The Effect of Strip Arrangement on Physical and Mechanical Properties of Petung Bamboo Laminated Board (*Dendrocalamus asper* Backer)

Febriana Tri Wulandari, Habibi, Raehanayati, and Rima Vera Ningsih

Abstract

One alternative material as a substitute for wood construction is laminated bamboo. Laminated bamboo is a product made from several bamboo strips which are glued together with the fiber direction parallel to the board with several requirements, among others, must have dimensions of length, width, and thickness that can be converted into boards or blocks. The type of bamboo that will be used in this research is petung bamboo (*Dendrocalamus asper* Backer). Petung bamboo was chosen because it has a diameter that can reach 20 cm with a wall thickness of 1-3 cm, making it suitable for use as laminated bamboo. The purpose of this study was to determine the effect of strip arrangement on the physical and mechanical properties of petung bamboo laminated boards. The method used in this study is an experimental method with a non-factorial completely randomized design experiment with two treatments and three replications. Based on the results of the study, the arrangement of the laminated board strip did not significantly affect all tests of the physical and mechanical properties of the petung bamboo laminated board. All tests of physical and mechanical properties have complied with JPIC standard No. 1152 except in the Modulus of Elasticity (MoE). The bamboo petung laminated board is classified as strength class III which can be used as a protected heavy construction material.

Keywords: physical and mechanical properties, petung bamboo, strip arrangement.

Introduction

Recently, wood as a construction material is increasingly limited. This can be seen from the data on the decreasing amount of wood products from natural forests, which were from 8.3 million m^3 in 2015 to 5.7 million m^3 in 2018 (Muhtariana 2013). This condition is due to the unbalanced use of wood compared to the efforts to plant new stands. Therefore, alternative materials are needed to replace wood. One alternative material as a substitute for construction wood is bamboo. One of the advantages of bamboo is that it is affordable, can grow in various fields, and grows fast. Bamboo is a fast-growing plant that can reach 15-18 cm in height in 4-6 weeks (Akinlabi *et al*. 2017). Bamboo in Indonesia varied over 143 species, of which 9 types of them are endemic on the Java island (Manik *et al*. 2017).

Bamboo is one of the non-timber forest products that need to be promoted as construction materials which is processed with high technology. The current technology that makes it possible to process bamboo into wood-like blocks is lamination technology. Laminated bamboo is a product made from several bamboo strips or bamboo peels that are glued together in parallel fiber directions (Qisheng *et al*. 2002). As a material of laminated board, bamboo has several requirements, including dimensions of length, width, and thickness that can be converted into boards or blocks. (Prabowo and Supomo 2013). The type of bamboo that will be used in this study is petung bamboo (*Dendrocalamus asper* Backer). Petung bamboo was chosen because it has a diameter that can reach 20 cm with a wall thickness of 1-3 cm, making it suitable for use as laminated bamboo (Morisco 2006).

Cahyadi *et al*. (2012) conducted a study on the effect of various addition methanol as adhesive diluent and powder weight on the physical and mechanical properties of laminated bamboo from petung bamboo. Yasin (2015) showed laminated petung bamboo with PVAc adhesive and large variations in compression pressure. Anokye (2016) conducted a study on the effect of nodes and adhesives on the mechanical properties of laminated bamboo of the *Gigantochloa scortechinii* species.

This research examines the effect of the arrangement of a bamboo strip on the strength of the laminated board, so it is necessary to do a test to see the physical and mechanical strength of the petung bamboo laminated board.

Physical and mechanical properties are indicators that can determine the quality of laminated boards. It is very important to know mechanical properties, which are properties to describe the strength of laminated wood and solid wood (Dumanauw 2001). The purpose of this study was to determine the effect of strip arrangement on the physical and mechanical properties of petung bamboo laminated board.

Materials and Methods

This research was carried out from December 2020 to June 2021. The physical test was carried out at the Forest Product Technology Laboratory, Faculty of Agriculture, Mataram University. Meanwhile, the mechanical test was carried out at the Physics Laboratory, Faculty of Mathematics and Natural Sciences, University of Mataram.

Materials used in this study was petung bamboo strip to be made of laminated bamboo with board dimensions of (2 x 8 x 38) cm^3 and PVAC adhesive**.** The research design was a non-factorial completely randomized design (CRD) with 2 treatments with 3 replications so that there were 6 test samples, as follow:

1. Treatment of the arrangement of the joints of the strip the thick direction (S1)
2. Treatment of the arrangement of the splicing of the strip towards the width (S2).

Table 1. Research design.

Treatments	Repetition		
	U1	U2	U3
S1	SIU1	S1U2	S1U3
S2	S2U1	S2U2	S2U3

Remark:
S1 = The strip arrangement in the thick direction; S2 = The strip arrangement towards the width

Figure 1. a) Strip arrangement the thick direction; b) Strip arrangement in the width direction.

Preparation of Raw Materials

The base of the bamboo was cut to a length of 50-80 cm to remove the crooked part of the bamboo stem. The bamboo was then cut into several pieces with a length of 40 cm, the bamboo pieces must be straight, cylindrical, and the bamboo walls are thick enough. Bamboo was air dried for 3 weeks. The splitting of the bamboo stem was carried out by paying attention to the part of the bamboo stem with a smaller diameter which was used as a reference for the cleavage trajectory. The bamboo strips used were straight bamboo on both sides of the length, then the strips were dried for one week. After that, the bamboo blades were shaved to get a flat strip surface.

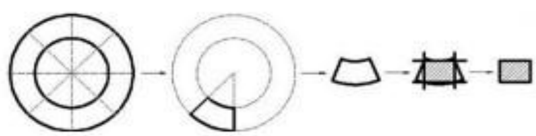

Figure 2. Bamboo strip making process (Wulandari 2012).

Assembling of Bamboo Strip

The bonding of the adhesive on the bamboo strip with glue spread 100 g/cm^3 was then assembled with a predetermined arrangement of strips. Then followed by the cold press for 24 hours with a compression pressure of 20 Nm. Conditioning was carried out in a constant room for 7 days to uniform the moisture content before testing. Sanding on both surfaces of the bamboo to even out the two surfaces.

Making Test Samples

Laminated bamboo cutting for each test sample was for moisture content and density (2 (p) x 2 (l) x 2 (t)) cm^3, thickness expansion and thickness shrinkage (5 x 5 x 2) cm^3, as well as MoE and MoR (30 x 2 x 2) cm^3.

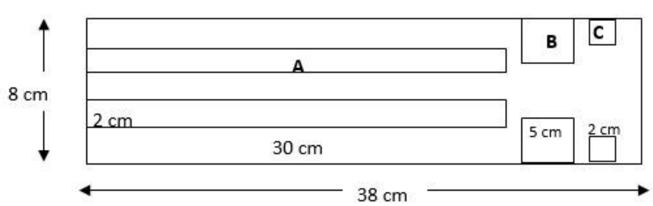

Figure 3. Test sample size.

Remark:
A: Test sample for MoE and MoR; B: Test sample for thickness swelling and shrinkage; C: Test sample for moisture content and density.

The testing of the physical and mechanical properties of laminated bamboo refers to ISO 21629-1: 2021. The data that had been obtained were then analyzed for variance ANOVA to determine whether the results were significantly different or not using the SPSS 25 prog.

Results and Discussion

The average values of physical and mechanical properties of petung bamboo laminated board are presented in Table 2 and the results of analysis of variance (ANOVA) are presented in Table 3.

Table 2. Average values of physical and mechanical properties.

Properties	Treatment		Average
	S1	S2	
Density (g/cm^3)	0.429	0.469	0.449
Moisture Content (%)	14.066	13.443	13.754
Thickness Swelling (%)	3.113	4.040	3.576
Thickness Shrinkage (%)	3.767	3.194	3.481
Modulus of Elasticity (kgf/cm^2)	14211.069	10585.980	12398.524
Modulus of Rupture (kgf/cm^2)	342.627	287.949	315.288

Remark: S1 = Arrangement of the strip towards thickness and S2 = Arrangement of strip towards width.

Table 3. Calculated F values of varian analysis.

Properties	F calculated	Sig.
Density	1.039	0.366
Moisture Content	4.114	0.112
Thickness Swelling	0.398	0.562
Thickness Shrinkage	1.522	0.285
Modulus of Elasticity	2.728	0.174
Modulus of Rupture	2.705	0.175

Density

The density of petung bamboo laminated board ranged from 0.37-0.49 g/cm^3 with an average value of 0.45 g/cm^3. Based on SNI 01-6240-2000 (2000) this value met the standard of laminated bamboo with a standard value of 0.40 - 0.80 g/cm^3. This result was lower compared to research conducted by Priyanto and Iskandar (2019) on the use of petung bamboo laminate for building materials with an average density value of 0.63 g/cm^3. The lower the density of a material, it will be followed decrease in the strength of the material (Oka 2005).

The results of the analysis of diversity analysis in Table 2 show that the arrangement of bamboo strips did not significantly affect the density of the petung bamboo laminated board which was marked with a significance value of 0.366.

Moisture Content

Moisture content can be defined as the weight of the water content in percent (Haygreen and Bowyer 2003). The value of the moisture content of the petung bamboo laminated board ranged from 13.07 - 14.49% with an average water content of 13.75%. Based on this value, the moisture content value of petung bamboo laminated board met the Japan Agricultural Standard (2003) standard with a value of 14%. This results was higher compared to the research conducted by Manik *et al*. (2017) moisture content of laminated beams with a combination of petung bamboo and apus bamboo for wooden ship components was ranging from 11.33 - 12.40%. The factors that determine the difference in water content of a laminated product are the type of adhesive, pre-treatment, the thickness of the laminate, specific gravity of bamboo, number of layers of laminate, lamination weight, adhesive water content and the procedure used in the gluing process (hot or cold pressing) (Sulastiningsih *et al*. 2005). The value of moisture content affects the quality of the petung bamboo laminated board produced. This statement is supported by Mahdavi *et al*. (2011) that structural wood types, the mechanical strength of bamboo such as compressive strength, tensile strength, MoE, and MoR will increase as the water content decreases.

The results of Table 3 show that the arrangement of bamboo strip did not significantly affect the moisture content of the petung bamboo laminated board which was marked with a significance value of 0.11.

Thickness Swelling

Thickness swelling is the addition of thickness due to immersion in water for 24 hours (Wulandari 2012). The average value of the thickness swelling of the laminated board ranged from 2.42 - 6.94% with the average value of thickness expansion of 3.58%. The value of thickness expansion in the arrangement of the blades towards the thickness tends to be lower than the arrangement of the blades towards the width. Based on the Japan Agricultural Standard (2003) standard which requires a thickness expansion value of 20%, the thickness development of the petung bamboo laminated board has met the standard. When compared with research conducted by Cahyadi *et al*. (2012) with a thickness development value of 5.60 - 18.30%, the thickness development value of petung bamboo was lower. Petung bamboo has a thick cell wall (0.90 microns) where the thicker the cell wall of a laminated bamboo material, the higher its ability to absorb water (Manuhuwa and Loiwatu, 2007).

The results of the varian analysis in Table 3 show that the arrangement of bamboo strips has no significant effect on the development of the thickness of the petung bamboo laminated board which is marked with a significance value of 0.562.

Thickness Shrinkage

Bamboo shrinks when dried in contrast to wood where wood shrinks from the fiber saturation point to oven dry (Manuhuwa and Loiwatu, 2007). The average value of thickness shrinkage of petung bamboo laminated board ranged from 2.73 - 4.21% with an average value of 3.48%. Thickness shrinkage value in the arrangement of the blades towards the thickness tended to be higher than towards the width. The thickness shrinkage value of petung bamboo laminated met the Japan Agricultural Standard (2003) standard with a standard value of 14%. The value of thickness shrinkage in this study was smaller than the results of Megawati *et al*. (2016) on Gerunggang wood (*Cratoxylon arborescen* Bl.) which is 6.62% and research by *Hidayati et al*. (2016) on 7.90% superior teak and 8.50% conventional teak.

The results of the analysis of varian in Table 3 show that the arrangement of bamboo strips did not significantly affect the shrinkage of the thickness of the petung bamboo laminated board which was marked with a significance value of 0.28.

Modulus of Elasticity

A high MoE value describes a material having high stiffness so that it can withstand large pressures with a small deformation value whose value is obtained by testing the static bending strength by measuring the deflection in the curved area of a material when loading occurs, the MoE value is seen if the point distance loading 1/2 the distance from the pedestal (Oka 2005). The average value of MoE in this study ranged from 9593.96 - 17952.04 kgf/cm^2 with an average value of 12398.524 kgf/cm^2. Based on Japan Plywood Inspection Corporation (2007) MoE value of laminated bamboo did not meet the standard which requires a minimum MoE value of 75000 kgf/cm^2. The MoE value in this study was higher than that of Arifin *et al*. (2017) which shows the average MoE value of bamboo laminated beams is 1361.63 kgf/cm^2.The MoE value of the arrangement of the blades towards the thickness tended to be higher than towards the width. This was in accordance with the statement of Espiloy (2000) in his research which shows that laminated bamboo will be stronger to withstand the load when tested with the test position in the thick direction. The results of the analysis of varian in Table 3 show that the treatment has no significant effect on the Modulus of Elasticity of the petung bamboo laminated board which is marked with a significance value of 0.174.

Modulus of Rupture

Modulus of Rupture (MoR) is defined as the ability of an object to withstand the maximum load until the object breaks (Prihandini 2012). The MoR values of petung bamboo laminated board ranged from 259.574 to 399.545 kgf/cm^2 with an average value of 315.288 kgf/cm^2. The MoR value in the thick directional bar arrangement was higher than that of the wide directional bar arrangement. Based on Japan Plywood Inspection Corporation (2007) then the MoR value of the laminated bamboo petung board has met the standard which requires a minimum MoR value of 300 kgf/cm^2. When compared to research by Cahyadi *et al*. (2012) with a value of 210 kgf/cm^2, the value of petung bamboo laminated board was higher. The MoR value towards thickness tended to be higher than towards width. This was in accordance with the statement of Espiloy (2000) in his research which showed that laminated bamboo will be stronger to withstand the load when tested with the test position in the thick direction.

The results of varian analysis test in Table 3 show that the treatment has no significant effect on the MoR of the petung bamboo laminated board which was marked with a significance value of 0.175 so that further DMRT testing does not need to be carried out to determine the differences between treatments.

Conclusions

The arrangement of the strips of the petung bamboo laminated board had no significant effect on all tests of the physical and mechanical properties. All tests of physical and mechanical properties meet with Japan Plywood Inspection Corporation (2007) except for the MoE testing. Based on the strength class of the laminated board, petung bamboo laminated board was included in the strong class III which can be used as a construction material that can be used as a protected heavy construction material.

Suggestions that need to be done for further research is to pay attention to the uniformity of the bamboo to be laminated because it is seen from the unevenness of the adhesive in the adhesive smelting process will affect the strength of the laminated bamboo made and further research needs to be carried out to increase the value of the physical and mechanical properties of laminated bamboo related to the amount optimum coating weight and the use of water-resistant adhesive according to the final use of the resulting laminated bamboo.

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