Effect of combined strip and zephyr laminated bamboo composite on physical and mechanical properties

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Abstract. Bamboo (Gigantochloa apus) is a potential material for wood substitution. However, the bamboo uses are limited according to the dimensions. Therefore, it needs modification technology such as transform bamboo into laminated bamboo boards. The combination of bamboo strips and zephyr as well as different fiber directions affected the physical and mechanical properties of laminated bamboo boards. The study was carried out on Gigantochloa apus, which were made into strip and zephyr manually. Each strip and zephyrs are dried and then formed into a laminated board, then glued using isocyanate adhesive in a double spread with a weight of 300 g/m². Arrangement of laminated bamboo boards perpendicularly between face/back and core (Ply bamboo) and the parallel between face/back and core (Laminated Bamboo Lumber/LBL). The laminated bamboo board was cold pressed at a pressure of 22.22 kgf/cm² for 1 hour. Physical and mechanical properties have been evaluated. Laminated bamboo boards have an average moisture content and density that meet IAS standards. The face/back of the strip has better dimensional stability value compared to zephyr. The combination of raw materials on the face/back and variations in the direction of the fiber can improve the mechanical properties of the bamboo laminate board.

1. Introduction

The ability of forests as a provider of raw materials has been unable to meet the increasing needs of the wood manufacturing industry. Especially, the demand for wood as structural components, furniture, and household equipment continues to increase along with population growth [1]. The main factor causing the lack of availability of wood as raw materials is the slow growth of wood from natural forests. Therefore, alternative substitution of wood as raw material is needed to meet industrial needs. Bamboo is a potential plant to be used as an alternative material to replace wood. Besides fast-growing time, bamboo is also easy to find, easy to plant in a variety of soil conditions, relatively cheap, and has good mechanical properties. However, bamboo has several characteristics that are taken into consideration when used as raw material, such as having node and internode so that it tends not to be homogeneous in each bamboo culms, then cylindrical and hollow shape which can limit the use of bamboo as a raw material that should be modified. The modification process aims to make the shape of bamboo more flexible and can be used as a structural or non-structural material [2].

Research related to bamboo modification has been developed, such as the manufacture of wood composite bamboo boards, laminated bamboo boards, ply bamboo, bamboo chipboard, Laminated
Bamboo Lumber (LBL) and other bamboo products [3]. The manufacture of a LBL is an alternative modification of the shape of the bamboo that can increase the use of bamboo as a raw material. A previous study related to LBL made of zephyr, that is processed through the destruction of bamboo culmns which are given a hot press and glued using resorcinol adhesive is an alternative to improve the adhesion and mechanical properties of bamboo [4]. Composite bamboo boards from Andong bamboo strips glued using isocyanate with varying composition of fiber direction and combination of glued bamboo strips have good adhesion quality and good dimensional stability [5]. Combination of bamboo Andong in the form of strips and zephyr and solid wood as a core part with isocyanate adhesives can be used in making wood composite bamboo boards that increasing strength and other mechanical properties [6]. Then, based on the anatomical structure of bamboo, in one internode of bamboo changes from the inner layer to the outer layer due to the greater concentration of cellulose fibers in the outermost layer compared to the inner layer which is more dominated by lignin. Therefore, the arrangement of bamboo and its orientation will affect the mechanical properties of the laminated bamboo board. Besides, bamboo also has inter-section fibers (node) which also affect the physical and mechanical properties of the laminated bamboo board [7]. This study aimed to determine the effect of a combination of strips and zephyr on face/back and core ply bamboo and LBL difficult to catch on physical and mechanical properties.

2. Materials and Methods

2.1. Materials and equipment

The materials used in this study were borax and 4 years old bamboo (Gigantochloa apus) culms obtained from Sumber area, and isocyanate adhesive (P.I. Bond). Then equipment used in this study are calipers, axes, mixer, cold press machine, moisture meter, oven, planer machine, running saw machine, sander machine, table saw machine, digital scales, universal testing machine (UTM) Shimadzu AG-I, adhesive container, and water bath.

2.2. Methods

2.2.1. Bamboo culms preparation

Fresh bamboo culms are cut along ± 40 cm bamboo is preserved by soaking using borax solution (Na₂B₄O₇.5H₂O) for 7 days.

2.2.2. Bamboo zephyr preparation

The preserved bamboo culm is crushed first to form flat sheets with an axe then dried at room temperature for 7 days or until it reaches a moisture content of 25%. Then, bamboo zephyr is planned on the outside and inside with a planer machine. Furthermore, zephyr is dried to reach 20% of moisture content. The target thickness of the zephyr layer is 0.5 cm. Then, cut and arranged into zephyr bamboo sheets of length and width of 40 cm.

2.2.3. Bamboo strips preparation

Preparation of making bamboo strips is carried out by drying at room temperature for 7 days or until it reaches a water content of 20%. Then, the bamboo culm is removed from the outer and inner parts and cut into 40 cm long, 2 cm wide and 0.4 cm thick by 20 pieces, then arranged into sheets of bamboo strips.

2.2.4. Producing laminated bamboo boards

Laminated bamboo boards with dimensions of 400 x 400 x 15 mm are arranged following the arrangement variations and material combination that prescribed and presented in Table 1 with 3 layers. Each layer of zephyr or strip is given an isocyanate adhesive using a brush with a double spread technique. The glue spread rate is 300 g/m². Then cold pressed at room temperature with a pressure of 22.22 kgf/cm² for 1 hour. After the cold pressing process, laminated bamboo boards were conditioned.
for 7 days. Then finishing laminated bamboo board by sanding and cutting with running saw machine or table saw machine according to the size needed for testing.

Table 1. Laminated bamboo board arrangement and combination

| Code | Name           | Fiber direction | Material Face/Back | Material Core |
|------|----------------|-----------------|-------------------|--------------|
| LBL-Z | LBL zephyr      | Parallel        | Bamboo zephyr     | Bamboo strip |
| LBL-S | LBL strip       |                 | Bamboo strip      | Bamboo zephyr |
| Ply-Z  | Ply bamboo zephyr | Perpendicular    | Bamboo zephyr     | Bamboo strip |
| Ply-S  | Ply bamboo strip |                 | Bamboo strip      | Bamboo zephyr |

2.2.5. Testing

2.2.5.1. Physical Properties.
The laminated bamboo board evaluated by water content, density, water absorption, and shrinkage. Determination of water content and density according to JAS for plywood and JAS for laminated veneer lumber [8,9]. Testing of shrinkage and water absorption according to modified ASTMD 1037 standard [10].

2.2.5.2. Mechanical properties.
The mechanical properties of ply bamboo and LBL include MOE, MOR, shear strength, and screw withdrawal strength. The determination of MOE and MOR ply bamboo board is according to JAS for plywood in the long and cross direction of the sample. Then, determination of MOE and MOR LBL according to JAS for laminated veneer lumber in flat and edge direction of the sample. The testing of shear strength is according to JAS for plywood standard with ply bamboo sample size (81 x 25 mm). Whereas, the LBL Horizontal shear strength was carried out according to the JAS standard for laminated veneer lumber in two directions of testing, flat direction (81 x 39 mm) and edge direction (99 mm x thickness) [8,9]. The standard used in determining screw withdrawal strength is SNI 03-2105-2006 with a sample size of 5 x 10 cm and a screw depth of 0.7 mm [11].

2.3. Data analysis
The design of the experiment was carried out using the Completely Randomized Design method with 2 factors, a combination of raw materials and variations in fiber direction. Each treatment used 4 replications. Data were analyzed using the Independent-sample T-test with α ≤ 0.05. Data analysis was performed using SPSS 16.0 software.

3. Result and Discussion

3.1. Physical properties: moisture content and density
The average result of moisture content, density, and thickness change are presented in Table 2. The thickness is measured in conditions before pressing (before gluing), after pressing, and after conditioning to determine the thickness changes that occur in producing laminated bamboo board. The value of moisture content after conditioning for 7 days is varied from 11.63 to 13.46%. These results indicate that the moisture content of the laminated bamboo board is in the range of JAS [8-9] ≤ 14%. Then, the density of laminated bamboo boards after conditioning is in the range of 0.77-0.83 g/cm³. The density of bamboo culm is 0.65 g/cm³ so that the manufacture of laminated boards can increase the density of bamboo due to the adhesive and pressing process [12]. The previous study related to composite bamboo boards made of Andong bamboo has a density varied from 0.78 to 0.80 g/cm³ [5].

According to Table 2, it can be seen that both ply bamboo and LBL boards have experienced a thickness change. It is suspected that compression can cause thickness shrinkage of laminated bamboo
boards. Shrinkage that occurs after conditioning is due to environmental conditions and the hygroscopic nature of the board so that it releases water into the environment until it reaches an equilibrium condition. Laminated bamboo boards with strips on the face/back (LBL-S and Ply-S) have an average thickness change higher than bamboo laminate boards with zephyr. This probably due to a decrease in the water content of the bamboo laminate board with strips on the face/back greater than the water content in the laminated bamboo board with zephyr. Zephyr on the face/back causing greater shrinkage. The results of the Independent-sample T-test show that the combination of strip and zephyr and the variation of fiber direction are significantly different for the value of water content, while not significantly different in the value of density.

| Testing                                    | Code       | LBL-Z     | Ply-Z     | LBL-S     | Ply-S     |
|--------------------------------------------|------------|-----------|-----------|-----------|-----------|
| Moisture content after cold press (%)      |            | 14.45 (1.52) | 13.90 (1.94) | 16.80 (0.70) | 17.53 (0.43) |
| Moisture content after conditioning (%)    |            | 11.63 (0.70) | 12.40 (0.41) | 12.71 (0.43) | 13.46 (0.43) |
| Density (g/cm³)                            |            | 0.77 (0.03) | 0.79 (0.05) | 0.83 (0.02) | 0.81 (0.04) |
| Thickness change (%)*                      |            | 1.30 (1.77) | 0.63 (0.58) | 1.90 (1.58) | 2.47 (1.61) |

*Thickness after conditioning - Thickness after cold press

3.2. Physical properties: swelling, shrinkage, and water absorption

Testing of water absorption, swelling, and shrinkage was carried out to determine the dimensional stability of laminated bamboo boards. Swelling and shrinkage are evaluated from changes in the dimensions of thickness and length of the sample, while water absorption is measured from changes in sample weights. Better discuss WA first, the others as effect of WA. Swell and shrink after soak in water.

![Figure 1. Swelling and shrinkage](image)

According to Figure 1, it can be seen that several shrinkage values are greater than the swelling value. This can occur due to the condition of the final water content which is lower than the initial condition. Based on these results, it is known that the lowest value of thickness changes is on LBL-S with a range between swelling and shrinkage of 4.63%. Then, the lowest length changes value is on the Ply-S with a range between swelling and shrinkage of 2.30%. Both of these results show that laminated bamboo boards with strips on the face/back can reduce the value of shrinkage both in the thickness direction and in the length direction. This probably due to more gaps found on the laminated bamboo board with zephyr on the face/back which can decrease the stability of the board. According to Figure 1 (a), crossed layers in the composition of the laminated bamboo board can withstand or reduce the occurrence of swelling or shrinkage. Layer direction of the laminated bamboo board greatly affects the stability of dimensions [5]. The results of the Independent-sample T-test show that the variation in direction of
parallel and perpendicular fiber is significantly different for the value of length shrinkage and thickness swelling of laminated bamboo boards. Whereas the combination of strip and zephyr material is only significantly different in length swelling.

Water absorption on the laminated bamboo board is obtained by soaking for 6 days (144 hours). Water absorption increases exponentially at a time of 0 to 24 hours immersion, then starts to be constant at a time of 120 hours. Based on Figure 4. It is known that LBL-Z has the highest water absorption (29.95% during 24 hours immersion). This probably due to more gaps found on the laminated board with zephyr on the face/back. Significant changes in water absorption in the first 2 hours are supposedly due to stress release on the laminated bamboo board which causes thickness swelling. This indicates that the bamboo laminate board absorbs more water. Composite board stresses occur due to compression, which is then released during immersion and will cause thickness swelling [13].

3.3. Mechanical properties: Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

MOE values indicate the nature of the board stiffness while the MOR indicates the strength of the fiber that occurs at maximum load. The density of the sample can affect MOE and MOR values. The relationship between density values and ply bamboo MOE/MOR values are presented in Table 3.

| Testing Direction | Code  | Density (g/cm³) | MOE(MPa)       | MOR (MPa)   |
|-------------------|-------|-----------------|----------------|-------------|
| Long              | Ply-Z | 0.80 (0.04)     | 10,168.15 (611.97) | 55.19 (13.04) |
|                   | Ply-S | 0.80 (0.03)     | 6,665.55 (1398.30) | 43.23 (1.08)  |
| Cross             | Ply-Z | 0.78 (0.03)     | 644.75 (67.20)   | 19.59 (10.56) |
|                   | Ply-S | 0.80 (0.06)     | 783.94 (162.20)  | 19.24 (2.09)  |

Figure 2. Water absorption of laminated bamboo

Figure 3. Bonding damage of ply bamboo strip sample
MOE/MOR values on ply bamboo are affected by the face and back of the laminated bamboo board because in this test the upper surface experiences compressive forces while the lower surface experiences tensile forces. Based on Table 3. It is known that the laminated bamboo board with perpendicular direction of fiber (ply bamboo) has a different MOE value in terms of the test direction (long and cross). In the long direction of testing (parallel to grain), the MOE value on the Ply-Z is greater than the Ply-S. This probably due to bonding damage during Ply-S testing which can be seen in Figure 3, thus reducing the MOE value. MOE values on laminated bamboo boards are affected by the nature of bamboo and the gluing of bamboo strips. Initial shear damage due to weak adhesion on the sample can reduce the MOE value [14]. In the cross direction of testing (perpendicular to the grain) the MOE value on Ply-S is greater than Ply-Z. According to JAS for plywood [8], the standard for MOE in long and cross direction is 5000 MPa and 4000 MPa, therefore MOE value in long direction meets the standard, while the MOE value in cross direction does not meet the standard. This was supposedly due to damage that occurred between the connections on the laminated bamboo board.

The MOR value of Ply-Z in both the long and cross directions of testing are greater than Ply-S. This probably due to bond damage on the laminated bamboo board with the strip on the face/back. According to JAS for plywood [8], the standard for MOR (long and cross direction) is 24 MPa and 20 MPa, so the results of MOR in long direction meet the standard, while the MOR in cross direction does not meet the standard.

| Table 4. MOE and MOR values of LBL |
|------------------------------------|
| Testing Direction | Code | Density (g/cm³) | MOE (MPa) | MOR (MPa) |
| Flat | LBL-Z | 0.80 (0.07) | 19747.53 (3638.18) | 76.04 (14.64) |
| | LBL-S | 0.77 (0.03) | 15326.30 (2855.22) | 75.73 (7.85) |
| Edge | LBL-Z | 0.82 (0.04) | 23917.63 (3455.13) | 84.44 (14.86) |
| | LBL-S | 0.81 (0.02) | 20173.03 (1804.74) | 108.62 (7.15) |

According to Table 4. It is known that LBL has different MOE values in different testing direction (flat and edge). In both the flat and edge testing direction, the LBL-Z MOE values were greater than LBL-S. Then, for the MOR value in the flat testing direction, LBL-Z has a greater value compared to LBL-S. While the MOR value on the edge testing direction LBL-S has a greater value compared to LBL-Z. According to JAS for LVL [9], the standard for structural type A MOE and MOR values for both LBL-S and LBL-Z are in the 180E class. Independent-sample T-test results proved that a combination of zephyr and strip raw materials was significantly different for the LBL MOE flat testing direction value and ply bamboo MOE long testing direction.

MOE/MOR values are greater on laminated bamboo boards with parallel fiber direction (LBL) compared to laminated boards with perpendicular fiber direction (ply bamboo). The tensile and flexural strength decrease with increasing lamina angle. On the laminated bamboo board, the aligned fiber direction shows the fibers are arranged in one direction with a continuous polymer [15]. Independent sample T-test results proved that the variation in the direction of parallel and perpendicular fibers was significantly different for the MOE and MOR values of the laminated bamboo board.

According to the Indonesian Timber Construction Regulations NI-5 [16], related to the strength of wood class in terms of the modulus of elasticity, Ply-Z is in the wood strength class II (10,000 MPa),
Ply-S is in the wood strength class IV (6000 MPa), and both LBL-Z and LBL-S are in the wood strength class I (12,500 MPa).

3.4. Mechanical properties: shear strength
The value of the shear strength indicates the quality of adhesion on the laminated bamboo board. According to Figure 5. It is known that the shear strength value of Ply-Z is greater than Ply-S. This is supposedly due to the silica on the surface that glued together in a laminated bamboo board with the strip on the face/back. The waxy layer and the silica layer found on the surface of the bamboo can reduce the shear strength of the laminated bamboo board [17]. According to JAS for plywood [8], the standard for shear strength is 0.7 MPa, so the value of shear strength in ply bamboo meets these standards.

According to Figure 7, it is known that in the direction of flat and edge testing the shear strength value of LBL-S is greater than LBL-Z. This is supposedly due to more gaps in the zephyr as face/back which can reduce the shear strength of the laminated bamboo board. Then, according to JAS for LVL [9] standard for structural type A, the value of shear strength of both LBL-S and LBL-Z are in the 65V-55H class. The quality of adhesion on bamboo lamination is affected by the cut in or wax layers and surface roughness. The presence of the cut in layer and a rough surface can reduce the value of shear strength or the adhesion of laminated bamboo boards [18]. Independent-sample T-test results proved that the combination of zephyr and strip is significantly different for the value of shear strength LBL in flat and edge testing direction.
3.5. Mechanical properties: screw withdrawal

The screw withdrawal strength is carried out on the surface of the laminated bamboo board in a flat direction. Screw withdrawal strength value is different based on the arrangement of the fiber directions. Ply bamboo has a greater value than LBL. According to Figure 9, it is known that Ply-Z has the highest value of screw withdrawal strength. Zephyr on the face/back of the laminated bamboo board gives a higher value of screw pulling strength on both ply bamboo and LBL.

![Figure 9. Screw withdrawal strength value](image)

The perpendicular direction of fiber (ply bamboo) gives a higher value than the parallel direction of fiber (LBL). The screw withdrawal strength value is affected by the moisture content, density, direction of the board fibers, the board layers, and the use of adhesive [19]. According to SNI 03-2105-2006 [11] for particleboard decorative and structural requirements, screw withdrawal strength minimum value is 500.14 N. so that the screw withdrawal strength value in this study meets the standard except for the LBL-S. This probably due to aligned orientation tends not to be able to withstand the load of the screw, so it caused splitting damage as can be seen in Figure 10. The screw withdrawal value on the laminated board can be affected by the orientation of the fiber, the thickness of the layer, and the quantity of adhesive on the laminated board [20]. Independent-sample T-test results proved that the combination of strip and zephyr and variation in the direction of parallel and perpendicular fibers is significantly different for the screw withdrawal strength value.
4. Conclusion
Based on this study it can be concluded that:
1) Laminated boards from bamboo strips have better dimensional stability and better shear strength than laminated bamboo boards from bamboo zephyr. Whereas laminated bamboo board from bamboo zephyr has better MOE and MOR values and better screw withdrawal strength.
2) The perpendicular fiber direction of laminated bamboo boards can increase dimensional stability, reduce water absorption, and increase the value of the screw withdrawal strength. The parallel fiber direction of laminated bamboo boards can increase the MOE/MOR values.

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