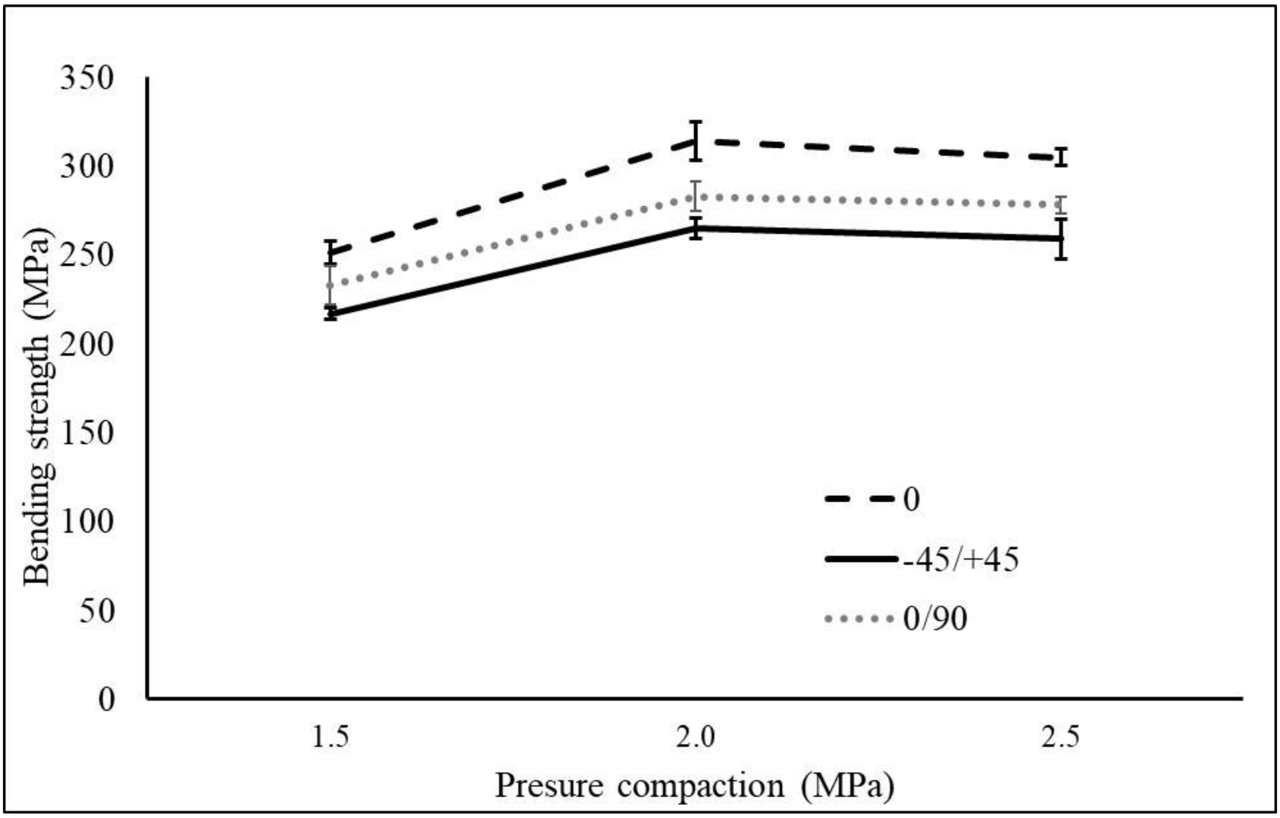
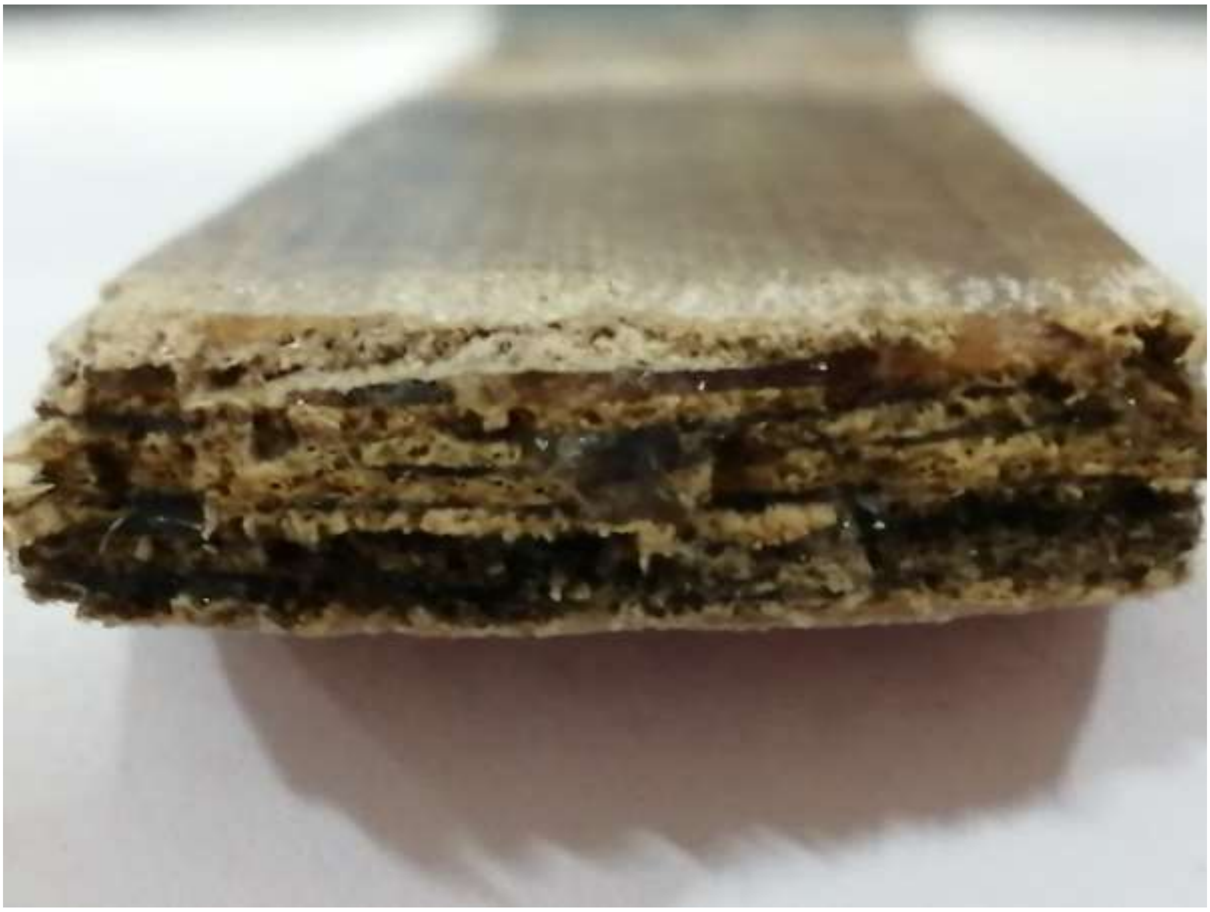


Fig. 14. The effect of Compaction Pressure on the Bending Strength of LBCs at 70 % Mass Fraction

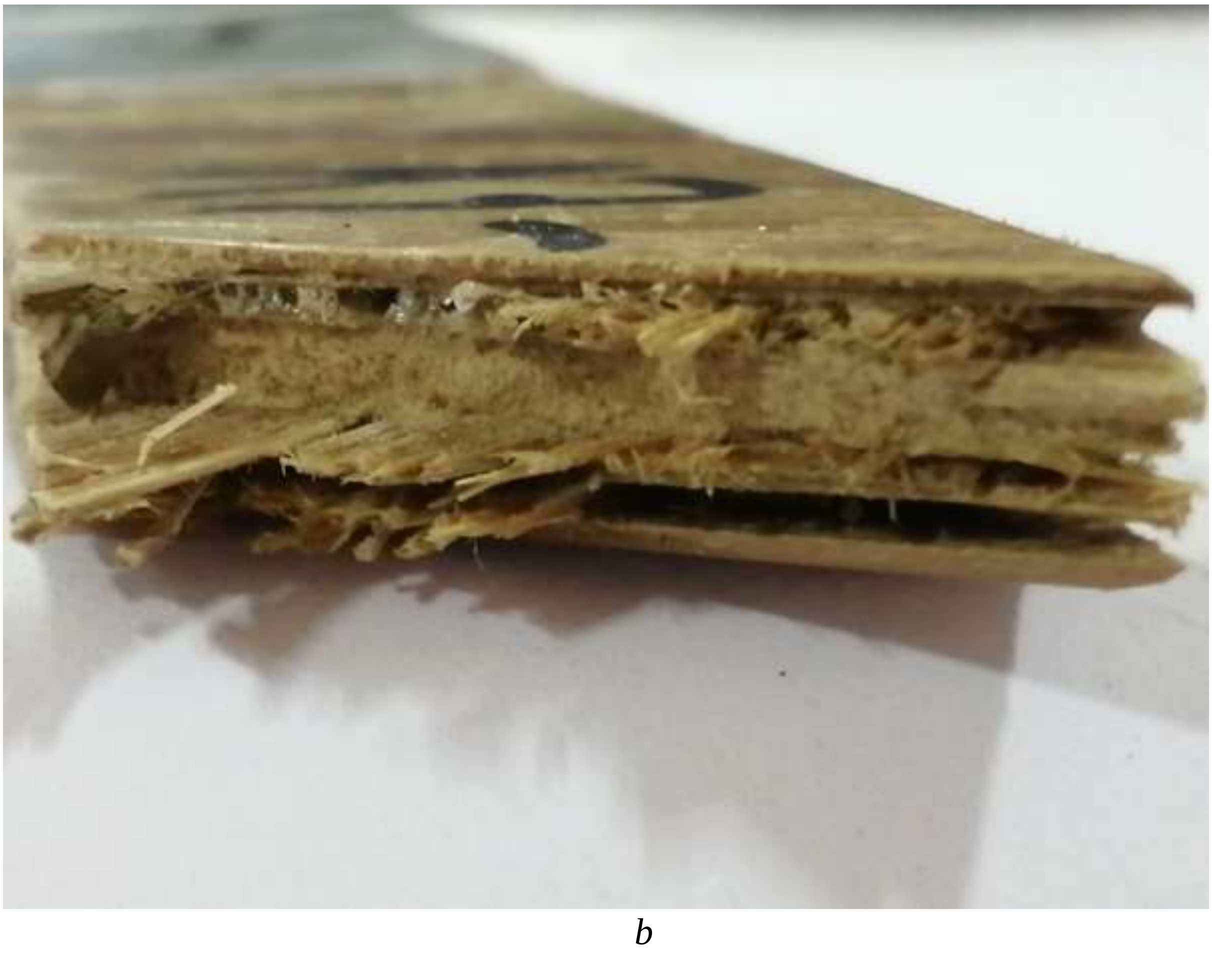
The graph in Fig. 14 also shows the effect of compacting pressure on the bending strength of LBCs at the mass fraction of 70 %. By increasing pressure compaction from 1.5 MPa to 2 MPa, the bending strength of LBCs increase by 25% in the 0^o laminates direction, 22% in the 45°/+45° laminates direction, and 21% in the 0^o/90^o laminates direction. As with the tensile tests, increasing the compacting pressure from 2 MPa to 2.5 MPa have no noticeable effect on the bending strength of LBCs.

5. 3. Investigation fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs)

Fig. 15 shows a macro photograph of the surface fracture of LBCs after tensile testing. Fig. 15, *a* shows the fracture of LBCs with laminates direction 0^o. The fracture surface of the LBCs with the laminates direction -45^o/+45^o (Fig. 15, *b*) and the fracture surface of the LBCs with the laminates direction -0^o/90^o (Fig. 15, *c*). The LBCs with 0^o direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by load transfer to bamboo laminas and subsequent bamboo lamina fracture. Fig. 15, *b* shows the fracture of matrix followed by delamination of lamina in the 90^o direction, and finally fracture of lamina in the 0^o direction. In LBCs with laminates orientation +45^o/-45^o, matrix fracture was followed by delamination and lamina clefting.



a



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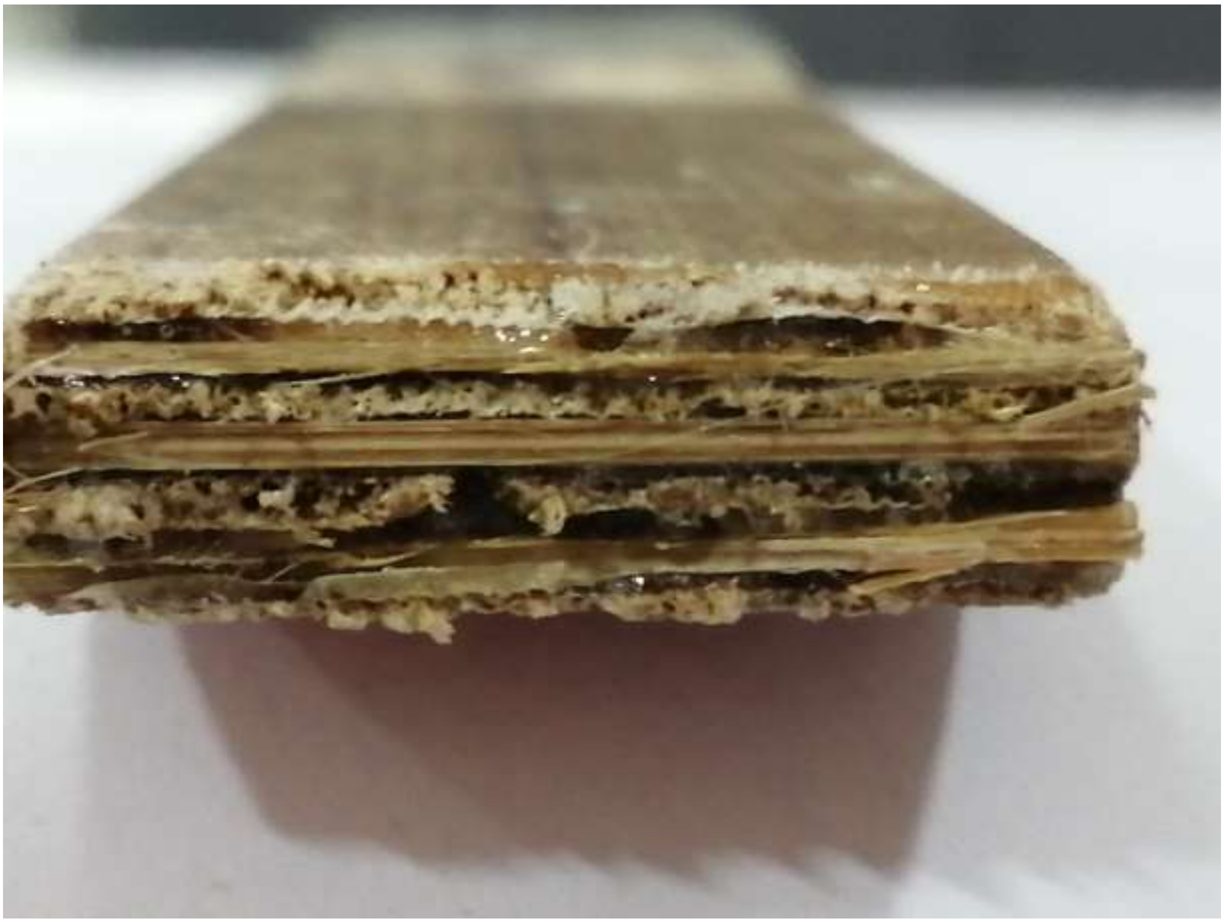

c

Fig. 15. Photomacrography The Fracture of Cross Section of The Tensile Test of 7 Layers Laminated Bamboo Composites (LBCs): *a* – direction of laminates 0^{o}; *b* – direction of laminates -45^{o}/+45^{o}; *c* – direction of laminates 0^{o}/90^{o}

a

b

c

Fig. 16. Bending Test Result Specimens of Laminated Bamboo Composites (LBCs) from 7 layers: *a* – layers direction of 0^o; *b* – layers direction -45^o/45^o; *c* – layers direction 0^o/90^o

The macro photographs of the LBCs after bending tested are shown in Fig. 16. Fig 16, *a* shows that bending tested of LBCs with 0^o laminates direction, produced fractured of matrix and followed fracture of laminates. Fracture photographs of LBCs with layers direction -45^o/45^o (Fig. 16, *b*) shows, that at At the bottom of the specimen, fracture occurs due to lamina delamination. Failure continues with delamination and the lamina splits due to shear stress. The failure of the specimen with the direction of the lamina 0^o/90^o as shown in Fig. 16.*c* indicates that the failure due to bending started with matrix fracture and fracture lamina at the bottom (outer) of the specimen. Failure is followed by delamination of the lamina in the 90^o direction

6. Discussion of the effect of configuration of lamina and pressure compaction on mechanical properties of laminated gigantochloa apus composites.

of....????? This section title should be clarified. The title should answer the question "Discussion of the results of the study of what?"

The effect of direction, thickness, number of laminas on tensile strength of LBCs at compaction pressure 1.5 MPa; 2.0 MPa; 2.5 MPa are shown in Fig. 5; Fig. 6; Fig. 7, respectively. These results indicate that as the number of layers increases and the reduced lamina thickness increase the tensile strength of LBCs. The highest tensile strength was achieved by LBCs, with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo lamina. It can be concluded that the highest tensile strength is in the composite with thinner bamboo reinforcement and more layers, even at a lower mass fraction. Increasing the tensile strength properties of LBCs in the thinner bamboo lamina reinforcement with a higher number of composites forming layers is an important concern in this study. This caused by the ability of the epoxy resin to enter the thinner pores of the apus bamboo fiber, thereby increasing the interface strength of the composite-forming bamboo layer. The other works also reported that increasing the number of laminas forming the Layered Laminate Bamboo Composites (LLBCs) will increase tensile and flexural stress [7]. The tensile strength of laminated composites is dependent on the interfacial properties of natural fibers and polymer composites. Additionally, the tensile properties are influenced by the laminates directions [19]. Study on mechanical properties of laminated bamboo composites with different bamboo and matrices (gigantochloa scortechinii and unsaturated polyester) showed that the thicker the bamboo blades produced the higher the tensile stress and flexural stress [20]. Fig. 5-7 also depict that the direction configuration of the composite laminates also affects the tensile strength of LLBCs. The configuration of the laminates with direction 0^o yields higher result of tensile strength compared to the configuration of the direction of the fiber crossed -45°/+45° and 0°/90°. Thus, the tensile strength of the LBCs decreases with increasing the angle of the laminates under the tensile stress. According to the Tsai–Hill criterion, the tensile and compressive properties of the composite will continue to decrease due to changes in the fiber orientation angle that increases from 0° [21]. This study's results prove that the direction of the lamina 0° provides the higher tensile strength compared to the direction of the laminates −45°/+45°, 0°/90°.

The compacting pressure applied to the manufacture of LBCs affects the mass fraction (wt) of the epoxy resin matrix contained in the LBCs. The compacting pressure will drive the epoxy resin out of the LBCs mold while the mass fraction of the bamboo laminates steady [9]. Higher compression pressure will reduce the % wt epoxy-resin and increase % wt. of lamina (Fig. 8). The pressure compaction of LBCs from 1.5 MPa to 2.0 MPa can reduce the weight fraction of epoxy resin in LBCs by 5 % of the initial mass fraction, but it can increase the tensile strength of LBCs by 55 % at laminates direction 0°, 40 % in the direction of laminates −45°/+45° and 64 % in the direction of laminates 0°/90°. The numerical analysis results demonstrate that the ultimate tensile loading increases by decreases of adhesive thickness [22]. The optimum tensile stress of Laminated Bamboo Composites (LBCs) was obtained at a 2 MPa compaction pressure variation with a mass fraction (wt) of lamina of 70 % and a mass fraction (wt) of epoxy-resin of 30 %. The application of compacting pressure above 2 MPa on LBCs didn't affect on the value of tensile stress. It can be consluded that compacting pressure

2.0 MPa also produces optimum thickness of apoxy-resin matrix in bamboo laminas. The anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds as a result of reduced mass fraction (% wt) of the epoxy resin matrix contained in the respective LBCs each by 5 % for each variation of the tested specimens.

Apus bamboo (gigantochloa apus) lamina has tensile strength of 230 MPa and an epoxy resin with a tensile strength of 57 MPa after being formed into a composite LBCs was able to produce the highest tensile strength of 185 MPa with a ratio of 70 % lamina bamboo lamina mass fraction and 70 % mass fraction. (wt) epoxy-resin 30 %. This result higher than previous research that reported composites used gigantochloa scortechinii (semantan reed) woven bamboo as reinforcement with a ratio of 33 % of the mass fraction (wt) of bamboo laminates and the mass fraction (wt) of 77 % epoxy matrix was only able to produce a maximum tensile strength of 89 MPa [11].

Bending test results for LBCs with varying lamina orientations 0^o, $-45^o/+45^o$, $0^o/90^o$; number of laminas (3, 5 and 7) and thickness of lamina (1 mm, 1.5 mm and 2 mm) with variation of compacting pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa are depict in Fig. 10-12. LBCs with direction of laminates 0^o resulted higher bending strength than LBCs with laminates direction $0^o/90^o$ or $-45^o/+45^o$ These results show that increasing the number of lamina with thinner lamina increase the bending strength of LBCs. The LBCs with 7 layers of bamboo laminas, 1 mm thickness, 0^o fiber direction and 2 MPa stress yield highest bending strength valued 321 MPa. It's aproximatelly 20 % stronger than LBCs with compacted pressure 1.5 and 5 % higher than LBCs with 2.5 MPa compaction pressure. Apus bamboo (gigantochloa apus) with a bending strength of lamina 348 MPa and epoxy-resin with bending strength of 175 Mpa, after being manufactured into a composite LBCs, this materials yield the highest bending strength of 321 MPa with a ratio of mass fraction (wt) of 70 % and mass fraction (%. wt) epoxy-resin 30 %. Gigantochloa scortechinii (semantan reed) woven bamboo with a ratio of 33 % of the mass fraction (wt) of bamboo laminates and the mass fraction (wt) of 67 % epoxy matrix was only able to produce a maximum bending strength of 120 MPa [11]. The bamboo allowed large flexural deformations because its outer part retains the tensile stress while the softer inner part undergoes large compressive deformation [23]. The configuration of the 0^o direction of the laminates yield the higher bending strength compared to the configuration of $0^o/45^o$ and $0^o/90^o$ crossed laminates [21].

The bending stress of laminated bamboo composites is also influenced by the direction (orientation) of the bamboo laminate and the number of layers. At each variation in the direction of the bamboo laminatesand stress, the bending strength of the LBCs increased with the increasing number of layers of bamboo laminas. In the number of layers, the bending strength of LBCs with the laminates direction of 0^o has the largest bending strength, followed by the crossed fiber direction of 90^o and the lowest bending strength is the LBCs with the $-45^o/+ 45^o$ fiber direction.

The Laminated Bamboo Composites (LBCs) with more layers of laminas produce higher tensile and bending strength compare with LBCs with less number of laminas. The thinner lamina provide a higher adhesive contact surface area than the thicker lamina. Higher adhesive contact area provides better stress transfer to the lamina [24].

Fig. 15 and Fig. 16 show the fracture surface of LBCs after tensile and bending test. It found same mechanism of fracture on the both of surface test. The cross section of fracture surface of tensile and bending test of LBCs with on axis laminas direction (0^o) show the phenomenon of fracture in the lamina due to the load transmitted by the matrix. Bamboo lamina can fully withstand the load transferred by the matrix. This causes LBCs with laminates 0^o direction (on axis) to be stronger than LBCs with off axis laminated direction. The cross section of fracture photograph demonstrates that the fracture mechanism is a fracture matrix followed by the breaking of the bamboo laminates. On the LBCs with laminas orientation $-45^o/+45^o$ and $0^o/90^o$ fracture mechanism of LBCs, there are delamination of lamina caused by debonding of adhesion between lamina. The fracture's cross-sectional images demonstrate the lamina delamination behavior.

In this version of the article, the Discussion section is not specific, so it is difficult to imagine what exactly the author interprets as the main scientific results and how exactly it explains them. To remove this problem, it is necessary to revise the section, bringing it into line with such a structurally-substantive scheme:

– how can the results be explained? This interpretation part is the first main part of the discussion and there are important nuances of its presentation. It is necessary to explain the results obtained for each research objective, referring to those objects in the article that display the discussed results. Such objects in the general case are figures and tables. That is, it should be seen which result is being discussed at this point in the section.

– how do the proposed solutions/results allow to close the problem area identified by the author, and if so, in which part and due to what exactly? This is the second main part of the discussion, because it is this that closes the research (feedback): the problem is identified – the aim is set – the results are obtained – the results are explained using some kind of evidence base (section "Discussion ...")

– what can be considered the advantages of this study in comparison with those known on this subject. In this case, it is necessary to indicate alternative solutions and say, thanks to which particular features of the proposed solutions, advantages (or, in general, differences) are provided?

– what limitations are inherent in this study? This is the third main part of the discussion.

– what are the disadvantages of the study and in what direction should the study be developed?

7. Conclusions

1. LBCs with 0o direction of laminas yield higher tensile strength than LBCs with off axis direction of laminates ($-45^o/45^o$; $0^o/90^o$). Incresing number of laminate increase tensile strength of LBCs. LBCs with thinner lamina provide a higher adhesive contact surface area than the thicker lamina and yield higher tensile strength of LBCs. The rise of the pressure compation from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0^o laminates direction, 40 % in the $-45°/+45°$ laminates direction, and 64 % in the $0^o/90^o$ laminates direction. Increasing the compacting pressure from

2.0 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. Highest tensile strength of LBCs with value 185 MPa is produced by LBCs with direction 0o, 7 laminas, 1 mm thickness of lamina with pressure compaction 2 MPa.

2. The highest bending strength of LBCs, 321 MPa, is achieved with LBCs in the 0^o direction, 7 laminas, 1 mm thickness of lamina, and 2 MPa pressure compaction. LBCs with laminates oriented on axis (0^o) have a greater bending strength than composites with orientation of laminates off axis ($-45^o/45^o$; $0^o/90^o$). LBCs' bending strength increases as the number of laminates increases. Increases the bending strength of LBCs by 25% in the 0^o laminates direction, 22% in the 45°/+45° laminates direction, and 21% in the $0^o/90^o$ laminates direction when the pressure compaction is increased from 1.5 MPa to 2.0 MPa. Increased compacting pressure from 2.0 to 2.5 MPa has no perceptible effect on the tensile strength of the LBCs.

3. The LBCs with 0^o direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by bamboo lamina fracture. Composites with $0^o/90^o$ laminates direction, the fracture of matrix followed by delamination of lamina in the 90^o direction, and finally fracture of lamina in the 0^o direction. In LBCs with laminates orientation $-45^o/+45^o$, matrix fracture was followed by delamination and lamina clefting.

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THE EFFECT OF CONFIGURATION OF LAMINA AND PRESSURE COMPACTION ON MECHANICAL PROPERTIES OF LAMINATED GIGANTOCHLOA APUS COMPOSITES

Parlindungan Manik, Agus Suprihanto, Sri Nugroho, Sulardjaka

This study aims to investigate the mechanical properties of bamboo apus (gigantochloa apus) as a natural reinforced composite material. Bamboo's laminates of gigantochloa apus was used as reinforcement on the epoxy resin matrix. The parameters examined in this study configuration of lamina and pressure compaction. Laminate configuration varies in the number, thickness and direction of the lamina. Variant compaction pressures of 1.5 MPa, 2 MPa, and 2.5 MPa were used to fabricate the Laminated Bamboo Composites (LBCs). The stem of bamboo with a length of 400 mm was split to obtain bamboo lamina with a size of 400×20 mm. The thickness of bamboo lamina is varied between 1 mm, 1.5 mm, and 2 mm. The bamboo laminas is then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution and dried in an oven until the water content reaches 10 %. LBCs were made with a hand lay-up method. After the LBCs were molded then were pressed with 3 variations of dies compaction 1.5 MPa, 2 MPa and 2.5 MPa. The tensile and bending test characteristics were carried out on the LBCs. Tensile testing is performed in accordance with ASTM standard D3039 and the bending tests were conducted based on ASTM standard D7264. The results shows at each compacting pressure, the highest tensile and bending strength was achieved by LBCs with a thickness of 1 mm of bamboo lamina and 7 layers of bamboo laminates. The LBCs with thinner bamboo lamina reinforcement and more layers has the highest tensile strength and bending strength, even it has lower mass fraction. The LBCs with laminates oriented 0° exhibited greater tensile and bending strengths than the LBCs with laminates structured –45°/+45° and 0°/90°. The LBCs with 0° laminates direction is matrix fracture than followed by lamina fracture. In the 0°/90° direction, matrix fracture followed by delamination in the 90° laminates and the 0° direction laminates. Delamination and lamina clefting were observed in LBCs with laminates oriented +45°/–45°

Keyword: Laminates Bamboo Composites, Gigantochloa Apus, Tensile Strength, Bending strength

1. Introduction

Bamboo is a group in the true grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. There are more than 1,450 bamboo species are found in cold mountains to hot tropical regions. Bamboo can be harvested in 3–4 years after planting, compared to the traditional timbers that need decades between planting and harvesting [1, 2]. Bamboo has specific mechanical properties that are superior to other types of natural fibers due to the longitudinal arrangement of the fibers. The small microfibrillar angles of the bamboo fibers support high volume stability and excellent mechanical properties [3–5]. The advantages of the mechanical properties of bamboo and the availability of abundant materials have attracted many researchers to use bamboo as reinforcement in composite materials. The use of bamboo fibers as a reinforcing material provide many benefits. Natural fibers that are low in density can be employed as a useful lightweight engineering material compared to synthetic fibers like glass fibers or carbon fibers [6]. Unfortunately, as for the area of bamboo composites characterizations in thermoset setting, only a handful of studies have looked into laminate-based bamboo composites. The use of bamboo as a composite material provides solutions in the development of the materials industry. The tensile strength of bamboo is about twice as high as the tensile strength of lumber, with the compressive strength is approximately 1.5 times stronger than lumber. The strength to weight ratio of bamboo is higher than lumber and plain steel [7]. Bamboo fiber has the potential to replace glass fibers as reinforcing composites. The bamboo fiber has a specific young modulus (Specific E) comparable with the E-glass fiber. It means that the bamboo fiber has a high stiffness with minimum weights [8, 9]. A rather recent study concerning bamboo strips had successfully characterized several imminent properties, for example, tensile, flexural, impact, and hardness of bamboo composite in a comprehensive manner [10].

Indonesia is a tropical country with various species of bamboo plants, including petung bamboo (*dendrocalamus asper*), wulung bamboo (*gigantochloa atroviolacea*), yellow bamboo (*bambusa vulgaris*), spotted bamboo (*bambusa maculata*), apus bamboo (*gigantochloa apus*) and others. Bamboo is widely used for flooring, roof construction, crafts/furniture, and fabrics. Apus bamboo (*gigantochloa apus*) is a type of bamboo that has the advantage of being easy to divide and cut up to the thickness of 1 mm. At this time, apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, ceiling/home asbestos and woven crafts. The Apus bamboo has tensile strength 230 MPa with density is 0.6 gr/cm^3. Strength to weight ratio of Apus bamboo is higher than woods. The abundant availability of apus bamboo and its good mechanical properties can be used to replace wood in various structural applications. The limitation of bamboo for engineering applications is due to its shape.

Bamboo engineering with lamination by develop Laminated Bamboo Composites (LBCs) is a method to increase the application of bamboo as an engineering material. Laminated bamboo is a processed bamboo based composite manufactured by gluing bamboo strips/lamina under controlled temperature or pressure. Therefore, the development and improvement of manufacture of LBCs by study the effect of the pressure, number, thickness and direction of Apus bamboo lamina with improved characteristics is the number one priority of researchers in this field.

2. Literature review and problem statement

Bamboo fiber was used as reinforcement of composite. The mechanical behavior of short untreated and treated with NaOH bamboo fiber reinforced epoxy resin composites were studied. Bamboo fibers with various lengths and contents are reinforced with epoxy resin to produce a composite. The results showed that the mechanical properties of the tensile strength, flexural strength, and impact strength of composites were influenced by the NaOH treatment. The tensile strength of composite with three layers of treated fiber is 18.07 MPa and 16.51 MPa for three layers of untreated fiber [11]. Treating the apus bamboo (*gigantochloa apus*) laminas by soaking it in methanol solution increases the tensile and flexure strength of laminated bamboo composites about 10 % [12]. The results have shown that treatment of bamboo by NaOH or methanol solution will enhance the mechanical properties of bamboo composites. However, the effect number, thickness, direction of the lamina and pressures compaction have not been investigated in the study.

The use of gigantochloa scortechinii woven bamboo fibers as reinforcement in composite materials has been investigated. Bamboo matting is made from sheets of bamboo layers measuring: 0.5 mm thickness and 5.0 mm width. Composites with 2 to 6 bamboo layers were made with a hand lay-up method by using unsaturated polyester [UP] as the matrix. The results indicate that increasing the thickness of the bamboo strips increases the tensile stress and modulus of the laminated UP/BF. This is attributed to the bamboo's increased physical interaction with an unsaturated polyester matrix [13]. Bamboo sheets made from thin-wall bamboo culm and isocyanate adhesive have been used to produce laminated bamboo esterilla sheets (LBES). LBES were fabricated by manual compaction and hydraulic compaction. Manual compaction of laminated bamboo was handled using a hand-tightened bolt without measuring the amount of applied pressure. Hydraulic compaction was conducted on the laboratory-scale Weili MH3848(A) 100 T hydraulic pressing machine. The results show that different compaction methods resulted different properties of LBCs. The manual compaction yield lower MOR than the hydraulic presses [14]. The results of this study indicate that in composites with a single laminate, increasing lamina thickness increase the mechanical properties of the composite. The method and amount of compaction in the manufacture of LBCs affect the tensile and bending strength of LBCs. Research to examine the effect of the interaction between the matrix and the bamboo lamina in composites with more than one layer needs to be investigated. A study is required to investigate the characteristics of the effect of the amount of compaction pressure used as a parameter in the manufacture of LBCs.

The laminated composites (LBCs) using four laminas of dendrocalamus strictus cold-pressed using epoxy resin result in maximum stress of LBCs of about 210 MPa. The specimens used had a cross-section of 16×10 mm. This study reported that compressive strengths of LBCs ranging between 55 MPa and 88 MPa. The fracture mode of LBCs found that the matrix failure occurs followed by fibers failure with metallic sound of anyone layer and subsequently other layers in specimens. There are good agreements between the theoretical values and experiment results for stiffness and strength [15]. Laminated Bamboo Composites (LBCs) of *dendrocalamus strictus* bamboo culms were manufactured from laminas and laminates using an epoxy resin matrix. The mechanical properties of LBCs have been evaluated with different loading conditions. The results show that the mechanical properties of LBCs are better than teak wood, which is one of the strongest woods [16]. The work [17] reported significant differences in strength and behaviour between small specimens sourced from different growth portions with the full-size structural members (cross-section 100×100 mm) constructed from laminated bamboo sourced from different growth portions of the culm. This study found that the bamboo laminate sourced from the middle growth section has the largest elastic modulus. The study of tensile properties of single and two ply laminated bamboo at various off-axis loading angles and laminates configurations has shown that composite laminate theory is applicable to LBCs composite and may be used for design of products and structures [18]. Researches are needed for fill the gap in existing knowledge of laminated bamboo composites, in order to characterization of mechanical behavior of single and multi ply laminates with off-axis loading angle, as well as laminate configuration.

Based on previous studies, it can be concluded that for enhancing the use of bamboo as an engineering material can be done by developing of Laminated Bamboo Composites (LBCs). Pressure compaction, the number of laminas, the thickness of the lamina, and the orientation of the laminates are critical fabrication variables for achieving a high strength of LBCs. The present study investigates epoxy resin reinforced with bamboo laminates. The type of bamboo studied was Apus bamboo (*Gigantochloa apus*). Apus bamboo was chosen because it has flexible properties and is easy to make into thin sheets. The research was conducted by varying the thickness, number of laminas, direction of laminates and compacting mold pressure. A detailed characterization, including the tensile and bending strength of the LBCs were investigated.

3. The aim and objectives of the study

The aim of this study is to determine the effect of configuration of lamina and pressure compaction on tensile and bending strength of laminated gigantochloa apus (Apus bamboo) composites.

The following objectives have been formulated:

– to investigate the effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites (LBCs);

– to investigate the effect of direction of bamboo laminates on tensile strength and bending strength of Laminated Bamboo Composites (LBCs);

– to investigate fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs);

4. Materials and Methods

4. 1. Material

Bamboo’s lamina of *gigantochloa apus* was used as primary reinforcement material. The bamboo used is three years old with an average diameter of 150 mm of bamboo. The selected part of the bamboo stem, 1 m to the base to 4 m, was used to make the lamina. The epoxy Bakelite® EPR 174 and resin hardener V-140 were used as a matrix and hardener.

4. 2. Methods

The process of making bamboo lamina begins with cutting the bamboo stalks to obtain a stem length of 40 cm. The bamboo stalks are then split into blades, making the bamboo slats by removing the outer shell. Then the splitting process is carried out to obtain a bamboo blade with a size of 40 cm×20 mm. The formation of bamboo lamina blades is carried out using the four-side planning tool. This process is carried out to obtain the thickness of 1 mm, 1.5 mm, and 2 mm. Fig. 1 shows the bamboo lamina-making process.

The bamboo laminas are then preserved by watering it with a preservative solution in the form of 2.5 % sodium tetraborate solution. After preservation, the bamboo laminas are dried. The bamboo lamina is dried in an oven until the water content reaches 10 %. A moisture meter measured the percentage of water content in the bamboo laminas. Drying takes approximately 2–4 weeks in an oven, depending on the weather. Dry bamboo slats are grouped according to their thickness and then sanded to smooth the surface using a sandpaper machine. The photo of bamboo lamina is depicted in Fig. 2.

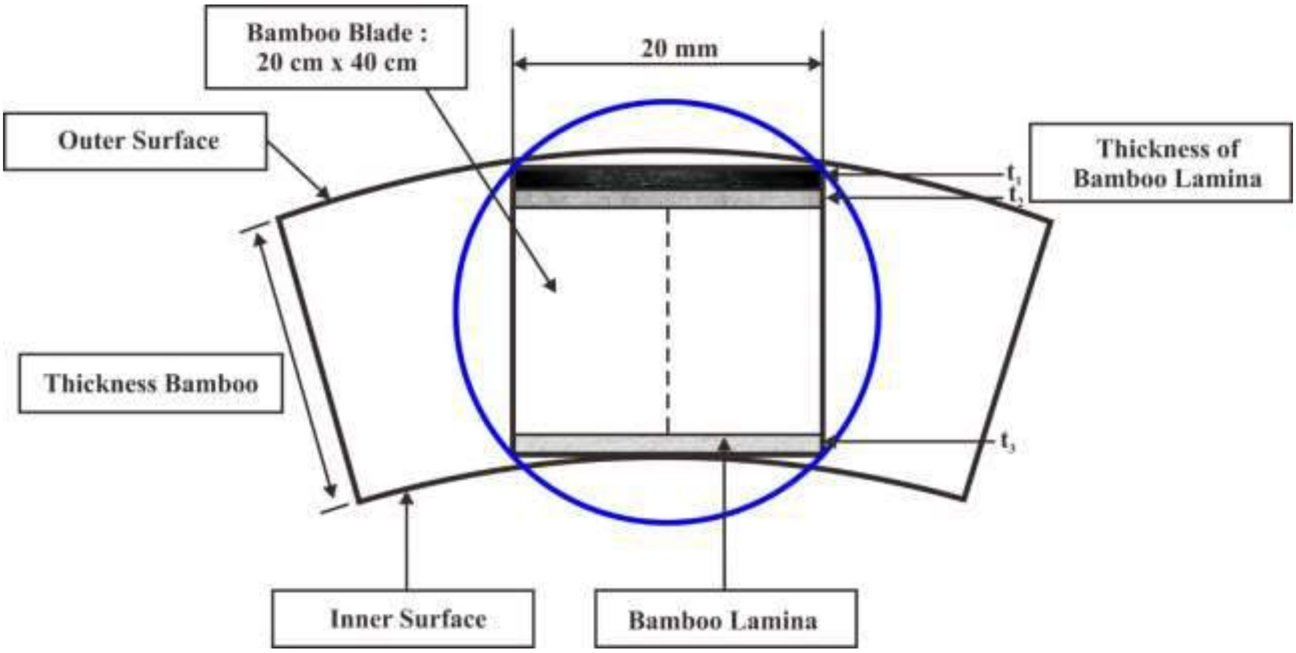

Fig. 1. Formation of the bamboo apus lamina (*gigantochloa apus*)

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Fig. 2. Bamboo Lamina

The dried bamboo laminas are then used as reinforcing composites to make Laminated Bamboo Composites (LBCs). An epoxy resin polymer is used as a matrix/adhesive material. LBCs were constructed by hand lay up method with three different number of laminas: 3, 5, and 7. Additionally, LBCs are manufactured in a variety of laminates directions: 0, –45°/+45° and 0°/90°. The configuration of the directional arrangement of the laminates in the composite is shown in Table 1. After hand lay up process, LBCs were compacted using a hydraulic pressing machine with variation of compacting pressure: 1.5 MPa; 2.0 MPa; 2.5 MPa. The LBCs were pressed for 24 hours. Table 2 shows the resulting composites with variations in compacting pressure and the number of lamina forming LBCs. This process produces a composite with a size of 400×250 mm with various thicknesses.

Table 1
Configuration of laminates direction in Laminated Bamboo Composites

	0°	–45°/+45°	0°/90°
3 layers	0°; 0°; 0°	–45°; +45°; –45°	0°; 90°; 0°
5 layers	0°; 0°; 0°; 0°; 0°	–45°; +45°; –45°; +45°; –45°	0°; 90°; 0°; 90°; 0°
7 layers	0°; 0°; 0°; 0°; 0°; 0°	–45°; +45°; –45°; +45°; –45°; +45°; –45°	0°; 90°; 0°; 90°; 0°; 90°; 0°

Table 2
The weight fraction of bamboo fibers and the epoxy resin matrix of the composites

No	Pressure compaction (MPa)	Lamina (layer)	Thickness lamina (mm)	Thickness LBCs (mm)	Bamboo Mass fraction (kg/cm^3)	Epoxy-resin mass faction (kg/cm^3)
1	1.5 MPa	3	2.0	7.0	0.70	0.30
2		5	1.5	7.0	0.65	0.35
3		7	1.0	7.0	0.60	0.40
4	2.0 MPa	3	2.0	6.5	0.75	0.25
5		5	1.5	6.5	0.70	0.30
6		7	1.0	6.5	0.65	0.35
7	2.5 MPa	3	2.0	6.0	0.80	0.20
8		5	1.5	6.0	0.75	0.25
9		7	1.0	6.0	0.70	0.30

Fig. 3. The tensile test specimens

Fig. 4. The bending test specimens

The tensile test refers to the ASTM standard D3039 with a specimen size of 250×25×*t* mm. The bending test was carried out using the ASTM standard D7264 with a 130×13×*t* mm specimen size. The test specimens were prepared using water jet cutting. Tensile and bending testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1000 KN. For each variation five specimens were tested. Fig. 3–5 present photo of tensile and bending test specimens.

5. Results of the effect of configuration of lamina and pressure compaction on mechanical properties of laminated gigantochloa apus composites

5. 1. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on tensile strength Laminated Bamboo Composites

Table 3 and graphs in Fig. 5–7 show the results of the tensile test of LBCs for variations in the number of laminates (3, 5, 7), laminates directions (0°, −45°/+45°, 0°/90°) and the compaction pressure (1.5 MPa, 2 MPa, 2.5 MPa) on the tensile strength of LBCs. It can be noticed from Fig. 5–7 that that the tensile strength of LBCs are influenced by number and direction of laminates. It depicted in Fig. 5, that at compacting pressure of 1.5 MPa, direction of laminates 0° (on axis) increasing number of laminates also increase the tensile strength of the LBCs. LBCs with 3 layers laminates has tensile strength about 115 MPa, increase about 7 % (124 MPa) when the layers of laminates are 5 layers. The highest tensile strength of LBCs at 0° direction and 1.5 MPa compaction is 139 MPa at 7 layers laminas. The same phenomenon is obtained in the fiber direction −45°/+45°, 0°/90° that as the number of layers in the LBCs increases from 3 to 7 the tensile strength also increases. LBCs with direction −45°/+45° and 0°/90° gain the highest tensile strength 76 MPa and 107 MPa respectively at 7 layers laminates. Lowest tensile strength of LBCs is 58 MPa (about 41 % of highest value) at 3 layers laminas and −45°/+45° laminates direction.

LBCs with a pressure of 2 MPa produce the highest tensile strength of 185 MPa at 7 laminates with laminates direction 0° (Fig. 6). Besides laminates direction −45°/+45 yield highest tensile strength 88 MPa and LBCs with laminates direction 0°/90° resulted highest tensile strength 156 MPa. LBCs with laminates direction −45°/+45, 3 layers laminas and 2 mm lamina thickness yield lowest tensile strength with the tensile strength value of 76 MPa (41 % from the highest value of tensile strength).

The graph in Fig. 7 shows that at a pressure of 2.5 MPa the highest tensile strength of LBCs is achieved composite with direction of laminates 0º with valued 180 MPa. The highest tensile strength also achieved by LBCs with laminates direction 0º (on axis laminates), 7 layers laminas and 1 mm thickness of lamina. The increase in number of laminate layers from 3, 5, 7 results in an increase in the tensile strength of 164 MPa, 175 MPa, and 180 MPa, respectively. The lowest value of tensile strength of LBCs is 71 MPa (39 % from the highest value) also find at LBCs with 3 layers laminates and direction laminates −45°/+45.

Table 3

Tensile strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0°	115	124	139	168	177	185	164	175	180
–45°/+45°	58	64	76	76	81	88	71	78	87
0°/90°	91	99	107	135	149	156	131	141	151

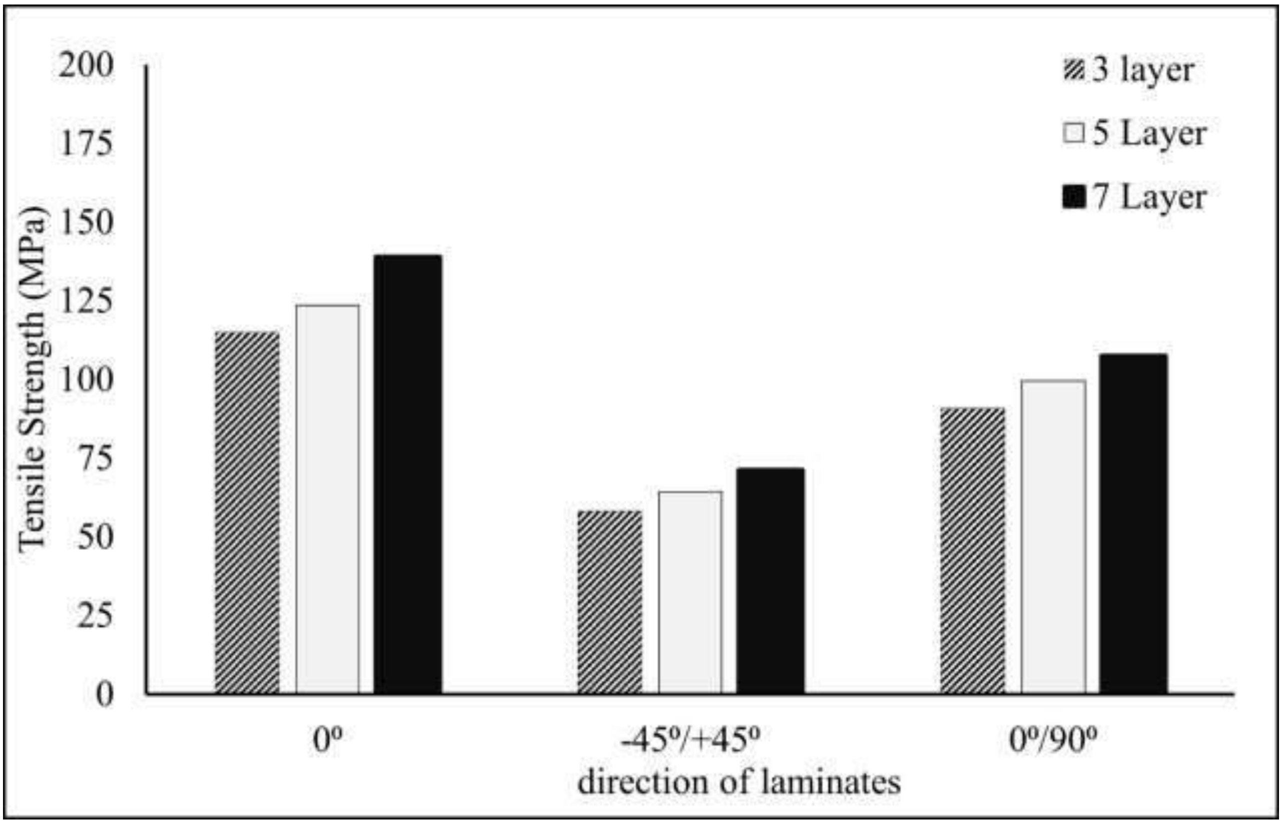

Fig. 5. Tensile strength of LBCs with 1.5 MPa pressure compaction

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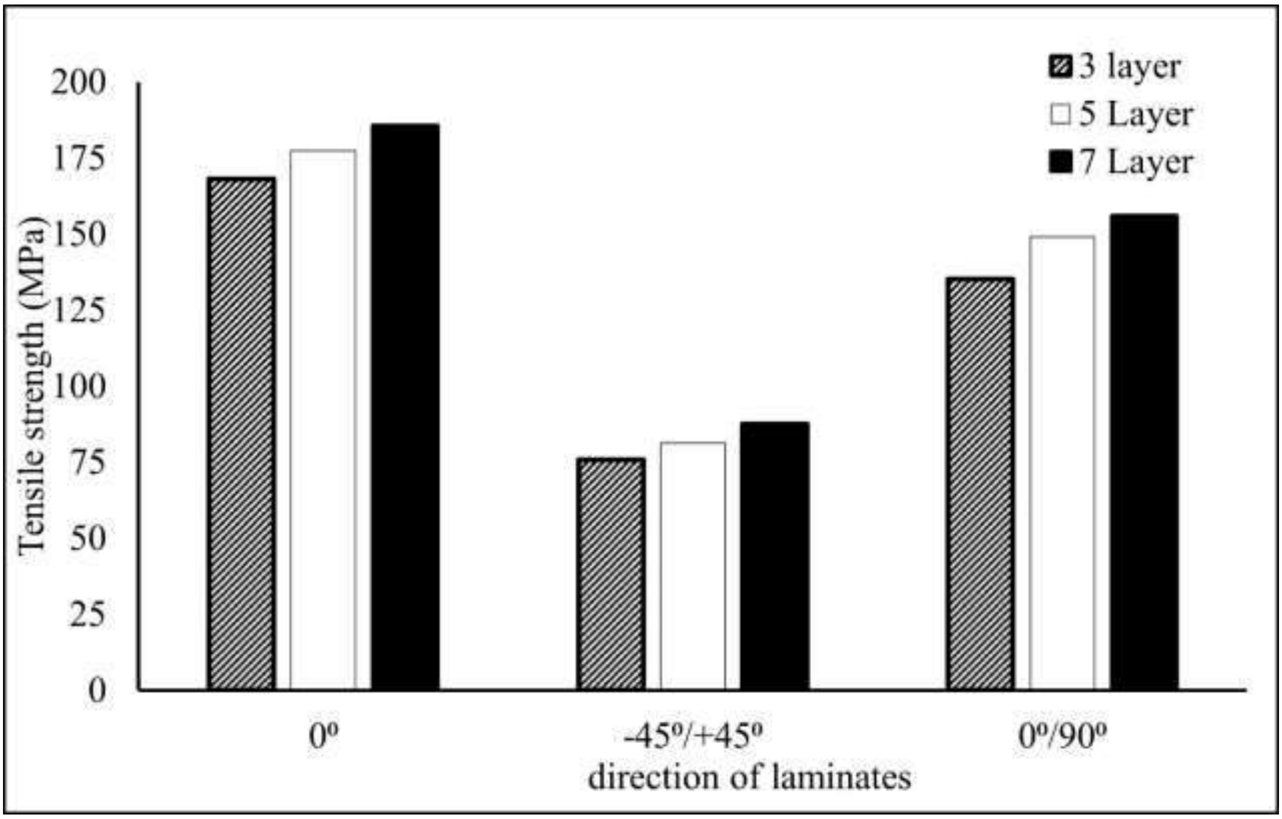

Fig. 6. Tensile strength of LBCs with 2 MPa pressure compaction

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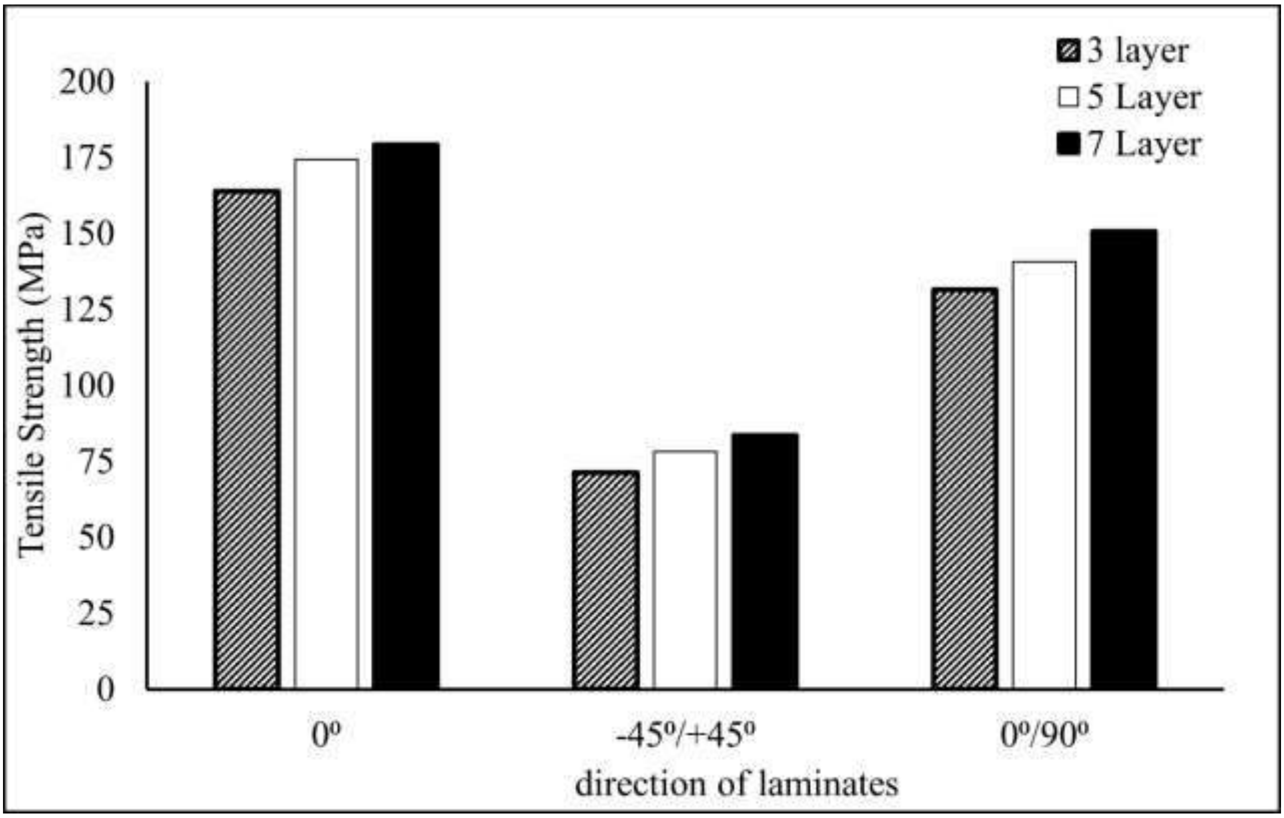

Fig. 7. Tensile strength of LBCs with 2.5 MPa pressure compaction

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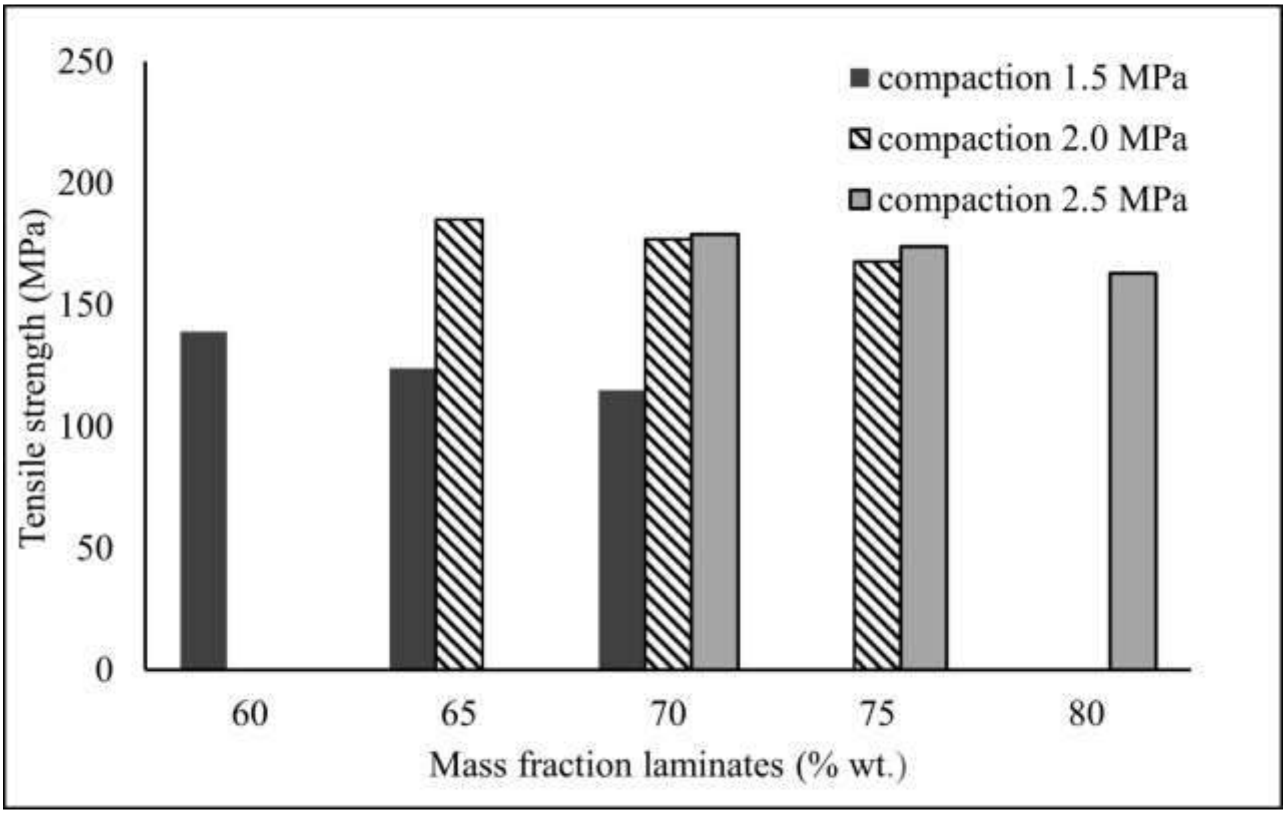

Fig. 8. The effect of mass fraction bamboo laminates on tensile strength of LBCs in composites with direction of 0°

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At all pressure variations, LBCs with a 0° laminates direction has a higher tensile strength than LBCs with a direction −45°/+45°and 0°/90°. LBCs with laminates direction –45°/+45° produced lower tensile strength than the others. The effect of mass fraction bamboo laminates and tensile strength of LBCs in composites with direction of 0° is shown in Fig. 8. LBCs with 7 layers laminates 1 mm lamina thickness and compacting pressure 1.5 MPa produces composites with % wt. reinforcement 60 %. At compacting pressure 2.0 MPa and 2.5 MPa, % wt. of LBCs with 7 layers laminates 1 mm lamina thickness are 65% and 70 % respectively. The tensile strengths of LBCs with seven layers are 139 MPa, 185 MPa, and 180 MPa at 1.5 MPa, 2.0 MPa, and 2.5 MPa compaction pressures, respectively. LBCs with 3 layers and 2 mm thickness of lamina yield composite with % wt. reinforcement higher than LBCs with 7 layers and lamina thickness 1 mm. LBCs with three layers and 1.5 MPa, 2.0 MPa, or 2.5 MPa pressure compaction produce LBCs with tensile strengths of 115 MPa, 168 MPa, and 164 MPa, respectively.

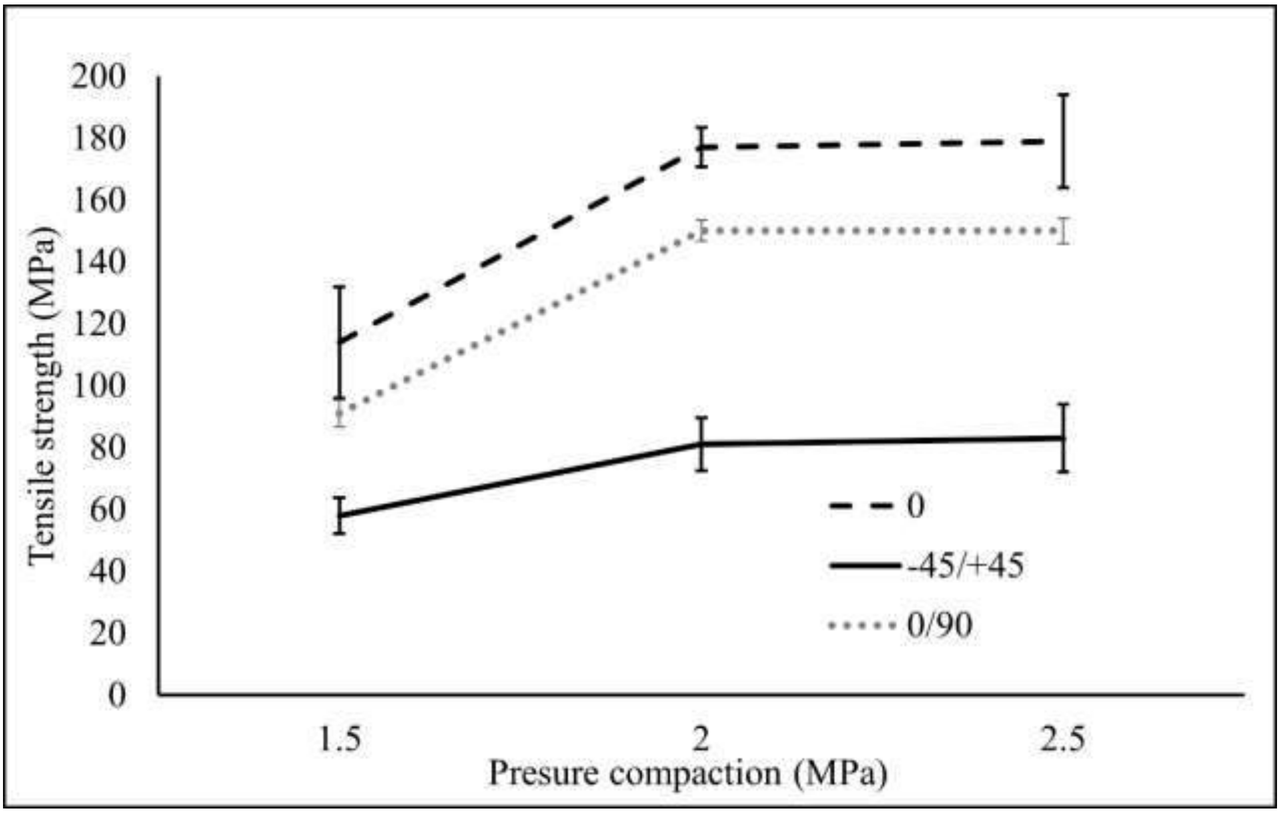

Fig. 9. The effect of Compaction Pressure on Tensile Strength of LBCs at 70 % Mass Fraction

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The graph in Fig. 9 also shows the effect of compacting pressure on the tensile strength of LBCs at the mass fraction of 70 %. This analysis selected a mass fraction of 70 % wt. because a mass fraction of 70 % wt. was generated for all variations studied (Fig. 8). Fig. 9 shows that increasing the compression from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0° laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0°/90° laminates direction. Increasing the compacting pressure from 2 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. The differences of tensile strengths are smaller than the standard deviation of the test. Therefore, it can be concluded the increase in pressure from 2 MPa to 2.5 MPa does not significantly affect the tensile strength of LBCs.

5. 2. The effect of the number of bamboo laminates, direction of laminates and pressure compaction on bending strength Laminated Bamboo Composites

Table 4 and Fig. 10–12 show the bending strength of LBCs with variations of the direction of laminates: 0°, −45°/+45°, 0°/90° and variations in the number (3, 5 and 7) and thickness (1 mm, 1.5 mm and 2 mm) of apus bamboo lamina with variation of compacting pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa. Fig. 10 shows LBCs with direction of laminates 0° resulted higher bending strength than LBCs with laminates direction 0°/90° or –45°/+45°. Bending strength of LBCs with 0° laminates is approximately 8 % stronger than either of LBCs with 0°/90° laminates and approximately 12 % greater than that of LBCs with –45°/+45° laminates. At pressure compaction 1.5 MPa, highest bending strength of LBCs is 265 MPa, lowest bending strength is produced by LBCs with laminates direction –45°/+45° with valued 218 MPa (approximately 82 % form highest bending strength).

Table 4
Bending strength of LBCs

Pressure	1.5 MPa			2.0 MPa			2.5 MPa		
Layers	3	5	7	3	5	7	3	5	7
0°	251	257	265	295	315	321	280	298	306
–45°/+45°	218	229	232	245	266	271	234	239	259
0°/90°	233	241	240	274	284	294	261	268	279

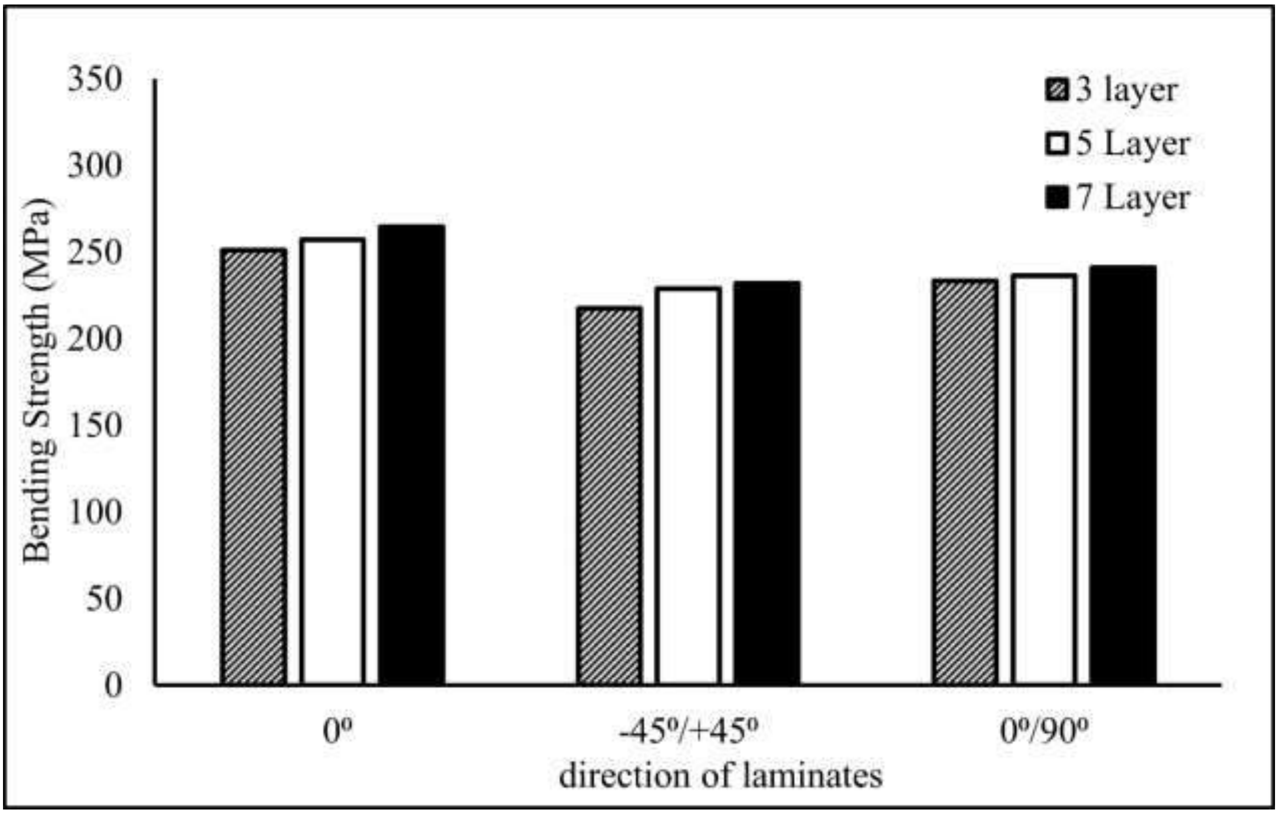

Fig. 10. Bending strength of LBCs with compaction pressure 1.5 MPa

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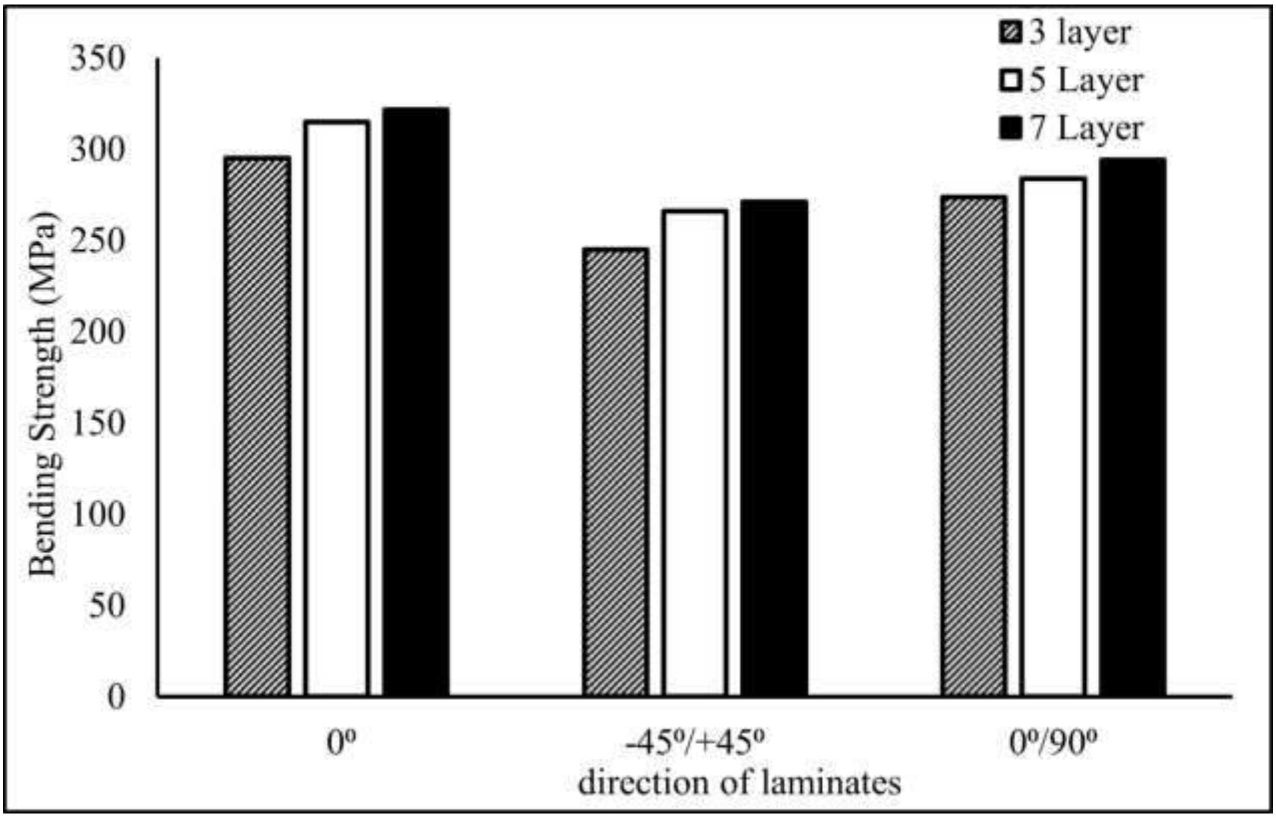

Fig. 11. Bending strength of LBCs with compaction pressure 2.0 MPa

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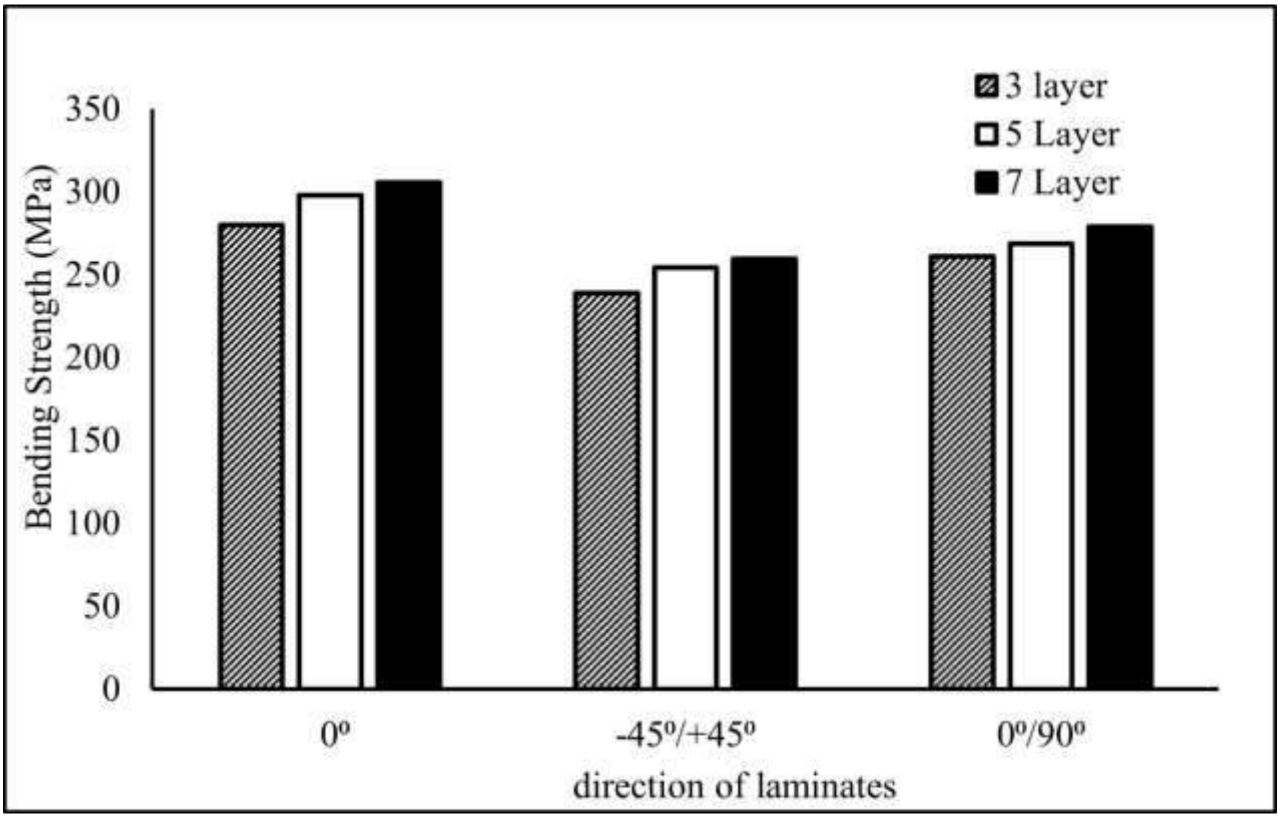

Fig. 12. Bending strength of LBCs with compaction pressure 2.5 MPa

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Bending strength of LBCs with compaction pressure 2.0 MPa and 2.5 MPa are depicted in Fig. 11, 12, respectively. the value of the bending strength of the composite with a compaction pressure of 2.0 MPa ranged from 245 MPa to 321 MPa. LBCs have a bending strength of between 234 and 306 MPa when compressed to 2.5 MPa. The composite with a 0^o layer direction and 7 layers of laminas produces the highest bending strength

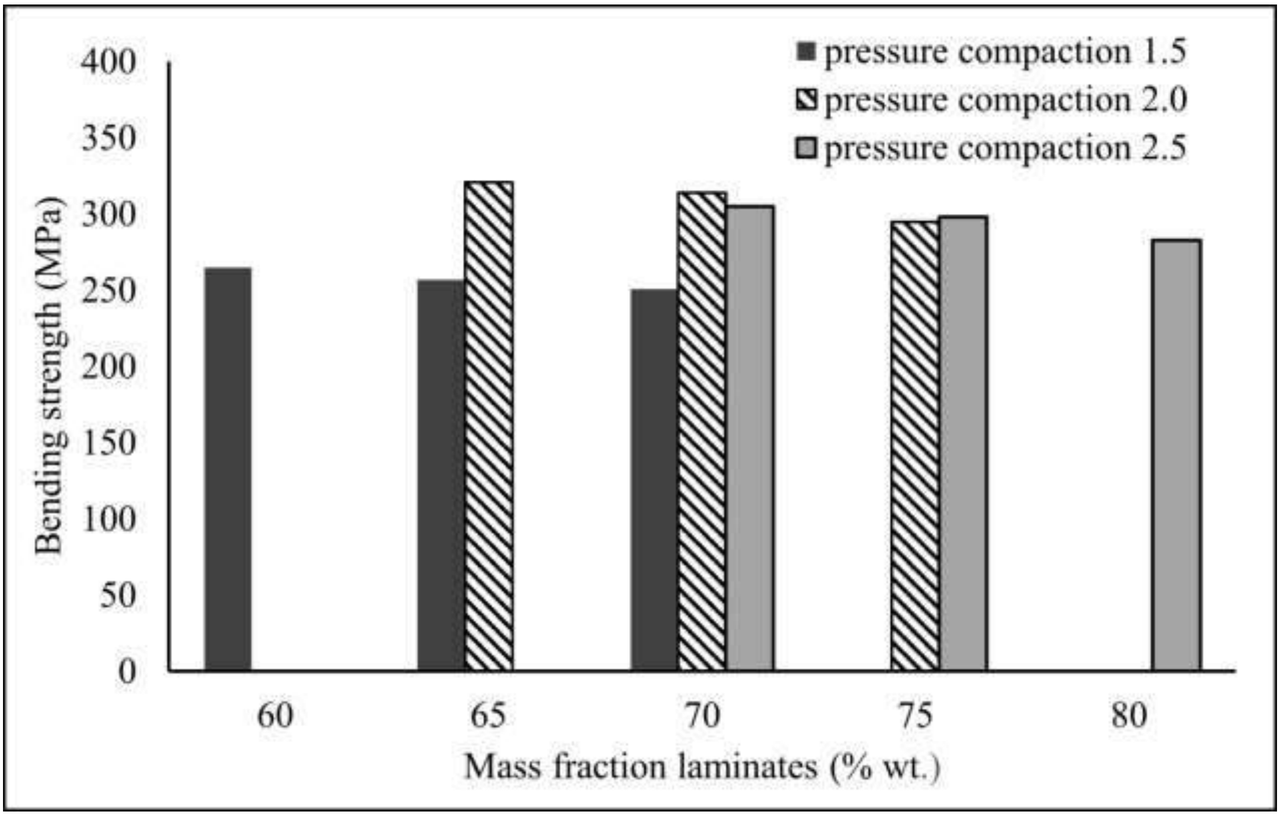

Fig. 13. The effect of mass fraction of laminates on bending strength of LBCs with 0° direction

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The relationship between the bending strength of LBCs and their mass fraction with the laminates on-axis (0°) direction is depicted in Fig. 13. At 1.5 MPa compaction pressure, LBCs with a mass fraction of 60 % have structured 7 layers of lamina with a thickness of 1 mm, yielding the highest bending strength of 265 MPa. At compression pressures of 2.0 MPa and 2.5 MPa, LBCs with 7 layers laminas exhibit the highest bending strength, with values of 321 MPa and 306 MPa, respectively. From the graph in Fig. 13, it can be concluded that the highest bending strength is in the composite with thinner bamboo reinforcement and a higher number of layers even at a lower mass fraction.

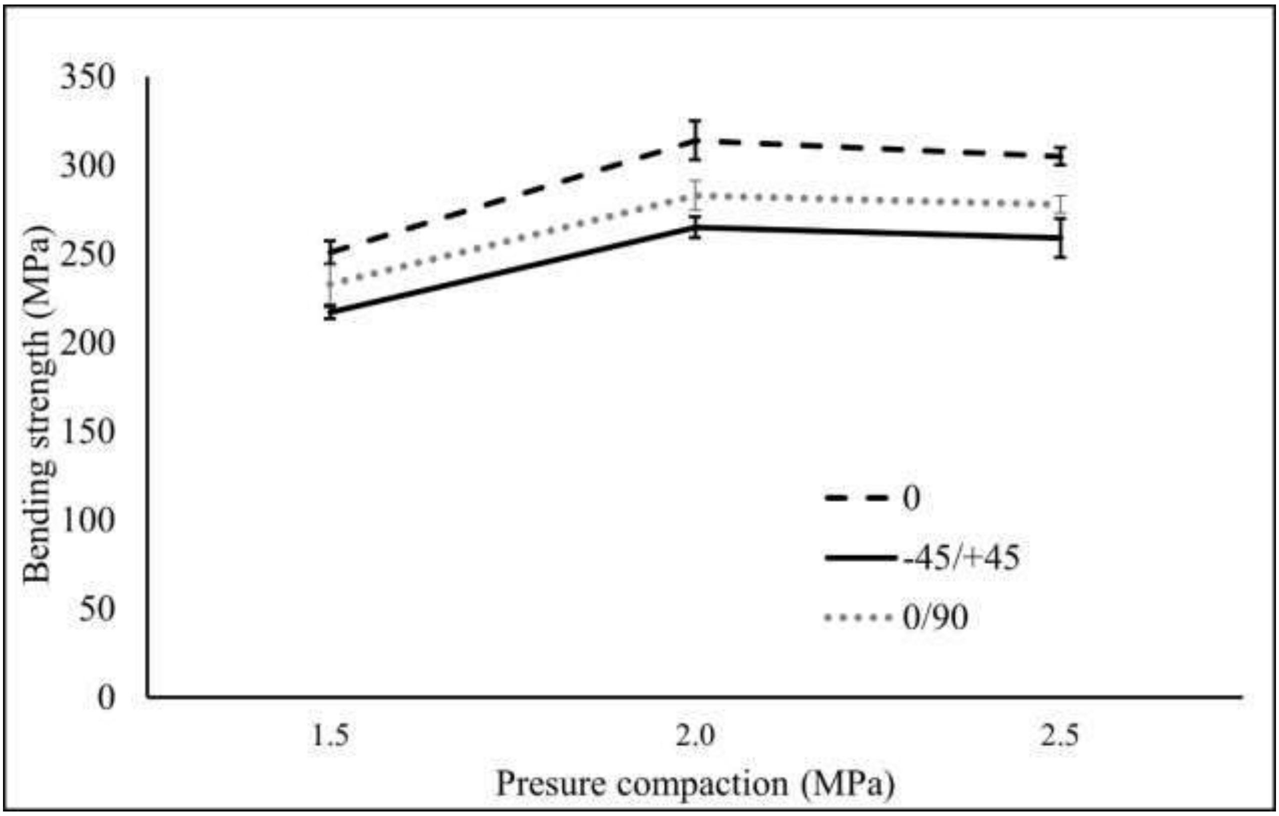

Fig. 14. The effect of Compaction Pressure on the Bending Strength of LBCs at 70 % Mass Fraction

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The graph in Fig. 14 also shows the effect of compacting pressure on the bending strength of LBCs at the mass fraction of 70 %. By increasing pressure compaction from 1.5 MPa to 2 MPa, the bending strength of LBCs increase by 25 % in the 0° laminates direction, 22 % in the 45°/+45° laminates direction, and 21 % in the 0°/90° laminates direction. As with the tensile tests, increasing the compacting pressure from 2 MPa to 2.5 MPa have no noticeable effect on the bending strength of LBCs.

5. 3. Investigation fracture of tensile and bending photo macrograph of Laminated Bamboo Composites (LBCs)

Fig. 15 shows a macro photograph of the surface fracture of LBCs after tensile testing. Fig. 15, *a* shows the fracture of LBCs with laminates direction 0°. The fracture surface of the LBCs with the direction of laminas –45°/+45° (Fig. 15, *b*) and the fracture surface of the LBCs with the direction of laminas –0°/90° (Fig. 15, *c*). The LBCs with 0° direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by load transfer to bamboo laminas and subsequent bamboo lamina fracture. Fig. 15, *b* shows the fracture of matrix followed by delamination of lamina in the 90° direction, and finally fracture of lamina in the 0° direction. In LBCs with laminates orientation +45°/–45°, matrix fracture was followed by delamination and lamina clefting.

a *b* *c*

Fig. 15. Photo macrography the fracture of cross section of the tensile test of 7 Layers Laminated Bamboo Composites (LBCs): *a* – direction of laminates 0°; *b* – direction of laminates –45°/+45°; *c* – direction of laminates 0°/90°

a *b* *c*

Fig. 16. Bending test result specimens of laminated bamboo composites (LBCs) from 7 layers: *a* – layers direction of 0°; *b* – layers direction –45°/45°; *c* –layers direction 0°/90°

The macro photographs of the LBCs after bending tested are shown in Fig. 16. Fig. 16, *a* shows that bending tested of LBCs with 0° laminates direction, produced fractured of matrix and followed fracture of laminates. Fracture photographs of LBCs with layers direction –45°/45° (Fig. 16, *b*) shows, that at the bottom of the specimen, fracture occurs due to lamina delamination. Failure continues with delamination and the lamina splits due to shear stress. The failure of the specimen with the direction of the lamina 0°/90° as shown in Fig. 16, *c* indicates that the failure due to bending started with matrix fracture and fracture lamina at the bottom (outer) of the specimen. Failure is followed by delamination of the lamina in the 90° direction

6. Discussion of the effect of configuration of lamina and pressure compaction on mechanical properties of laminated gigantochloa apus composites

The effect of direction, thickness, number of laminas on tensile strength of LBCs at compaction pressure 1.5 MPa; 2.0 MPa; 2.5 MPa are shown in Fig. 5–7, respectively. These results indicate that as the number of layers increases and the reduced lamina thickness increase the tensile strength of LBCs. The highest tensile strength was achieved by LBCs, with a thickness of 1 mm of bamboo lamina and

7 layers of bamboo lamina. It can be concluded that the highest tensile strength is in the composite with thinner bamboo reinforcement and more layers, even at a lower mass fraction. Increasing the tensile strength properties of LBCs in the thinner bamboo lamina reinforcement with a higher number of composites forming layers is an important concern in this study. This caused by the ability of the epoxy resin to enter the thinner pores of the apus bamboo fiber, thereby increasing the interface strength of the composite-forming bamboo layer. The other works also reported that increasing the number of laminas forming the Layered Laminate Bamboo Composites (LLBCs) will increase tensile and flexural stress [7]. The tensile strength of laminated composites is dependent on the interfacial properties of natural fibers and polymer composites. Additionally, the tensile properties are influenced by the direction of laminas [19]. Study on mechanical properties of laminated bamboo composites with different bamboo and matrices (gigantochloa scortechinii and unsaturated polyester) showed that the thicker the bamboo blades produced the higher the tensile stress and flexural stress [20]. Fig. 5–7 also depict that the direction configuration of the composite laminates also affects the tensile strength of LLBCs. The configuration of the laminates with direction 0° yields higher result of tensile strength compared to the configuration of the direction of the fiber crossed –45°/+45° and 0°/90°. Thus, the tensile strength of the LBCs decreases with increasing the angle of the laminates under the tensile stress. According to the Tsai–Hill criterion, the tensile and compressive properties of the composite will continue to decrease due to changes in the fiber orientation angle that increases from 0° [21]. This study's results prove that the direction of the lamina 0° provides the higher tensile strength compared to the direction of the laminates −45°/+45°, 0°/90°.

The compacting pressure applied to the manufacture of LBCs affects the mass fraction (wt.) of the epoxy resin matrix contained in the LBCs. The compacting pressure will drive the epoxy resin out of the LBCs mold while the mass fraction of the bamboo laminates steady [9]. Higher compression pressure will reduce the % wt. epoxy-resin and increase % wt. of lamina (Fig. 8). The pressure compaction of LBCs from 1.5 MPa to 2.0 MPa can reduce the weight fraction of epoxy resin in LBCs by 5 % of the initial mass fraction, but it can increase the tensile strength of LBCs by 55 % at laminates direction 0°, 40 % in the direction of laminates −45°/+45° and 64 % in the direction of laminates 0°/90°. The numerical analysis results demonstrate that the ultimate tensile loading increases by decreases of adhesive thickness [22]. The optimum tensile stress of Laminated Bamboo Composites (LBCs) was obtained at a 2 MPa compaction pressure variation with a mass fraction (wt.) of lamina of 70 % and a mass fraction (wt.) of epoxy-resin of 30 %. The application of compacting pressure above 2 MPa on LBCs didn't affect on the value of tensile stress. It can be concluded that compacting pressure 2.0 MPa also produces optimum thickness of epoxy-resin matrix in bamboo laminas. The anatomy of bamboo has a maximum limit for compacting or is caused by decreased matrix bonds because of reduced mass fraction (% wt.) of the epoxy resin matrix contained in the respective LBCs each by 5 % for each variation of the tested specimens.

Apus bamboo (gigantochloa apus) lamina has tensile strength of 230 MPa and an epoxy resin with a tensile strength of 57 MPa after being formed into a composite LBCs was able to produce the highest tensile strength of 185 MPa with a ratio of 70 % lamina bamboo lamina mass fraction and 70 % mass fraction (wt.) epoxy-resin 30 %. This result higher than previous research that reported composites used gigantochloa scortechinii (semantan reed) woven bamboo as reinforcement with a ratio of 33 % of the mass fraction (wt.) of bamboo laminates and the mass fraction (wt.) of 77 % epoxy matrix was only able to produce a maximum tensile strength of 89 MPa [11].

Bending test results for LBCs with varying lamina orientations 0°, –45°/+45°, 0°/90°; number of laminas (3, 5 and 7) and thickness of lamina (1 mm, 1.5 mm and 2 mm) with variation of compacting pressures of 1.5 MPa, 2.0 MPa and 2.5 MPa are depict in Fig. 10–12. LBCs with direction of laminates 0° resulted higher bending strength than LBCs with laminates direction 0°/90° or –45°/+45° These results show that increasing the number of lamina with thinner lamina increase the bending strength of LBCs. The LBCs with 7 layers of bamboo laminas, 1 mm thickness, 0° fiber direction and 2 MPa stress yield highest bending strength valued 321 MPa. It's approximately 20 % stronger than LBCs with compacted pressure 1.5 and 5 % higher than LBCs with 2.5 MPa compaction pressure. Apus bamboo (gigantochloa apus) with a bending strength of lamina 348 MPa and epoxy-resin with bending strength of 175 MPa, after being manufactured into a composite LBCs, these materials yield the highest bending strength of 321 MPa with a ratio of mass fraction (wt.) of 70 % and mass fraction (%. wt.) epoxy-resin 30 %. Gigantochloa scortechinii (semantan reed) woven bamboo with a ratio of 33 % of the mass fraction (wt.) of bamboo laminates and the mass fraction (wt.) of 67 % epoxy matrix was only able to produce a maximum bending strength of 120 MPa [11]. The bamboo allowed large flexural deformations because its outer part retains the tensile stress while the softer inner part undergoes large compressive deformation [23]. The configuration of the 0° direction of the laminates yield the higher bending strength compared to the configuration of 0°/45° and 0°/90° crossed laminates [21].

The bending stress of laminated bamboo composites is also influenced by the direction (orientation) of the bamboo laminate and the number of layers. At each variation in the direction of the bamboo laminates and stress, the bending strength of the LBCs increased with the increasing number of layers of bamboo laminas. In the number of layers, the bending strength of LBCs with the laminates direction of 0° has the largest bending strength, followed by the crossed fiber direction of 90° and the lowest bending strength is the LBCs with the –45°/+45° fiber direction.

The Laminated Bamboo Composites (LBCs) with more layers of laminas produce higher tensile and bending strength compare with LBCs with less number of laminas. The thinner lamina provide a higher adhesive contact surface area than the thicker lamina. Higher adhesive contact area provides better stress transfer to the lamina [24].

Fig. 15, 16 show the fracture surface of LBCs after tensile and bending test. It found same mechanism of fracture on the both of surface test. The cross section of fracture surface of tensile and bending test of LBCs with on axis laminas direction (0°) show the phenomenon of fracture in the lamina due to the load transmitted by the matrix. Bamboo lamina can fully withstand the load transferred by the matrix. This causes LBCs with laminates 0° direction (on axis) to be stronger than LBCs with off axis laminated direction. The cross section of fracture photograph demonstrates that the fracture mechanism is a fracture matrix followed by the breaking of the bamboo laminates. On the LBCs with laminas orientation –45°/+45° and 0°/90° fracture mechanism of LBCs, there are delamination of lamina caused by debonding of adhesion between lamina. The fracture's cross-sectional images demonstrate the lamina delamination behavior.

7. Conclusions

1. LBCs with 0^o direction of laminas yield higher tensile strength than LBCs with off axis direction of laminates (–45°/45°; 0°/90°). Increasing number of laminas increase tensile strength of LBCs. LBCs with thinner lamina provide a higher adhesive contact surface area than the thicker lamina and yield higher tensile strength of LBCs. The rise of the pressure compaction from 1.5 MPa to 2.0 MPa increases the tensile strength of LBCs by 55 % in the 0° laminates direction, 40 % in the −45°/+45° laminates direction, and 64 % in the 0°/90° laminates direction. Increasing the compacting pressure from 2.0 MPa to 2.5 MPa did not significantly increase the tensile strength of the LBCs. Highest tensile strength of LBCs with value 185 MPa is produced by LBCs with direction 0°, 7 laminas, 1 mm thickness of lamina with pressure compaction 2 MPa.

2. The highest bending strength of LBCs, 321 MPa, is achieved with LBCs in the 0° direction, 7 laminas, 1 mm thickness of lamina, and 2 MPa pressure compaction. LBCs with laminates oriented on axis (0°) have a greater bending strength than composites with orientation of laminates off axis (–45°/45°; 0°/90°). LBCs' bending strength increases as the number of laminates increases. Increases the bending strength of LBCs by 25 % in the 0° laminates direction, 22 % in the 45°/+45° laminates direction, and 21 % in the 0°/90° laminates direction when the pressure compaction is increased from 1.5 MPa to 2.0 MPa. Increased compacting pressure from 2.0 to 2.5 MPa has no perceptible effect on the tensile strength of the LBCs.

3. The LBCs with 0° direction of laminates, the first phenomenon when tensile tested is matrix fracture, followed by bamboo lamina fracture. Composites with 0°/90° laminates direction, the fracture of matrix followed by delamination of lamina in the 90° direction, and finally fracture of lamina in the 0° direction. In LBCs with laminates orientation –45°/+45°, matrix fracture was followed by delamination and lamina clefting.

Acknowledgments

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