Mechanical Properties Analysis of Slats Inter-lay Joint Gap of Bamboo Laminates for Fishing Boat Construction

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Keywords: Laminated Bamboo Slats, Fishing Boat Construction, Bamboo Slats Interlay Joint Gap, Mechanical Properties.

Abstract: Today, the use of laminated bamboo as a ship construction material is increasing. With the limited length of bamboo stems, it is not possible to make a component of a ship construction without a blade connection. This bamboo slat interlay joint gap greatly determines the mechanical properties of the bamboo laminate formed. Thus, the bamboo slat interlay joint gap needs to be examined so as to obtain a minimum limit that meets the requirements of the construction strength of the Indonesian classification bureau (BKI). This writing will focus on the effect of Bamboo slat interlay joint gap as a function of the thickness of the blade (t) on tensile strength, flexural strength and modulus of elasticity. These three mechanical properties are a requirement in determining the strength of a ship's construction material. The bamboo material studied for the construction of a fishing vessel is bamboo ori (Bambusa Arundinacea). The testing standards used are ASTM D3500 (Pull) and ASTM D3043 (Flexure). In accordance with the results of specimen testing and the requirements of BKI vol: vii 2013, the mechanical properties of tensile strength, flexure strength and modulus of elasticity that fulfill the conditions are the specimen with a variation of slats interlay joint gap ≥10t.

1 INTRODUCTION

Solid wood is the main raw material in traditional fishing boats in Indonesia, but now the availability of solid wood is increasingly difficult to obtain. The scarcity of solid wood is caused by uncontrolled illegal logging, according to the Ministry of Forestry of the Republic of Indonesia, forest destruction in 2012 reached more than 1.08 million hectares per year (Wibowo & Gintings, 2010). On the other hand, to obtain wood that meets construction standards, it takes a very long time, as well as the time of planting, so that it can be used as raw material for construction of fishing boats that take around 30-40 years (Budyatmojo, 2013). Therefore, an alternative material is needed for wood substitution which has several criteria for its application: a short regeneration period, renewability and a more practical processing (Supomo, 2016).

Figure 1: Bamboo forests in Mojokerto district.

To provide alternative solutions, laminated bamboo can be used as a consideration for solid wood replacement materials for the construction of fishing vessels. Bamboo is a type of grass plant that has a relatively very fast regeneration rate and shorter harvesting age compared to other types of solid wood

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(Khotimah & Sutiono, 2014). For more details, the availability of bamboo can be seen in Figure 1, which is one of the bamboo forests in Mojokerto, East Java. Utilization of bamboo as an alternative fishing boat construction is carried out The use of bamboo as an alternative fishing boat construction is done by using special gluing techniques into one unit which is called laminated bamboo (Sharma, et al., 2015).

Several studies on the mechanical properties of laminated bamboo with various types of bamboo have been written. From the results of their research it has been proven that bamboo is a very good material for construction (Sharma, et al., 2015; Huang, et al., 2017; Jakovljević, et al., 2017; Nurdiah, 2016; Sharma, et al., 2015). In addition there are several studies that have produced several outcomes in the form of bamboo strength standards for building construction. Some of these writings include: (Raj & Agarwal, 2014; Gatóo, et al., 2014; Xiao, et al., 2010). However, related to the bamboo interlay joint gap bar, this has never been tested and there is no standard that can be called for the application of laminated bamboo for construction. So there is no guidence to apply the blade connection between layers in bamboo laminate.

Variation testing of bamboo slats interlay joint gap needs to be tested for its effect with mechanical properties. The distance of the inter-layer blade joints greatly determines the strength and size of the fishing vessel construction components. Blade connections are very necessary because besides bamboo it has advantages: easy to cultivate, sustainable, renewable, high producability, besides that bamboo also has a limited length of stem (Supomo, et al., 2015).

The length of betung bamboo stems (Dendro Calamus Asper) which can be used as construction material is between 9m to 12m. While the type of bamboo ori (Bambusa Arundinacea), the length of the stem that can be used for construction is only 6m to 8m. To make laminated bamboo, the bamboo blades used must be perfectly straight. The perfect alignment of the blade can only be obtained if the length is about 2m, width (25-30) mm and thickness (3-5) mm. Thus to make construction components - especially fishing vessels made from bamboo laminate, it is necessary to connect the blades to each layer (Supomo, et al., 2018).

With a minimum limitation of tensile strength and flexural strength - in accordance with BKI regulations 2013 regarding small vessels L ≤ 24m, the influence of blade joints between layers on bamboo laminate material needs to be tested and analyzed. So that the results of this study will be able to provide a reference in fabricating fishing boat components.

2 METHOD

2.1 Preparation of Bamboo Slats

The basic material used in this study is bamboo Ori (Bambusa Arundinacea). This is because this type of bamboo is very abundant in terms of availability. To facilitate the fabrication process, the bamboo to be cut down must have several criteria, namely: the age of bamboo is at least 3 years, bamboo stems are sought as straight as possible without extreme curves. Besides that bamboo sticks also have water content below 50% (Khotimah & Sutiono, 2014; Sharma, et al., 2015; Jakovljević, et al., 2017; Sá Ribeiro, et al., 2016).

Selected bamboo stalks then cut to a length of 2m, divided into sections with a width of blades (3-4) cm. Bamboo that has been cleaved is then preserved by immersion in a tub containing a mixture of clean water and 25% borax solution, 20% salt and 10% Ureum. The preservation process is carried out for a minimum of 7 days. This soaking is done so that the bamboo material that is ready to be used for the test material is free from destructive pests. Bamboo is then left in the open without being exposed to direct sunlight for two days for the drying process (Huang, et al., 2017; González & Gutiérrez, 1995). This bamboo blade illustration can be seen in Figure 2.

Figure 2: Bamboo slats before flattening.

The next process is thick leveling using a Single Planar Auto engine. In this process the bamboo slats should be leveled up and down. Bamboo blades are then cut into 500 mm lengths for tensile test specimens and 700 mm for bending test specimens. The cutting process can use a jig saw or disc saw machine manually. Bamboo blades that have been cut 500 mm and 700 mm are then flattened on each side with hand planar tools. This process is carried out so that the bamboo blades are really precise, both left and right and top-down so that the final dimensions of the slats can be obtained with sizes (500 x 30 x 5) mm and (700 x 30 x 5) mm. Bamboo skin and fine powder left as a result of the fabrication process is very resistant to the adhesive, so before being formed into laminated bamboo boards, it must be cleaned using a knife or cutter and scouring paper. For more details, bamboo blades that have been plannered and ready to be laminated can be seen in Figure 3.

Figure 3: The Flattened Bamboo slats.

2.2 Preparation of Test Specimens

Bamboo blades that have been flattened on all sides are then arranged so that the size of the thickness matches the standard. To do the tensile and flexure tests on this laminated bamboo, the arrangement is done with variations of slats interlay joint gap. This is intended to obtain the level of influence of interlay joint gap on the tensile strength and flexure of laminated bamboo. Blade interlay joint gap are made with 5 variations: 1t, 3t, 5t, 8t, 10t, where t: thick bamboo slats.

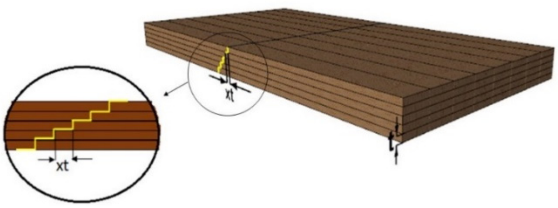

Figure 4: Bamboo laminate board.

Laminated bamboo boards for tensile tests measuring 500 x 250 x 28 (mm) and for bending tests have a size of 700 x 250 x 28 (mm). Laminated beams that have been arranged are then cut back in accordance with the variation of the bamboo slat intersection distance between layers. This laminated bamboo board picture can be expressed in Figure 4.

After the arrangement of the bamboo blades is in accordance with the specimen testing design, the next step is to glue them with epoxy polyamide marine use EWA135. The process of gluing and pressing bamboo laminates takes 3 hours to get laminated bamboo with perfect adhesion. The laminate board is then cleaned from the rest of the sticking paper and excess adhesive using a planar machine and sandpaper. Finally, the laminate bamboo board is formed into test specimens with dimensions that refer to ASTM D3043 standard for tensile testing and ASTM D3500 for bending test. The total number of specimens for all tests is 5 (blade joint variation) x 4 (test) x 2 pieces (pull & flexure) = 40 pieces. For more details the size and shape of the test specimen can be selected in Figure 5 (tensile) and Figure 6 (flexure).

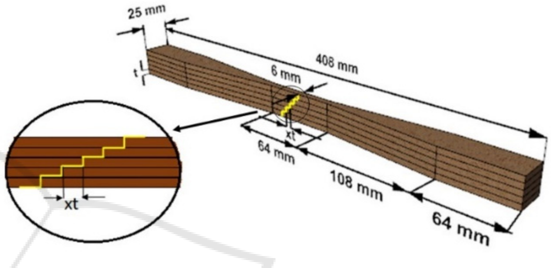

Figure 5: Dimension of the specimen for tensile test.

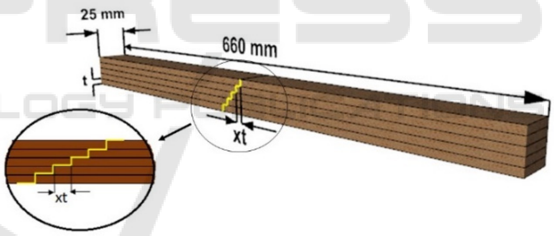

Figure 6: Dimension of the specimen for flexure test.

2.3 Testing

Specimens that have been prepared are then tested according to the mechanical properties required by BKI. This tensile and flexural testing process uses UTM (Universal Testing Machine). Tests were carried out to find out the strength of each material with a variety of bamboo slats interlay joint gap which is a multiple of bar thickness (t). From the tensile test, a load vs strain graph is produced, while in flexural testing, a load vs deflection graph is created.

Tensile and bending tests were carried out in accordance with the standards of ASTM D3500 and D3034 using UTM (Universal Testing Machine) with the specifications described in Table 1. Figure 7 shows the tensile strength test of Bambusa Arundinacea using UTM. For this flexural test, the application of a load of 20 kN and 2 mm / minute is applied. Figure 8 illustrates the flexural strength test on the same material also using UTM.

Table 1: Process Used to Evaluate Tensile and Flexure Strength.

Mechanical Properties	**Capacity**	**Cross head speed (mm/min)**
Tensile	UTM MFL/UFD.20kN up to 200 kN	2 - 3
Flexure		

Figure 7: Tensile Test Process.

Figure 8: Flexure test process.

Tensile testing results for each specimen with bambbo slats interlay joint gap variations is a graph of load vs. elongation. This curve must be converted into a graph tensile strength vs. strain. This conversion graph of (5t) variation of bamboo slats interlay joint gap can be seen in Figure 9. According to the graph, it can be explained that for variation (5t) the tensile strength is close to the value of 40MPa with a strain of 15%. All test pieces will be calculated and illustrated by the curve.

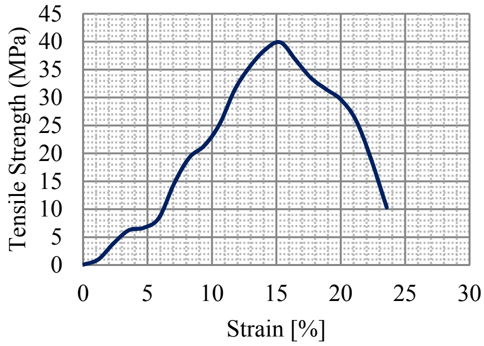

Figure 9: Graph of tensile test results (specimen with variation of slats interlay joint gap 5t).

As for flexure testing, the graph obtained is a load vs. deflection curve. Each coordinate point on the test results diagram needs to be calculated using the ASTM D3034 standard formula. The MOR value is obtained from the calculation of the flexural strength of the bamboo laminated beam that is given a centered load (P) in the middle of the span (L) using the formula:

$$MOR = \frac{3PL}{2bh^2} \tag{1}$$

Where the MOR is the Flexure strength of the laminated beam tested (Mpa), the length of the span of the beam L (mm), the width of the beam b (mm) with the height of the beam h (mm). The centered load given to the beam is represented by P (N). From this calculation, a graph of variation joint (8t) is obtained and can be shown in Figure 10.

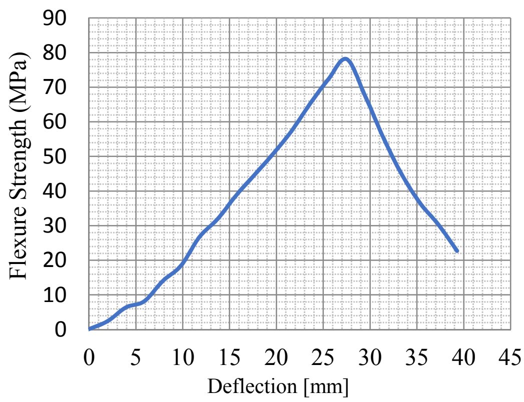

Figure 10: Graph of Flexure test results (specimen with slats interlay joint gap variation of 8t).

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From tensile and flexure graphs for all test specimens, then tabulated and taken the maximum mechanical properties of each test specimen. Each tensile and flexure values are then grouped according to the variation of slats interlay joint gap starting from (t) up to (10t).

In addition to the modulus of elasticity (MOE) bamboo laminated will be calculated according to the formula ASTM D3034. This is intended to obtain the MOE value perpendicular to the bamboo fiber that meets the regulatory requirements.

2.4 Analysis of Test Results

The tensile, flexural strength and modulus of elasticity (MOE) values were then averaged for all the results of the laminated bamboo specimens. The average value of all testing within a variation of the bamboo slats interlay joint gap of 1t, 3t, 5t, 8t and 10t. This mean value is then displayed in the graph of the tensile, flexure strength, and modulus of elasticity. Furthermore, it is matched with the curve trend in each graph, compared to the BKI vol permit limit: vii, 2013 regarding L Small Ship ≤ 24 m as a requirement for fishing vessel construction material.

3 RESULT AND DISCUSSION

3.1 Tensile Strength

From the results of tensile testing with variations of slats interlay joint gap (t) up to (10t), with each amounting to 4 specimens, the average values are as shown in Table 2. It can be seen the tensile strength value of each bamboo slats interlay joint gap variation, then be analyzed to determine the relationship between tensile strength and joint gap variation. This variation is a multiple of the thickness of the blade (t). The level of correlation greatly determines the test results.

Table 2: The Average Value of Tensile Testing Results.

Specimen No.	Interlay Joint Gap - (Mpa)				
	t	3t	5t	8t	10t
1	19.44	27.87	42.51	61.43	72.67
2	17.63	33.54	47.33	62.25	73.80
3	20.57	31.58	45.13	66.17	73.19
4	19.12	24.79	44.63	60.58	78.11
Average	**19.19**	**29.44**	**44.90**	**62.61**	**74.44**

In Figure 11 it can be seen that there is an increase in the average value of a significant tensile strength from the variation of the joint gap interlay 3t to 5t. Whereas from 8t to 10t, it increased but slightly sloping. Even so, in Figure x9 it can be explained from the graph that the average tensile strength value is increasing along with the addition of bamboo slats interlay joint gap. Based on Figure 1, the tensile strength after the 10t variation always increases until reaching the maksimum value of bamboo laminated without interlay joint.

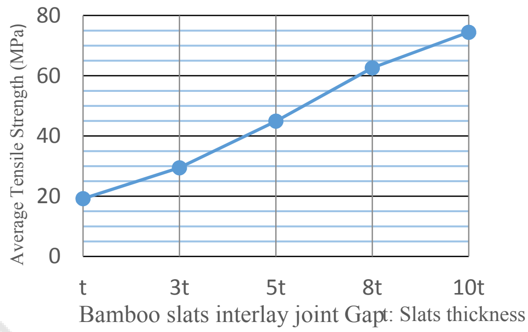

Figure 11: Tensile strength vs slats interlay joint gap.

Thus, according to Figure 11, it can be stated that the longer the bamboo blade joint distance on a laminated bamboo material, the higher the tensile strength produced. Whereas the shorter the bamboo blade connection distance in a laminated bamboo material, the lower the tensile strength produced. The magnitude of the tensile strength value is one of the requirements for the use of material for the construction of a fishing boat, according to the Indonesian classification bureau regulations.

3.2 Strain

Although strains are not a basic requirement for material properties that must be fulfilled according to BKI, this is very influential on changes in shape when the vessel receives more load. Therefore in the process of strain testing must be considered in applying bamboo laminate as a fishing boat construction material.

In accordance with the results of the tensile test experiment, the average value of the strain as illustrated in Figure 12 are carefully obtained. In the strain chart it can be said that with the variation of slats interlay joint gap (t) to (3t), the addition of the strain value is very small. However, starting from variations (5t) to (10t) these values increase significantly. Thus, by increasing slats interlay the joint gap, the bamboo lamination material will be more stable to accept the load without experiencing damage. The characteristics of the bamboo blade laminated strain will complement other properties as a consideration to be used to make a fishing vessel.

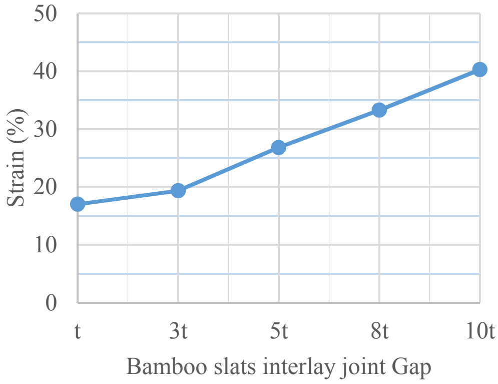

Figure 12: Strain Comparison Chart of Connection gap.

3.3 Flexure Strength

Tabulation of the average value of flexure testing with variations in bamboo blade connection distance can be seen in Table 3. From this value, an analysis was then performed to determine the effect of bamboo blade connection gap between layers in flexure testing.

Table 3: The Average Value of Flexure Test Results.

Specimen No.	Interlay Joint Gap - MPa (t: Slats thickness)				
	t	3t	5t	8t	10t
1	10.800	30.672	55.296	62.640	70.416
2	12.096	33.264	51.840	58.320	74.736
3	10.800	28.080	42.336	56.160	66.960
4	10.800	29.808	49.680	61.776	72.576
Average	**11.124**	**30.456**	**49.788**	**59.724**	**71.172**

Furthermore, the flexure strength average value in Table 2 is plotted in graphical form to determine the effect of blade interlay joint distance with flexure strength of bamboo lamination. So the graph of the relationship between flexure strength and the variation of slat interlay joint gap can be seen in Figure x11.

According to the curve in Figure 13, it can be said that the increase in slides interlay joint gap will increase the flexure strength value. Gradient increase in flexure strength from variation (t) to (5t) can be thought to be extreme (mean: 19.332 MPa), whereas from (5t)to (10t), the addition of flexure strength is somewhat reduced (average: 9.936 MPa). If the slats interlay joint gap is added continuously, then there is a possibility that flexure strength will also increase until it equals the strength value of flexure bamboo lamination without connection (= 111.56 MPa).

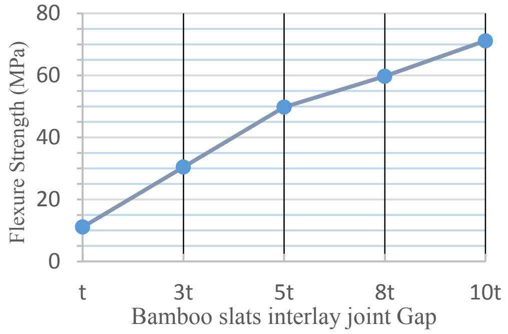

Figure 13: Flexure strength versus slats interlay joint gap.

3.4 Modulus of Elasticity

Modulus of elasticity (MOE) is one of the mechanical properties of fishing vessel construction materials required by BKI. Therefore, in making bamboo blade lamination, the joint gap must be carefully monitored so that the elasticity of the bamboo laminate material meets the requirements of BKI.

In accordance with the experiments that have been carried out (tensile and flexure tests), the modulus elasticity value has been calculated for each slats interlay joint gap variation (t) to (10t). In the tensile test, MOE value is done in direction of parallel to bamboo fiber, whereas for flexure test, the value of MOE is perpendicular to the bamboo fiber path. In making the construction of a fishing vessel made from bamboo laminate, the MOE that needs to be considered is perpendicular to the direction of the bamboo fiber. The calculation of the MOE value is using the equation :

$$MOE = \frac{PL^3}{48I\delta} \quad (2)$$

MOE (GPa) is the elastic modulus of laminated bamboo beams perpendicular to its fiber (Gpa), P (N) is the maximum load, while the spacing of L (mm), I is the moment of inertia from the cross section of the tested specimen, while deflection is denoted δ (mm).

From the value of this calculation, the MOE value and its correlation with the slats interlay joint gap factor are obtained graphs as shown in Figure 14.

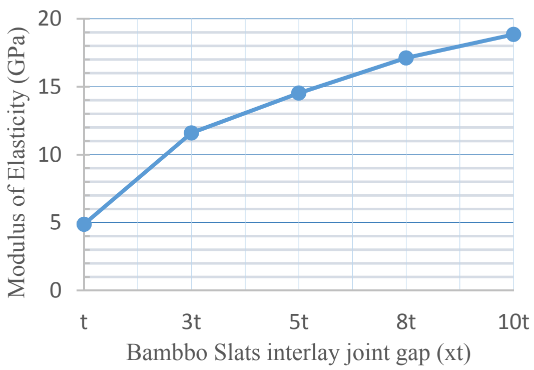

Figure 14: MOE versus slats interlay joint gap.

In the variation between (t) to (3t), the MOE value has increased dramatically by 6.72GPa. However, starting from variations (5t) to (10t), the increase was rather gradual, ie. an average of 2.42 GPa. MOE values that meet BKI requirements are ranging from variations of 5t to 10t. However, this still has to be considered with other mechanical characteristics and provisions.

3.5 Material Requirements for Ship Construction

According to BKI in 2013 concerning Small Vessels ≤ 24, plywood or laminate used as a whole construction material must have tensile strength greater than 42.169 MPa, whereas based on the test results, the tensile strength that meets the requirements is bamboo slats interlay joint gap variation of 5t, where the tensile strength is 44,244 MPa. So for the tensile strength value, which meets BKI regulations as a fishing vessel construction material is a variation of ≥(5t).

As for the flexure strength required is the Strong Class III, which is a minimum of 71,098 Mpa. In accordance with the test results, flexure strength values that meet the minimum requirements are (10t) variation, which is 71.172 MPa. So that for the flexure strength value, which meets the requirements of BKI so that it can be used as a ship construction material is the variation of (10t).

The modulus of elasticity required in the rules of classification is 6.68 Gpa. Based on the results of testing with a variety of bamboo-slats interlay joint gap (3t), this test gives MOE results of 11.59 Gpa. However, each of these test results cannot stand alone as a precondition for fishing vessel construction material. These three mechanical properties as a whole must meet the minimum limits stated in the BKI rules.

Thus, based on the results of testing in this study, bamboo slats interlay joints gap that can be accepted as requirements for fishing vessel construction materials, according to BKI vol rules: vii 2013, is a variation of ≥10t, (t: thickness of bamboo slat).

4 CONCLUSIONS

Based on the results of testing, analysis and discussions that have been carried out, the following conclusions can be drawn:

- Bamboo lamination material is very limited by the size of the blade naturally, so that a connection is needed to make a component of ship construction with a certain size.
- In laminated bamboo, tensile strength, flexural strength and modulus elsticity are directly related to bamboo slats interlay joint gap, where the longer the connection distance, the greater the tensile strength, flexural strength and MOE.
- Based on the minimum material stress in accordance with BKI vol: vii, 2013 concerning Small Vessels, 24 meters, each mechanical properties that meet the requirements are: tensile strength = 42.169 MPa, strong flexure = 71.098 MPa, and MOE = 6.86 GPa. From the results of testing the laminated bamboo with variations in blade joint spacing, which meets the regulations as a fishing vessel construction material is slats inter-lay joint gap > (10t).

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