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Research Article

Impact and Bending Tests of Coconut Palm and Thorny Bamboo Laminated Beams for Wooden Ship Keel Construction

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ABSTRACT

Impact and bending tests were conducted on laminated beams made from coconut palm and thorny bamboo to evaluate their potential as alternative materials for wooden ship keels. The study compared the shock load and bending strength of laminated beams with three-layer variations (3, 5, and 7), arranged in a carvel pattern. Testing followed ASTM D6110-10 for impact and ASTM D143 for bending, with moisture content kept below 18% per BKI standards. Results showed that impact strength increased with more layers, from 0.144 J/mm² (3 layers) to 0.248 J/mm² (7 layers). Bending strength also improved, from 14.37 MPa (3 layers) to 38.32 MPa (7 layers). However, the materials fell into Strength Class IV-V under Indonesian Classification Board standards, making them unsuitable as solid wood alternatives for ship keels due to insufficient strength.

Keywords: Impact Test; Bending Test; Laminated Beams; Coconut Palm; Thorny Bamboo

1. INTRODUCTION

Indonesia, an archipelago consisting of numerous islands, spans an area of approximately 1.905 million km². This vast area provides Indonesia with abundant marine resources, which serve as a key livelihood and source of income for its people. Currently, the primary material used in ship construction is wood, which results in high operational costs and environmental concerns. The growing demand for wood leads to a yearly depletion of forest stock due to large-scale deforestation. Over time, the availability of wood for shipbuilding has become increasingly limited, creating a need for new innovations in the shipbuilding industry to accelerate the development of the domestic maritime sector. One of the materials in short supply is the wood used for ship keels, which requires strong and solid wood for construction. As the size of the ship increases, the demand for larger timber also grows.

The wooden keel is a long backbone at the bottom of the boat, on which the ivory and leather parts sit. The keel has a function to strengthen the left and right tusks which are then supported by the keel. The size of the keel is determined by the size and construction structure of the ship (Hutauruk dkk., 2017). Wooden boat keels are usually made from one whole wood without joints so that the strength and rigidity of the wooden beam are more sturdy, but to get a wooden beam that is intact and has large dimensions is difficult to obtain, on the one hand wooden boat craftsmen use many components such as nut bolts to fasten the joints of wooden beams and the disadvantage is frequent corrosion. Usually this ship keel is made from various types of wood such as bedaru wood, laban wood, ironwood, and others, but now it is increasingly difficult to get this type of wood in the size of large wooden blocks, as a result of which hinders wooden boat craftsmen in making wooden boats. One of the breakthroughs taken to find new and cheap materials is by a method called lamination. The lamination method allows for the replacement of wood materials because it has better strength and is more affordable than solid wood materials. Lamination involves combining two or more different or identical materials into one strong form through the use of glue/adhesives. The result of lamination is a layer/arrangement consisting of materials that have been combined with the aim of increasing the strength, durability, appearance, or characteristics of the material.

Some of the materials that are often used in this lamination process are paper, plastic, wood, and fibers. Lamination itself can be done in various forms from thin sheets to complex shapes. This method of lamination is still rarely used on ships, which leads to the need for more testing of the material. In this study, there are two materials studied, namely coconut stems and thorny bamboo. Coconut (cocos nucifera) is an agricultural plant that is commonly found in tropical areas. According to Arancon, the total area of coconut plantations in Indonesia in 1995 was around 3.71 million hectares, with about half of them in need of rejuvenation. Coconut trees that have been cut down will have a negative impact on plantations because they can become breeding grounds for rhino beetles, the main pests of coconuts. As wood is becoming increasingly scarce, coconut stems are used as a substitute for wood to reduce waste (Handayani, 2016) .

Bamboo thorns (bambusa blumeana) are plants that commonly live in tropical areas. Bamboo thorns have a stem diameter ranging from ± 8-15 cm with the characteristics of dense, thick, short segments and small holes, and there are small thorns on the branches. Generally, this type of bamboo is often used by the community for agricultural equipment, local bridge construction materials, and others. Thus, to find out how strong the coconut stem and thorny bamboo are, impact testing and bending testing are carried out which aims to know how the ability of the laminated material is. Departing from this, a solution is needed so that there is a material that can replace the hard-to-obtain solid wood. The background in making this research is due to the availability of wood that is starting to decrease and also the high price of wood, thus hindering the process of making wooden ships. This study itself was made to find out the comparison and measure of strength produced from laminated materials after impact testing and bending testing, because ship keel materials require excellent and strong material resistance. So this spurred the author to conduct this research.

2. RESEARCH METHOD

The research employed experimental testing methods, specifically impact and bending tests, to evaluate the performance of laminated beams made from coconut palm and thorny bamboo for use in ship keel construction. The study involved three different laminate layer variations: 3, 5, and 7 layers, arranged in a brick-layer pattern (carvel). For the impact test, the laminated beams were tested according to ASTM D6110-10, and for the bending test, ASTM D143 standards were followed. The beams were conditioned to ensure their moisture content was below 18%, in accordance with BKI guidelines. The impact test measured the absorbed energy and impact resistance of each laminate variation, while the bending test determined the bending strength. Results showed that as the number of layers increased, both the impact energy absorption and bending strength improved. The strength classifications obtained for both materials (coconut palm and thorny bamboo) fell within Strength Class IV-V according to the Indonesian Classification Board (BKI), which indicated that these materials were unsuitable as replacements for solid wood in ship keels due to their insufficient strength.

3. RESULTS AND DISCUSSION

3.1 Results

Base material of the test specimen

The basic materials for the manufacture of laminated beam specimens are coconut stems and thorny bamboo that are glued using X4 crossbond glue. The difference in test specimens is found in the variations of the layers used, namely variations 3, 5, and 7. There were about 42 total specimens, which were divided into impact testing totaling 21 specimens, and bending testing totaling 21 specimens. The manufacture of laminated beams starts from cutting coconut stems and thorny bamboo in the form of small blades which are then connected using X4 crossbond adhesive and continued with the pressing process until dry. The beginning of specimen making is carried out by drying coconut stems and thorny bamboo naturally using sunlight and after drying the moisture content is calculated using a moisture meter. The moisture content contained in dried coconut stems was 9.2%, and the moisture content in dried thorn bamboo was 12.8%. The results of the moisture meter for the moisture content of coconut stems and thorny bamboo can be seen in **Figure 1**.

Coconut stem water Thorn bamboo water

Figure 1. Moisture content of coconut stems and thorny bamboo

This moisture content itself is used as a reference for the drying time, and also the moisture content greatly affects the adhesion time of the laminate beam layer, this happens because the high moisture content will inhibit the bonding of the adhesive process between layers. Good adhesive bonding occurs at a low level of moisture content and the difference in moisture content between layers should not exceed the predetermined standard, this is to avoid shrinkage that causes damage to the laminate beam joints. The process of gluing and arranging the fibers is carried out by following the direction of the length of the wood. The shape of the layer arrangement on the laminate beam of this study is a carvel shape joint where the purpose is to see what kind of fracture effect will occur when testing and what kind of fracture cause will occur, the adhesion effect or the fracture effect of the material caused by the fracture. The direction of lamination will greatly affect the strength and characteristics produced by an object.

Impact testing

The impact test had 21 specimens with 3 layer variation models, and each variation model totaled 7 specimens. The three specimens have different layer thicknesses, with the total overall thickness plus the adhesive (crossbond X4) specimen being 12.7 mm. Specimens with 3-layer variations have a thickness of 4.2 mm per layer, for specimens with 5-layer variations each thickness is 2.5 mm per layer, and specimens with 7-layer variations have a thickness of 1.8 mm per layer. The effect of the difference in impact test values can be caused by the number of layers of each laminated beam specimen. Based on the table of impact test results that have existed above, a graph of impact testing data can be seen in **Figure 2** and **Figure 3**.

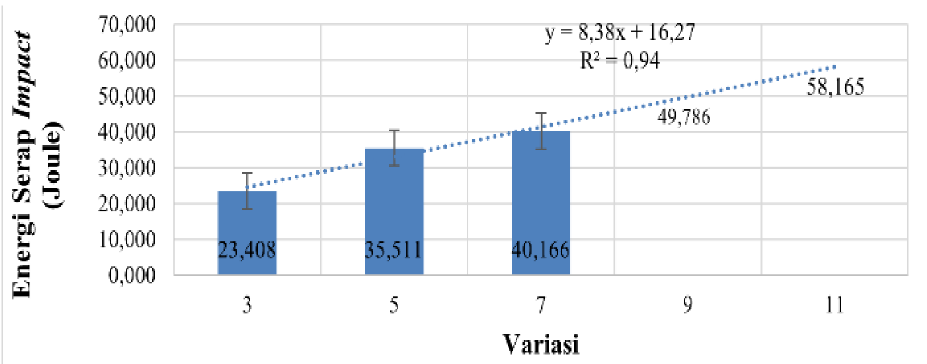

Figure 2. Impact absorption energy graph

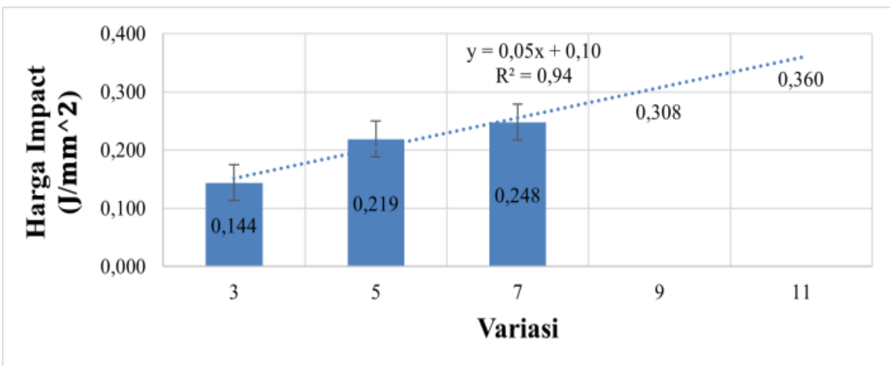

Figure 3. Impact price chart

Based on **Figure 3**, and **Figure 4**, the data obtained from the results of the above calculation on impact testing with the charpy method with a specimen size of 12.70 mm × 12.70 mm 124.5 mm and the process of making a notch on the specimen which functions to facilitate the fracture process that occurs, the shape of the notch made is with a depth of 2 mm. the initial angle of impact () used is, and the final angle of impact () on the specimen obtained different values. ×α160°β The test model has 3 different specimen variations, specimen variations cause differences in impact test values between each specimen variation. In impact testing, the results presented are only the overall average value of each specimen variation. Thus, the energy value absorbed by the variation of the 3-layer specimen is 23.408 J, and the impact price value of the 5-layer variation specimen has an absorbed energy value of 35.511 J, and the impact price value 0,144 J⁄mm^2 . of the 7-layer specimen variation model is 40.166 J, and the impact price value 0,219 J⁄mm^2. is .0,248 J⁄mm^2

According to the impact absorption energy graph and the impact price, judging from the graph trendline, the two values of the impact test can increase even more if layer variations are added to the specimen. This is because the more layers of the specimen, the higher the strength value of the specimen.

Bending testing

The specimens in the bending test totaled 21 specimens with 3 layer variation models, and each variation model amounted to 7 specimens. The three specimen models have different layer thicknesses, and with the total overall thickness plus the adhesive (crossbond X4) the specimen is 25 mm. The 3-layer variation specimen has a thickness of 8.3 mm per each layer, for the 5-layer variation specimen the thickness is 5 mm per each layer, and the specimen with a 7-layer variation thickness of 3.5 mm per each layer., then the bending test graph can be seen in **Figure 4**.

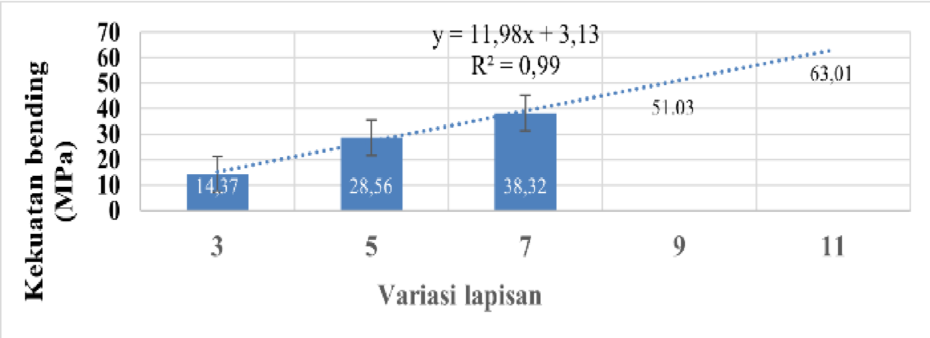

Figure 4. Bending test chart

Based on the results of the calculation of bending test data, a graph is obtained as shown in **Figure 4**. Bending specimens follow the standard size of ASTM D143 with the second method, which is 25mm × 25mm 410 mm, the choice of this × second method is to make it easier when making specimens and make it easier when testing specimens. Based on the average value of bending strength obtained from the test, the average value of bending strength in the 3-layer variation is 14.37 MPa. The 5-layer variation has a bending strength value of 28.56 MPa, while the 7-layer variation has a bending strength value of 38.32 MPa. This shows that the variation of the layer on the laminated beam affects the strength value obtained, the higher or more layers are made, the higher the strength value will be obtained. According to the graph above, it can be explained according to BKI regulations that variations of 3, 5, and 7 layers are included in the strong class IV-V and this does not meet the standards to be an alternative to ship keels, the minimum standard for wooden ships is strong class III. Judging from the trend line of the graph in order to meet the minimum standard of strong class according to BKI, then by adding a layer variation higher than 7 layers will increase the bending strength of coconut stem and thorn bamboo laminated beams, at least 9 or 11 layers are needed to reach the minimum standard of strong class III with a prediction of the bending strength value of 9 and 10 layers variation of 51.03 MPa and 63.01 MPa. The test report data obtained an average value of force (force) variation of 3 layers of 23.1 kgf. The force graph is as shown in **Figure 5**.

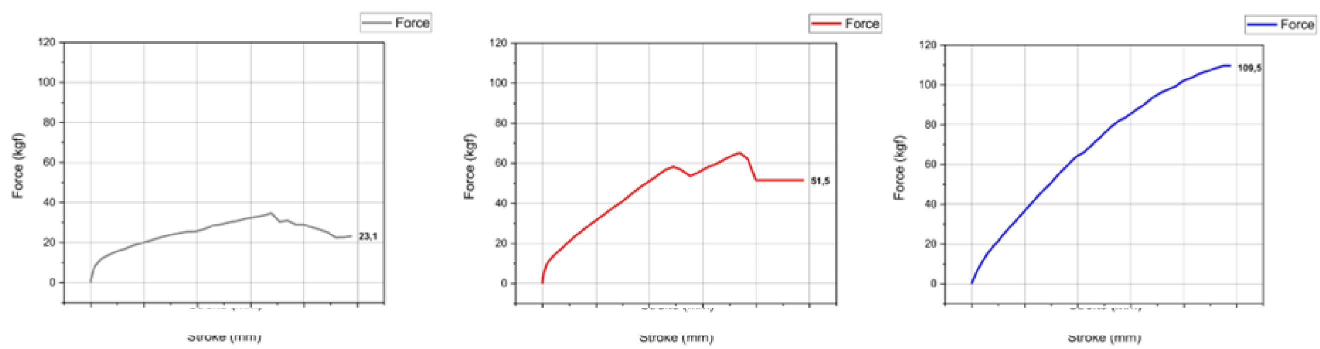

Figure 5. Force of graph

The test results for the 5-layer variation showed an average force value of 51.1 kgf, as depicted in **Figure 3**. For the 7-layer variation, the average force value was 109 kgf. The average force values across the three variations varied, reflecting the material processing, where increasing the number of layers strengthened the specimens. A summary of the average force values for all variations is presented in **Figure 6**.

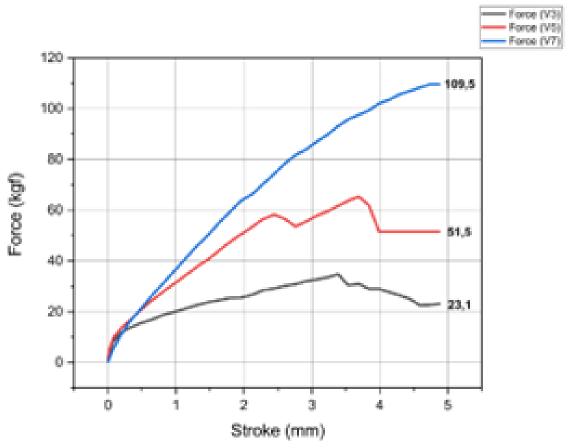

Figure 6. Summary of the average force values for all variations

3.2 Discussion

Based on tests that have been carried out on coconut stem and thorny bamboo laminated beams with variations of layers 3, 5, and 7, the results of this test can be compared based on the regulations of the Indonesian Classification Bureau (2023). According to BKI regulations, materials are only determined based on the results of (Setiawan et al., 2017) *the bending* test, so the results of *the impact* test only provide information about the strength of the material to *the impact* energy. According to Indonesian Classification Bureau (2023), in general, the wood that is often used for keel components of wooden ships is such as bedaru wood, laban wood and ironwood which are classified as strong classes I - II, while the test results of coconut laminated blocks and thorny bamboo on the three layer variations that have been carried out by the author have lower values compared to the strong wood class standard at the Indonesian Classification Bureau. This difference in results occurs because the absolute bending strength value does not reach the minimum of the permissible provisions. The results of this study show that laminated blocks of coconut stems and thorny bamboo belong to different classes of strength. The 3-layer variation laminated beam is classified as strong class V with a bending strength test result of 14.37 MPa and an absorbed energy result of 23.408 J and *an impact* price of 0.144. Laminated beams with 5 layers variations are classified as strong class V with bending strength test results of 28.56 MPa and absorbed energy results of 35.511 J and impact price J/mm^2 of 0.219. The 7-layer variation laminated beam is classified as strong class IV with a bending strength test result of 38.32 MPa and an absorbed energy result of 40.166 J and an J/mm^2 *impact* price of 0.248. J/mm^2

The moisture content obtained from coconut stems is around 9.2% and thorny bamboo is 12.8%, where the maximum moisture content according to the standard is 14% - 18% for the keel component of wooden boats. This moisture content itself serves as a reference for the duration of drying the material, which is in accordance with the standards that refer to the BKI itself. The high and low moisture content in the wood will affect the adhesion rate and adhesion time, in the process too much moisture content in the wood will inhibit the bond between the adhesive and the material layer. The high moisture content will make the adhesive effect according to and cause the bond to weaken. The average overall *elongation* and *stress* scores obtained varied. The 7-layer variation had the highest *elongation* of 10.29% and *a stress* of 0.18kgf/mm^2, while the 5-layer variation had the lowest *elongation* of 2.72% and *a stress* of 0.13kgf/mm^2. On the other hand, *the elongation* value of the 3-layer variation is between the two variations of 3.11% and the *stress* value is 0.07kgf/mm^2. The difference in values occurs due to the imperfect adhesion and embedding process of the specimen, causing the *elongation value* to decrease and be far proportional to the values in other variations. Based on the results of *impact* and *bending* tests for coconut stem laminated beams and thorny bamboo, they are not suitable for use in wooden ship components, so they cannot replace wooden ship keel components. This is because the values obtained from the two tests do not meet the standards that refer to the regulations of the Indonesian Classification Bureau Vol. VI of 2023 which states that important construction parts must use the minimum quality wood of strong class III.

4. CONCLUSION

Based on the analysis of impact and bending tests on coconut stem and thorn bamboo laminated beam specimens with 3, 5, and 7 layer variations, it was found that the number of layers directly affected the strength of the beams. Thicker beams with more layers exhibited higher strength values, while beams with fewer layers showed lower strength. The impact test results revealed that the 3-layer variation absorbed 23.408 J of energy, the 5-layer variation absorbed 35.511 J with an impact price of 0.144 J/mm², and the 7-layer variation absorbed 40.166 J with an impact price of 0.219 J/mm². The bending test results showed that the 3-layer variation had a bending strength of 14.37 MPa, the 5-layer variation had 28.56 MPa, and the 7-layer variation had 38.32 MPa. However, the strength values of these laminated beams did not meet the standards for ship keel components, as per the Indonesian Classification Board (BKI), which requires materials with at least a Strong Class III rating. The coconut stem and thorn bamboo laminated beams were classified as Strong Classes IV and V, indicating that they are not suitable substitutes for solid wood in ship keels due to insufficient strength.

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