Analysis of Bamboo Species Variation Effect Against Physical and Mechanical Properties of Laminate Bamboo Slat for Fishing Boat Construction Materials

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Abstract. Several studies on the mechanical properties of bamboo slats have been carried out using various types of bamboo species, including Dendro Calamus Asper sp, Gigantochloa Apus sp, Bambusa Arundinacea sp. Until now, variations and combinations of bamboo species have not been carried out, especially about physical and mechanical properties. This paper investigates the effect of variations in bamboo species on the physical and mechanical properties of laminated bamboo slats for ship construction. Each species of bamboo has advantages and disadvantages, which are expected with this combination will produce better physical and mechanical properties. The best value of shrinkage properties occurred in the variation of Bambusa Arundinacea sp with Gigantochloa Apus, namely 3.86%. This variation also extends the highest mechanical properties: Tensile Strength: 151.9 Mpa; Flexure Strength MOR: 118.6 Mpa; MOE: 5.54 GPa. The Bambusa Arundinacea sp and Gigantochloa Apus hybrid perfectly meet the limit requirements according to the rules of BKI: 2013, Vol vii.

1. Introduction
As innovation replacing wood as the primary material for building wooden boats in Indonesia, the use of laminated bamboo slats is one of the solutions to reduce wood usage. The development of research on laminated bamboo boats has been carried out by experts and researchers from Indonesia, where preliminary research was carried out on the use of laminated bamboo slats as a substitute for wood in the construction of frames, beams, and keel of wooden boat [1]. This research then examines if all wooden boat constructions can be replaced by laminated bamboo slats [2].

Several studies have been carried out to identify bamboo material's mechanical properties, physical properties and shrinkage treatment. In this study, several characteristics of bamboo slats were obtained and used as references. The previous studies [3] stated the mechanical properties of three types of bamboo, namely Ori Bamboo (Bambusa arundinacea), Betung bamboo (Dendro Calamus Asper), and Apus Bamboo (Gigantochloa apus). This research found that Bambusa arundinacea had a tensile strength of 185.55 MPa, flexure strength of 86.92 MPa, and an elastic modulus of 17.46 GPa. The Dendro calamus asper had a tensile strength of 149.75 MPa, flexure strength of 74.82 MPa, modulus of elasticity of 13.91 GPa. Meanwhile, the Gigantochloa apus obtained a tensile strength of 70.41 MPa, a flexure strength of 47.61 MPa and a modulus of elasticity of 10.31 GPa.

In general, the various physical properties of bamboo caused by the growing habitat of the bamboo. The physical properties of bamboo, such as density and moisture content, were relatively influencing the mechanical properties [4]. This is also related to the bamboo's swelling and shrinking behavior when
used as a laminate material. Naturally, the older bamboo has a lower moisture content due to the increasing density of the bamboo fiber as it grows. Bambusa arundinacea has an average thickness development of 6.97% in the middle and 4.26% at the bottom. Temporarily, Dendro calamus asper has a much more significant swelling and shrinking behavior than Bambusa Arundinacea. At 12% water content, there is a shrinkage of 9.94% in the middle of the slat and 9.26% at the base part [5]. In a separate study, the percentage of swelling and shrinkage of Bambusa Arundinacea with a moisture content of 12%-40% was 5.8% of the initial thickness [6].

Each type of bamboo also has a different physical form. Bambusa arundinacea, although its good mechanical properties, has thin and quite extreme curve slats. On the other hand, despite of its weak mechanical properties, D. asper has thick and straight slats. Gigantochloa apus has moderate mechanical properties among the other two types of bamboo. However, G. Apus has almost the same slat thickness as D. Asper.

By those property differences, each type of bamboo has its own benefits and drawbacks (physical and mechanical properties). This study was conducted to combine several types of bamboo to determine the advantages of hybrids of several types of bamboo in a laminated structure to support construction on fishing boats. This study also conducted to identify the mechanical and physical properties of the composite laminate of various types of bamboo. This was carried out to provide a variety of laminates that meet the requirements of strength and modulus of elasticity as well as to determine the most economise variation.

The type of bamboo used also considers the availability bamboo material, especially in Java. Bamboo plants on the Java Island have a considerable number and are relatively easy to harvest, and are cheaper than solid wood [5]. According to data survey in particular [2], it is known that the availability of Ori Bambusa arundinacea has a habitat of a 0-300 m above sea level. Furthermore, Dendro Calamus Asper can be found in highland areas (350-700 m above sea level). The Gigantochloa apus is found in rural areas on the island of Java [7]. For this reason, these three types of bamboo will be used as a hybrid material and will be tested in terms of mechanical or physical properties. This test uses seven variations: Bambusa Arundinacea laminate, Gigantochloa Apus laminate, Dendro Calamus Asper laminate, and the combination of Bambusa arundinacea-Gigantochloa Apus hybrid; Bambusa Arundinacea - Dendro Calamus Asper hybrid; Gigantochloa Apus-Dendro Calamus Asper hybrid; and compos of the three types Bambusa Arundinacea-Gigantochloa Apus- Dendro Calamus Asper hybrid.

2. Material and Method

2.1. Material Selection
The bamboo types that used in this research is 3 to 4 years old at the time of harvest. Thus, the bamboo slats used will have good quality. The density of the bamboo fiber has been perfectly formed and will make the water content in the bamboo slats stable. [4]. The bamboo Slats of Dendro calamus asper and Bambusa arundinacea are obtained from Kediri City in East Java, while Gigantochloa apus is obtained from Trenggalek Regency in East Java.

2.2. Test Material Preparation
The test specimens made in this study were tensile test specimens based on ASTM D3500 [9], flexure test specimens based on ASTM D3043 [10], and the physical shrinkage properties test based on ASTM D143 [11]. The manufacture of test specimens begins with arranging different types of bamboo slats to form a laminated board. For the tensile test, the laminated board is designed with 45 cm length and 15 cm width (Figure 1a). Meanwhile, the laminated board for flexure test have dimension of 65 x 15 (cm) shown in Figure 1b.
The variation specimen consists of seven variations of the bamboo slats thickness. The thickness of the Bambusa Arundinacea slat is 4mm thick; the Giganthocloa Apus slat is 5 mm and the Dendro Calamus Asper slat is 6 mm thick. The variation layers of laminate are shown in Table 1, in which for each specimen type consists of four layers with different slat thickness. Therefore, since the slat's thickness in each type of bamboo is different, then the composition of the thickness of each variation of laminate will also be different.

| Type of Variation     | Layer 1 | Layer 2 | Layer 3 | Layer 4 |
|-----------------------|---------|---------|---------|---------|
| Bambusa Arundinacea (O) | O       | O       | O       | O       |
| Giganthocloa Apus (A)  | A       | A       | A       | A       |
| Dendro Calamus Asper (B) | B       | B       | B       | B       |
| O-A                   | O       | A       | A       | O       |
| O-B                   | O       | B       | B       | O       |
| A-B                   | A       | B       | B       | A       |
| O-A-B                 | O       | A       | B       | O       |

Figure 1 Laminate board design, 1-4 shows the bamboo slats used in the variation. (a) bending test specimen board, (b) tensile test specimen board

The laminate board then formed into several specimens. The size of each specimen is based on ASTM standards (ASTM D3500 for the tensile test; ASTM D3043 for the flexure test and ASTM D143 for the shrinkage test). Therefore, each specimen must be marked to make it easily distinguished when tested in Universal Test Machine (UTM). The shrinkage test is just done for the laminate of Giganthocloa Apus, Dendro Calamus Asper and Bambusa Arundinacea. Variations with different types of bamboo were not tested because this test was conducted to determine the shrinkage level of each type of bamboo.

2.3. Material testing
2.3.1. Physical Properties Testing. Physical properties testing in this study is carried out for the effect of density and shrinkage expansion on the seven variations of the laminate. Before testing, the water content of the specimen is measured with a moisture meter. Following ASTM D143 regulations, this water content measurement must be executed at room temperature. From the research conducted, the water content value is 12% [11]. Furthermore, the specimens were measured for their thickness, length, width and weight as shown in Figure 2.

The initial measurement of the specimen was performed in dry condition before they immersed in the water until they reach the saturation point. The saturation point condition is determined, presuming that the specimen's weight didn't increase anymore. After that the size of the specimen is measured according to the objectives stated in the ASTM rules. The difference of specimen's initial dimension and weight then analysed by comparing them to the condition in the saturation point. Each type of bamboo will have different results. Nevertheless, if different types of bamboo would be used as combined material, each bamboo must comply with BKI regulations regarding shrinkage levels and dimensional changes.
2.3.2. Mechanical Properties Testing. The purpose of this mechanical properties test is to determine the tensile strength and the flexure strength of each specimen. These tests were carried out according to ASTM rules (D3043 for the flexure test and D3500 for the tensile test). The experiments on the mechanical properties were performed using a Universal Testing Machine (UTM) (Figure 3). Both tests are done by applying load to the specimen based on the related ASTM requirements.

The results of the tests are then represented through load vs deflection graph. The maximum load on the graph represents the ultimate strength condition. Furthermore, the UTM result graph must be converted into a stress vs deflection diagram. The highest strength value stated in the graph then used as the tensile or flexure strength of the laminated bamboo slats.

The tensile and flexure strength values used to calculate the elastic modulus of the material. A predetermined calculation can identify the modulus of elasticity based on the results of the tensile test under ASTM D3500 [9], which can use the following formula:

\[ MoE = \frac{l}{A} \left( \frac{AP}{\Delta l} \right) \]

Where in formula (1) is calculated, the modulus of elasticity is obtained by multiplying the separation of the length of the specimen \( l \) and the cross-section area of the specimen \( A \) with the value of the load \( AP \) and the elongation of the specimen \( \Delta l \).

The calculation of the modulus of elasticity in the bending strength test is carried out using the formula listed in ASTM D3043, namely [10]:

\[ MoE = \frac{l}{A} \left( \frac{AP}{\Delta l} \right) \]
According to formula (2), to determine the modulus of elasticity, it is done by substituting the values obtained from the experiment which include: the length of the specimen \( l \); width of the specimen \( b \), thickness of the specimen \( t \) and deflection \( \delta \). so that the modulus of elasticity of the flexure test specimen is obtained correctly.

**2.4. Design and Construction Profile of Fishing Boat**

In accordance with the principles of design and construction, to calculate the size of the construction components, the experimental results in this study were applied to a 7 GT fishing boat. This fishing boat is the result of the design of the Baito Deling team which has been carried out several calculations according to its function. Line plans, general arrangements, and construction profiles will be used as the basis for calculating the size of all construction components. This scantling calculation is based on the rules of the Indonesian Classification Bureau vol: vii, 2013. [8].

As shown in Figure 4, the construction design is used as a reference for calculation of the construction members. In general, the construction of a wooden boat consists of keel, hull, stern, side stringers, stringers, deck beams, floors and frames. The scantling is determined by the mechanical properties of the material used. The modulus of the construction parts calculated based on these seven tested variations. Furthermore, the size of this ship construction affects the economic value of a ship. The larger the size of the construction of a ship it will affect the cost of shipbuilding, as a result the price of the ship becomes higher.

![Figure 4 7 GT fishing boat construction design](image)

**3. Results and Discussion**

**3.1. Physical Properties Testing**

Shrinkage test included measurements of weight, moisture content, and density of the material. Measurements were carried out in two conditions, dry and wet material. The measured material
consisted of three variations of laminates which were coded O for B. Arudinacea, A for G. Apus, and B for D. Asper. Each variation of the laminate consists of three test specimens.

Table 2 Measurement results of dry condition specimens

| Code | Dry Condition |   |   |   |   |   |
|------|---------------|---|---|---|---|---|
|      | Length (mm)   | Wide (mm) | Bold (mm) | Weight (gram) | Water content (%) | Density (ton/m³) |
| O.1  | 105,12        | 24,68     | 24,44     | 48             | 11,8              | 0,757           |
| O.2  | 103,83        | 24,57     | 25,51     | 48             | 12,2              | 0,738           |
| O.3  | 101,48        | 24,53     | 25,14     | 45             | 11,5              | 0,719           |
| A.1  | 99,38         | 24,6      | 23,3      | 47             | 11,6              | 0,825           |
| A.2  | 99,75         | 24,98     | 23,3      | 54             | 11,2              | 0,930           |
| A.3  | 99,28         | 25,08     | 23,82     | 50             | 11,9              | 0,843           |
| B.1  | 100,99        | 25,05     | 23,89     | 47             | 12,3              | 0,778           |
| B.2  | 101,77        | 24,7      | 24,6      | 43             | 11,1              | 0,695           |
| B.3  | 103           | 24,54     | 24,14     | 47             | 11,1              | 0,770           |

Based on the data presented in Table 2, the weight of the test specimens ranged from 43 grams to 54 grams where the specimen with the largest weight was G. Apus variation and the smallest weight on the D. Asper variation. The density of the test specimens in dry conditions ranged from 0.695 tons/m³ to 0.930 tons/m³. The water content ranges from 11.1% to 12.3% where the highest water content is 12.3% which is found in the D. Asper variation.

Table 3 Wet condition specimen measurement results

| Code | Wet Condition |   |   |   | Water Content (%) | Density (ton/m³) |
|------|---------------|---|---|---|--------------------|------------------|
|      | Length (mm)   | Wide (mm) | Thickness (mm) | Weight (gram) |                   |                  |
| O.1  | 105,15        | 25,77     | 26,32     | 65             | 54,6               | 0,911            |
| O.2  | 103,92        | 25,61     | 27,23     | 63             | 38,8               | 0,869            |
| O.3  | 101,56        | 25,56     | 27,07     | 62             | 52,8               | 0,882            |
| A.1  | 99,4          | 25,92     | 24,04     | 60             | 36,9               | 0,969            |
| A.2  | 99,79         | 25,73     | 24,16     | 66             | 28,1               | 1,064            |
| A.3  | 99,32         | 26,07     | 24,72     | 63             | 35,5               | 0,984            |
| B.1  | 101,06        | 25,82     | 25,08     | 60             | 28                 | 0,917            |
| B.2  | 101,78        | 25,73     | 25,91     | 58             | 39,2               | 0,855            |
| B.3  | 103,05        | 25,34     | 25,27     | 60             | 26,2               | 0,909            |

Table 3 presents material measurement data after immersion to obtain material with wet conditions. Based on the data in table 3, the smallest test specimen weight was 58 grams on the D. Asper variation and the heaviest was 66 grams on the G. Apus variation. Meanwhile, the density of the test specimens ranged from 0.855 tons/m³ to 1.064 tons/m³. The water content contained in the test specimen was the lowest at 54.6% which was found in the B. Arudinacea variation and the lowest at 26.2% which was found in the D. Asper variation.
Based on the results shown on Figure 5, it was found that there was no particular length change in the direction of the bamboo fibre as the length change was less than 1%. The most significant increase in width was found in B. Arudinacea at 4.1068%. However, this result was much smaller than previous studies [2]. The notable change in thickness also found in B. Arudinacea with a change of 6.863%. This thickness change is more significant than previous studies [2]; this phenomenon occurs because the young bamboo slats in the middle of the specimen do not withstand the increase in the thickness of the young slats.

The increasing of bamboo weight occurs because the water is absorbed by the bamboo and makes them expand. This weight gain is quite essential because the ship material will operate in a humid environment and will absorb water. Figure 6 shows the weight gain of each type of bamboo after soaking in water. B. Arudinacea is the type of bamboo with the highest absorption capacity. This type of bamboo gained a weight of 25.794%. On the other hand, G. Apus has the lowest absorption capacity, as proved by the weight gain only of 20.161%. D. Apus takes to the middle position with a weight gain of 23.065%.

### 3.2. Tensile Strength Test

The tensile strength of laminated bamboo slats material was tested by applying the ASTM D3500 standard [9]. This test was carried out to produce the average results of stress, strain, and modulus of elasticity from each variation of the laminated bamboo slats material. According to BKI regulations vol.
VII [8], the minimum tensile strength of wood material is 42.169 MPa. A ship's material must be complying this regulation, as tensile strength is important for supporting the longitudinal load of the ship (especially wooden ships).

![Figure 7](image-url) The average tensile strength in each variation of the laminate

Based on the test results, all variations meet BKI regulations and can be used as ship materials (Figure 7). B. Arudinacea has the highest tensile strength average of 158.397 MPa, while D. Asper has the lowest average with only 117.148 MPa. However, B. Arudinacea has the lowest average of thickness among the others variation. This will lead to the increasing of bamboo slats usages. On the other hand, the combination of G. Apus and D. Asper is the second highest tensile strength average of 151.941 MPa. Thus, variation AB is the most tensile material among other variations combinations of bamboo.

Figure 8 shows the average modulus of elasticity (MOE) of each variation. MOE is used to measure the material's durability to elastic deformation. B. Arudinacea has the highest MOE value of 19.1 GPa, while the combination of B. Arudinacea and G. Apus has the lowest MOE value of 13.9 GPa. Among the other variation of bamboo combination, Variation OB has the highest average MOE value with 18.3 GPa. This variation has a good combination because D. Asper has sufficient thickness while B. Arudinacea has good strength in spite the low in thickness.

![Figure 8](image-url) Average modulus of tensile elasticity for each variation

3.3. Flexure Strength Test
Using the ASTM D3034 [10] standard, the bending test performed to obtain the flexural strength, deflection and modulus of elasticity. Based on BKI vol. vii, the required flexural strength for a ship's material is 71.098 MPa [8]. Thus, the material must have a flexural strength more than that value because the ship's side loads supported by this strength.
Figure 9 The average flexure strength of the material for each variation

The test result, shown in Figure 9, state that all variations meet the standard and can be used as ship material. B. Arudinacea has the highest flexural strength average of 123.168 MPa. This fits the previous research [12] that B. Arudinacea has flexible and strong properties. In the other hand, D. Asper has the lowest flexural strength average of 71.34 MPa. That value is slightly higher than the standard, thus making Variation B could be used as ship material.

Figure 10 shows the result of the flexural strength MOE. Variation AB with the combination of G. Apus and D. Asper has the highest MOE value with an average of 8.42 GPa. Variation AOB take the second place of highest MOE value with an average of 7.68 GPa. Although it's thickness, variation B has the lowest MOE value of 5.33 GPa. The same goes with B. Arudinacea. In spite of its high flexural strength, that variation only has MOE value of 5.87 GPa. On the other hand, D. Asper has the highest MOE value among other variations with no bamboo combination. Thus, by adding D. Asper to the combination will increase the MOE value.

Figure 10 Average modulus of flexure elasticity for each variation

3.4. Economic Analysis
Each variation of bamboo laminate has different economic value. Economic analysis was performed to determine the economic value of each variation to distinguish the most cost-effective. Economic value is obtained by calculating the cost for glue, bamboo slats and labour of 7 GT fishing boat production for each variation. Although the 7 GT fishing boat was designed, the scantling for each variation will differ because each variation has different tensile and flexural strengths. Adjustment of the scantling uses BKI vol. VII [8]. The adjustment done by comparing the bending moment with the following formula:
After conducting experiments and research, the conclusions of this study are as follows:

1. Based on the shrinkage test, the extreme changes in dimension and the most extensive changes in weight were found in B. Arudinacea. Combined lamination should be applied with graded shrinkage material as the difference in shrinkage between layers does not cause deformation of the laminate due to too significant shrinkage rate differences. The arrangement of the slat layers is based on the change in shrinkage of the material. This method can prevent cracking and other deformations due to the push and pull forces arising from the difference of shrinkage rate.

2. The variation OAB has an average tensile strength of 144.6 MPa and a modulus of elasticity (MoE) of 15.1 GPa. This variation also has an average flexural strength of 117.726 MPa and a modulus of elasticity (MoE) of 7.68 GPa. However, the variation OAB has a tensile strength of 8.703% and a flexural strength of 4.418% lower than the variation without combination of bamboo type. Although it has a lower strength, this variation has a higher average thickness of slats than B. Arudinacea. Thus make this variation is economically cheaper than other variations.

\[ \Sigma_{\text{wood}} \times W_{\text{wood}} = \sigma_{\text{hybrid}} \times W_{\text{hybrid}} \] (3)

Based on equation 3, it is found that the force that applies to the ship's construction is the multiplication result of the flexure strength (\(\Sigma_{\text{wood}}\)) and the cross-sectional area of construction (\(W_{\text{wood}}\)). The applied force will remain the same even though the material is different. Therefore, to meet the value of the force, it is necessary to make a scantling adjustment.

Laminate bamboo slats have different flexure strength (\(\sigma_{\text{hybrid}}\)) values from wood. Thus, to produce the same force applied as wood-based construction, the cross-sectional area of the construction (\(W_{\text{hybrid}}\)) must be adjusted. In this case, the approach is carried out by using wood material as a benchmark because wood is a material similar to bamboo.

The material cost calculation (glue and bamboo slats) uses a volumetric approach. The calculation done by multiplying the volume of each variation scantling with the material cost per m$^3$. The same goes with labor cost, where each variation requires different processing times. The labor used in this calculation consist of 2 craftsmen with a cost of IDR 150,000 per man day and 4 helpers with cost of IDR 100,000 per man day.

### Table 4 The cost of building fishing boats for each variation

| Bamboo Variation | Material needs (m$^3$) | Bamboo price/ m$^3$ (IDR) | Days | Month | Total cost (IDR) |
|------------------|------------------------|---------------------------|------|-------|------------------|
| O                | 3.150                  | 21,177,219                | 44.89| 1.60  | 98,136,805       |
| A                | 3.523                  | 16,928,781                | 37.94| 1.36  | 86,208,212       |
| B                | 4.438                  | 14,096,490                | 38.49| 1.37  | 89,504,780       |
| OA               | 3.282                  | 18,816,976                | 44.11| 1.58  | 92,624,450       |
| OB               | 4.091                  | 16,928,781                | 39.03| 1.39  | 96,568,288       |
| AB               | 4.102                  | 15,383,895                | 38.52| 1.38  | 90,072,069       |
| OAB              | 3.219                  | 17,823,189                | 37.37| 1.33  | 83,532,723       |

Based on Table 4, it is concluded that the most cost-efficient variation is the OAB. The variation OAB has the cheapest construction cost with IDR 83,532,723. This variation also has the fastest building time, which is 37.37 days or 1.33 months. On the other hand, variation O has the most expensive construction cost with IDR 98,136,805. Variation O also has the longest building time, which is 44.89 days or 1.6 months.

### 4. Conclusion

After conducting experiments and research, the conclusions of this study are as follows:

1. Based on the shrinkage test, the extreme changes in dimension and the most extensive changes in weight were found in B. Arudinacea. Combined lamination should be applied with graded shrinkage material as the difference in shrinkage between layers does not cause deformation of the laminate due to too significant shrinkage rate differences. The arrangement of the slat layers is based on the change in shrinkage of the material. This method can prevent cracking and other deformations due to the push and pull forces arising from the difference of shrinkage rate.

2. The variation OAB has an average tensile strength of 144.6 MPa and a modulus of elasticity (MoE) of 15.1 GPa. This variation also has an average flexural strength of 117.726 MPa and a modulus of elasticity (MoE) of 7.68 GPa. However, the variation OAB has a tensile strength of 8.703% and a flexure strength of 4.418% lower than the variation without combination of bamboo type. Although it has a lower strength, this variation has a higher average thickness of slats than B. Arudinacea. Thus make this variation is economically cheaper than other variations.
3. The combination of B. Arudinacea and G. Apus has an average tensile strength of 151.9 MPa and flexural strength of 118.693 MPa. The combination of B. Arudinacea and D. Asper has an average tensile strength of 134.4 MPa and flexural strength of 82.14 MPa. The combination of G. Apus and D. Asper has an average tensile strength of 129.2 MPa and a flexural strength of 81.656 MPa. However, the combination of all bamboo type has a tensile strength of 144.6 MPa and a flexure strength of 117.726 MPa. Based on the requirement of BKI Vol VII (Tensile Strength: 42.169 MPa; Flexure Strength: 71.098 MPa), all combination stated previously can be used as ship material.

4. The variation OAB has the lowest production cost of building a 7 GT fishing boat among other variations tested with a full price of IDR. 83,532,723. This variation consist of B. Arudinacea, D. Asper and G. Apus. However, only two types of bamboo with the highest strength are used for the scantling under 15 mm (B. Arudinaca and G. Apus).

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