International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-3, January 2020

The Analysis of Size and Arrangement Effects of Petung Bamboo Split Fiber to the Matrix Interface Bond with Laminated Bamboo Split Fiber as Construction Materials for Wooden Vessels

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Abstract: Bamboo is an extraordinary natural material. Bamboo can grow quickly, is cheap and widely available. The material property is light but harder and stronger than wood or glass fiber composites. The purpose of this study was to determine the effect ofarrangement and size of petung bamboo split fiber to the matrix interface bond of laminated bamboo split fiber. The benefits of this study can contribute knowledge and innovation to the development of science in the field of vessel material technology in education field, especially in the field of shipping. This research was carried out by compressive test, tensile test, and shear test to the matrix interface bond of laminated bamboo and petung bamboosplit fiber with the tangential and radial test directions (x, y, and z axis) using the ASTM D143 standard.After testing, it can be concluded that the tensile strength and compressive strength of the brick arrangement is better, while for the shear strength, it is better in the parallel arrangement, furthermore the thicker the bamboo split size, the greater the stress value. The average results obtained for tensile test is 44 kg/cm^2, the shear test is 38,5 kg/cm^2, and the compressive test is 341,05 kg/cm^2. The average compressive strength of these results can be classified into Strong Class III on BKI (Indonesian Classification Bureau) of Wooden Ships. The direction of the best tensile strength test is on the Y axis, the direction of the best shear strength test is on the Z axis, and the direction of the best compressive strength is on the X axis. The higher the glue Interface value for each cm^2, the greater the interface bond strength due to the need of glue in mm/cm^2 is higher, on the contrary the lower the glue Interface value in each cm^2, the lower the interface bond strength due to the need of glue in mm/cm^2 is lower.

Keywords: Composite, Laminated Bamboo, Arrangement And Size Of Fiber, Tensile Test, Compressive Test, Shear Test, Shipping

I. INTRODUCTION

Laminated bamboo products are expected to be able to provide the latest solutions as a substitute for materials, especially wooden vessels. The use of this composite bamboo beam product is as an alternative to increasingly expensive and rare of wooden beams.

Revised Manuscript Received on January 30, 2020.

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In Indonesia, there are still rare vessels made of bamboo even though the results of laminated bamboo are strong and can be categorized into Class II-III in Wooden Vessel. The combination of laminated bamboo and meranti wood can be used as construction materials on wooden vessels [1]. Also, a combination of same bamboo species, apus and petung bamboo, can be used as a component for wooden vessels [2]. The thicker the bamboo split thickness, the greater the laminated bamboo strength value [3]. In general, the tests carried out only focus on the strength of the bamboo material, but in this study, the strength of the matrix interface bond with laminated bamboo split fiber was examined. Therefore, the tests were done in three different axes (x, y, and z axes) using different sizes and arrangement of different splits. The purpose of this study was to determine the effect of the arrangement and size of petung bamboo split fiber to the matrix interface bond of laminated bamboo split fiber [4]. In addition, it was also to find out the difference in strength comparison for each variation of laminated bamboo as a construction material of wooden vessels [5] [6].

II. MATERIALS AND METHODS

2.1.Petung Bamboo

This bamboo has a rather dense clump that can grow to a height of 20-30 meters, thick stems with a thickness of 20-30 mm, diameter 8-20 cm and the bamboo color is brown. This bamboo isusually used as building materials, such as for vessels [7] [8].The mechanical properties of petung bamboo can be seen in table 1:

Table 1. Mechanical properties of petung bamboo

No	Mechanical Properties	(MPa)
1	Flexural strength	134,972
2	Tensile strength parallel to the fibers	228
3	Compressive strength parallel to the fibers	49,206
4	Compressive strength perpendicular to the fibers	24,185
5	Shear strength parallel to the fibers	9,505
6	Modulus of elasticity and flexibility	12888,477

In this study, we will compare the strength of petung bamboo before lamination and after lamination towards the interface.

2.2. *PVAc* Glue

This glue is made from water based polyvinyl acetate (*PVAc* modifier) which has been modified with inner cross linker material at the same time in one adhesive material component which has water resistance properties, solvent resistance and heat resistance for the laminated bamboo [9].The composition of *PVAc*glue can be seen in table 2:

Table 2. Composition of PVAc glue

No	Material	Percentage
1	Polyvinyl Acetate 55% solid	29,1 %
2	Polyvinyl Alcohol	3,6%
3	Dextrin	10,9%
4	Resole 65%	25,5%
5	Water	30,9%

Polyvinyl Acetate (PVAc), is a polymeric compound that is elastic, this substance is flexible and not acidic. This is useful for making a flexible layer when white glue dries. Polyvinyl Alcohol (PVA) is useful as a solution stabilizer. Dextrin is useful for making film layers when the glue dries. Resole (Phenol Formaldehyde Resin) is useful as a resin that adds glue adhesion. Water is useful for diluting the solution. [9]

2.3. Research Location

The test in this study refers to ASTM D143 [10]. Laminated bamboo usedpetung bamboo materials from Klaten and Salatiga Regency. The glue used wasPVAc.

The making of specimens was carried out at the Material Laboratory of Marine Engineering Bachelor, Diponegoro University. The location of the testing was carried out at the Diploma 3/ Vocational Mechanical Engineering laboratory, Engineering Faculty, Gadjah Mada University, Yogyakarta.

2.4. Research Methodology

In this study, a compressive test, tensile test, and shear test will be carried out towards the matrix interface of laminated split fiber of petung bamboo. Each size and arrangement of bamboo split used has 7 different specimen variants on each laminated bamboo beam based on the technical testing to determine the strength of the interface bond on the bamboo split fiber.

In 1 homogeneous beam with a length of 2 meters at least produces 21 specimens to be tested with the same arrangement and thickness so that a total of 10 beams are needed. Variations used are the arrangement of parallel and brick bamboo split fibers with thickness of blades 2mm, 4mm, 6mm, 8mm and 10mm.So, that the total specimens in this study are 210 specimens.

2.5. Tools and Materials

Materials Required

1. 5 PVAc/ 4kg Glue Buckets
2. 70 Cuts of PetungBamboos / 4 meters

Supporting Tools

1. Gloves
2. Masks
3. Measuring cup
4. Brush
5. Vernier Caliper
6. Press Tool
7. Cut machine

2.6. Making Steps

Some basic steps in petung bamboo lamination are as follows:

1. Firstly, do brushing on the surface of the petung bamboos so the glue is firmly attached. After that, cleanse all surfaces that will be done coating.
2. Ensure that the surfaces are clean of any contaminations.
3. Prepare PVAc glue.
4. Then,use a brush to do the coating. Things that need to be considered when doing coating is that the bamboos must be clean so that glue can attach perfectly.
5. In the first layer, use PVAc glue for all parts of the petung bamboo surfaces evenly. Previously, cut the petung bamboo splits in length and width according to the needs of the lamination.
6. Align the 2 meter cut bamboo splits and then form into homogeneous beams according to the size and arrangement of laminated bamboo split fibers.
7. After laminating with the bamboo beams, in the top layers coat them again with PVAc glue, then leave them to dry.
8. After that, laminate petung bamboos until they harden.

2.7 Research Parameters

This research is an experimental research. The experiment was carried out by making laminated beams with petung bamboo material, then testing the tensile, shear, and compressive strengthtowards the matrix interface bond with laminated bamboo split fibers which then the test results will be compared with the strengths of previous studies based on BKI regulations.

2.7.1 Fixed Parameters

a. Tensile strength perpendicular to the fiber with the direction of the y and z axis.
b. Shear strength with the direction of the y and z axis.
c. Compressive strength with the direction of the x, y, and z axis.

2.7.2 Variable Parameters

a. Arrangement of brick and parallel splits
b. Thickness of petung bamboo splits

2.8 Composite Interface Characteristics

The strength of the interface between the matrix and the amplifier in a composite is very important for the force transfer media between the matrix and the amplifier. The rule of mixture of a composite will be fulfilled if the composite interface strength is good so that the desired properties of the composite can be fulfilled [11]. The press strength of laminated bamboo can be assumed about 2 MPa.

2.9 Equations and Calculations

Stress is defined as the force required by an object to return to its original form. It also can be defined as the force (F) given to an object divided by the cross-sectional area A where the force works. Stress is formulated by:

$$\sigma = \frac{F}{A}\ (Kg/cm^2) \qquad (1)$$

Stress (σ) is a length scale.

The force acting on load (F) has a unit (Kg), and the cross-sectional area (A) has units (cm^2). Length changes in the size or shape of an object because the use of stress is called strain (strain). MOR (Modulus of Rupture)is the flexural strength of the ultimate load that has a unit (Kg/cm^2). The definition of flexural strength based on the formula is three times of the maximum bending load (P) multiplied by the buffer distance (L) divided by 2 times of the specimen width (b) squared of the specimen thickness (h) [12]. It can be written mathematically:

$$\text{MOR} = \frac{3\text{PL}}{2bh^2}\ (Kg/cm^2) \qquad (2)$$

Modulus of Elasticity (MOE) has a unit (Kg/cm^2). An object can be calculated by giving a load as the stress applied to the object and divided by the magnitude of the strain [12] [13]. Modulus of elasticity is determined through mathematical equations as follows:

$$MOE = \frac{\sigma}{\text{e}}\ (Kg/cm^2) \qquad (3)$$

The volume fraction of the amplifier can affect the strength of a composite [14]. The calculation uses the formula:

$$Vf = \frac{vf}{vc} \times 100\% \qquad (4)$$

Which*vf*is the volume of fiber and *vc* is the total volume of the composite.

III. RESULTS AND DISCUSSIONS

3.1 Tensile Strength

The test results obtained a perpendicular strength value of laminated bamboo fiber with a radial direction (z axis) and tangential direction (y axis) each of them has an average value of 37,36 Kg/cm^2 and 50,64 Kg/cm^2. The average modulus of elasticity for radial and tangential directions respectively is 145,8 Kg/cm^2 and 180,07 Kg/cm^2.Chart ofperpendicular tensile strength relationship to the tangential direction (y axis) can be seen from figure 1:

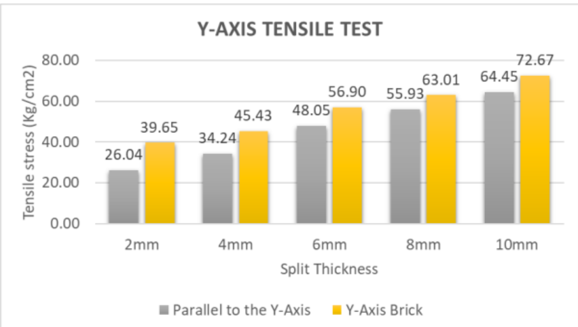

Figure 1. Diagram of the strength value average of the y-axis tensile test on a laminated petungbamboo towards the interfaces

Figure 1 shows an increase in the results of the y-axis tensile test. In parallel specimens of the y-axis increased 247,50%, and y-brick specimens increased 183,28%.Chart of perpendicular tensile strength relationship to the radial direction (z axis) can be seen from figure 2:

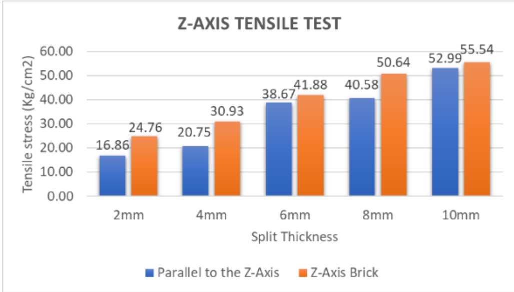

Figure 2. Diagram of the strength value average of the z-axis tensile test on laminated petung bamboo towards the interfaces

Figure 2 shows an increase in the results of the z-axis tensile test. In parallel specimens of z-axis increased 214,29%, and z-brick specimens increased 224,31%.Chart of the MOE relationship of perpendicular tensile test to the tangential direction (y axis) can be seen fromfigure 3:

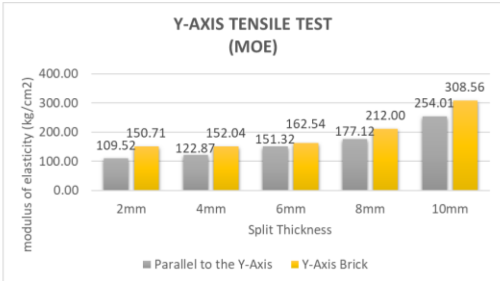

Figure 3. Diagram of the elastic modulus value average of the y-axis tensile test on laminated petung bamboo towards the interfaces

Figure 3 shows an increase in the results of MOE in the y-axes tensile test. In parallel specimens of y-axis increased 231,94%, and y-brick specimens increased 204,74%.Chart of the MOE relationship of perpendicular tensile test to the radial direction (z axis) can be seen from figure 4:

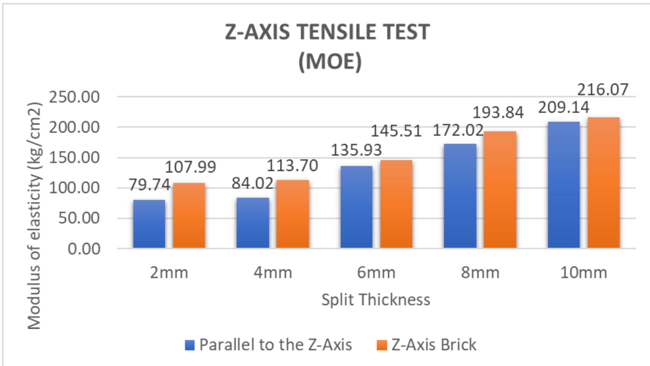

Figure 4. Diagram of the elastic modulus value average of the z-axis tensile test on laminated petung bamboo towards the interfaces

Figure 4 shows an increase in the results of MOE in the z-axis tensile test.

In parallel specimens of z-axis increased 262,28%, and z-brick specimens increased 200,09%.

3.2. Shear Strength

The test results obtained the shear strength of laminated bamboo with tangential direction (y axis) and radial direction (z axis) each of them has an average value of 36,37 Kg/cm^2 and 40,77 Kg/cm^2.Chart of shear strength relationship of the tangential direction (y axis) can be seen from figure 5:

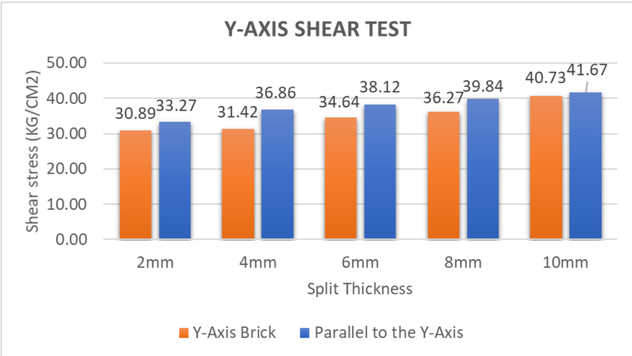

Figure 5. Diagram of the strength value average of the y-axis shear test on laminated petung bamboo towards the interfaces

Figure 5 shows an increase in the results of the y-axis shear test. In parallel specimens of y-axis increased 125,25%, and y-brick specimens increased 131,85%.Chart of shear strength relationship of the radial direction (z axis) can be seen from figure 6:

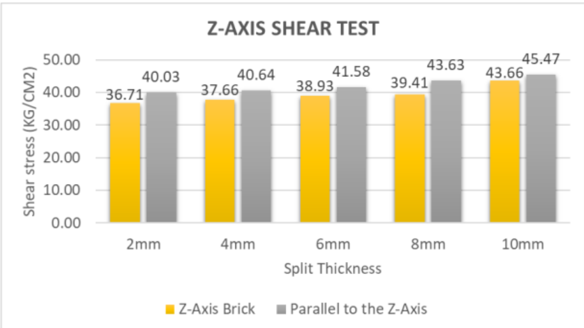

Figure 6. Diagram of the strength value average of the z-axis shear test on laminated petung bamboo towards the interfaces

Figure 6 shows an increase in the results of the z-axis shear test. In the parallel specimens of z-axis increased 113,59%, and z-brick specimens increased 118,93%.

3.3 Compressive Strength

The test results obtained the compressive strength of laminated bamboo with fiber direction (x axis), radial direction (z axis), and tangential direction (y axis) each of them has an average value of 468,75 Kg/cm^2, 269,46 Kg/cm^2 and 284,93 Kg/cm^2. The average elasticity modulus for fiber direction, radial direction and tangential direction respectively is4833,59 Kg/cm^2 2406,71 Kg/cm^2 and 2648,44 Kg/cm^2.

Chart of compressive strength relationship of the fiber direction (x axis) can be seen from figure 7:

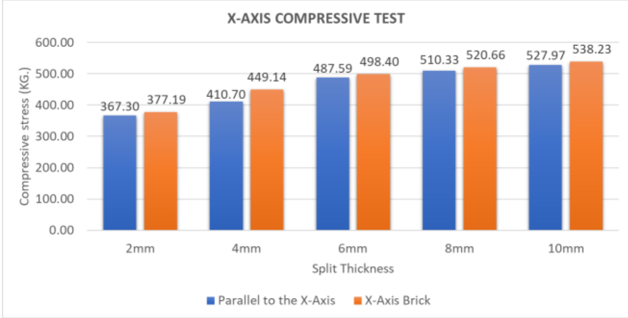

Figure 7. Diagram of the strength value average of the x-axis compressive test onlaminated petung bamboo towards the interfaces

Figure 7 shows an increase in the results of the x-axis compressive test. In the parallel specimens of the x-axis increased 143,74%, and x-brick increased 142,69%.Chart of the compressive strength relationship of the tangential direction (y axis) can be seen from figure 8:

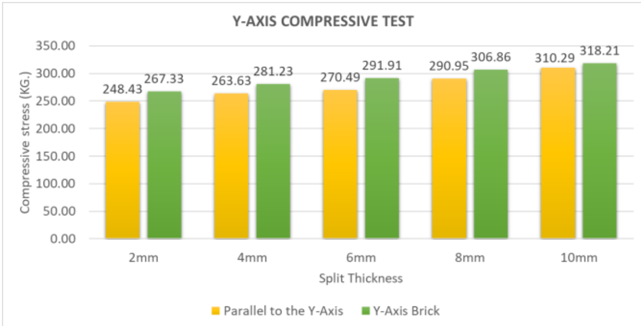

Figure 8. Diagram of the strength value average of the y-axis compressive test on laminated petung bamboo towards the interfaces

Figure 8 shows an increase in the results of the y-axis compressive test. In the parallel specimens of the y-axis increased 124,90%, and y-brick specimens increased 119,03%.Chartof compressive strength relationship of the radial direction (z axis) can be seen from figure 9:

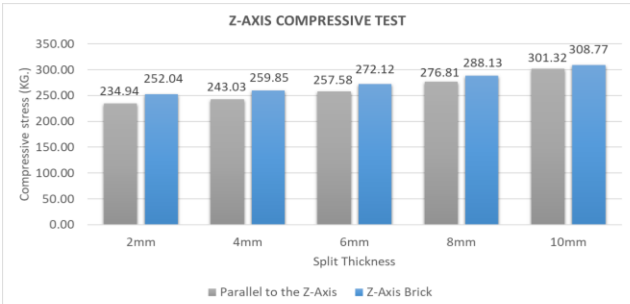

Figure 9. Diagram of the strength value average of the z-axis compressive test onlaminated petung bamboo towards the interfaces

Figure 9 shows an increase in the results of the z-axis compressive test. In parallel specimens of the z-axis increased 131,43 and the z-brick specimens increased 119,54%.Chart of MOE relationship of fiber direction compressive test (x axis) can be seen from figure 10:

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-3, January 2020

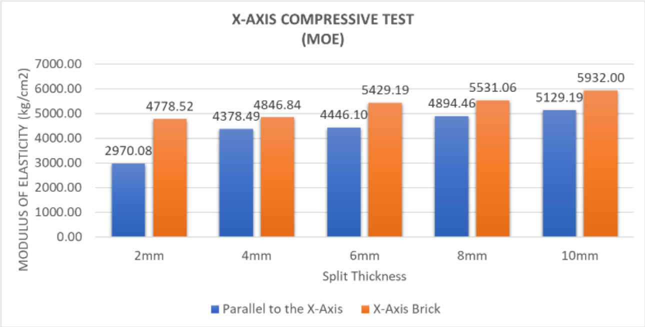

Figure 10. Diagram of the elastic modulus value average of the x-axis compressive test on laminated petung bamboo towards the interfaces

Figure 10 shows an increase in the results of MOE in the x-axis compressive test. In the parallel specimens of the x-axis increased 172,70%, and x-brick specimens increased 124,14%.Chart of MOE relationship of tangential direction compressive test (y axis) can be seen from figure 11:

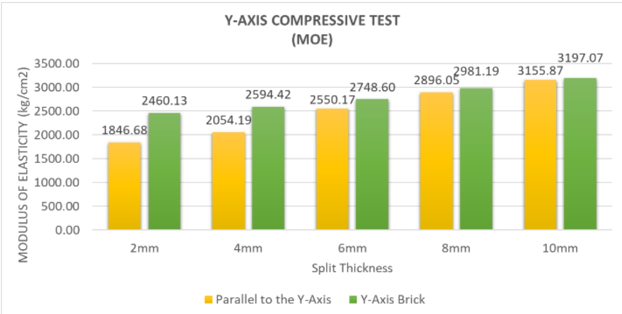

Figure 11. Diagram of the elastic modulus value average of the y-axis compressive test on laminated petung bamboo towards the interfaces

Figure 11 shows an increase in the results of MOE in the y-axis compressive test. In parallel specimens of the y-axis increased 170,89%, and y-brick specimens increased 129,96%.Chart of the MOE relationship of radial direction compressive test (z axis) can be seen from figure 12:

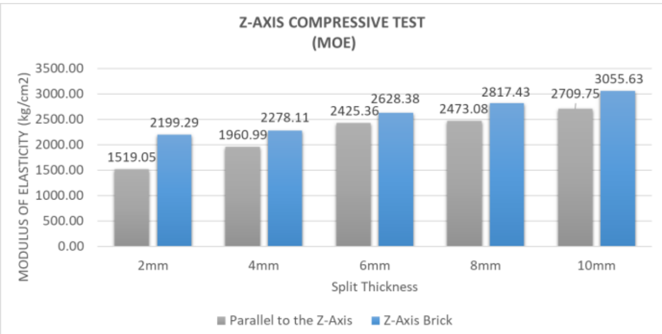

Figure 12. Diagram of the elastic modulus value average of the z-axis compressive test on laminated petungbamboo towards the interfaces

Figure 12 shows an increase in the results of MOE in the z-axis compressive test. In parallel specimens of the z-axis increased 178,38%, and z-brick specimens increased 138,94%.Chart of the MOR relationship of fiber compressive test (z axis) can be seen from figure 13:

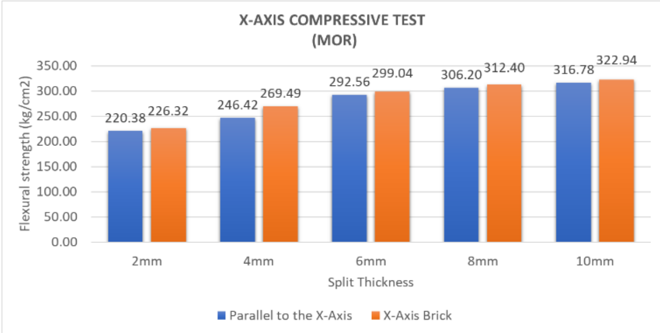

Figure 13. Diagram of flexural strength value average of the x-axis compressive test on laminated petung bamboo towards the interfaces

Figure 13 shows an increase in the results of the MOR in the compressive test. In the parallel specimens of the x-axis increased 143,74%, and x-brick increased 142,69%.Chart of the MOR relationship of tangential direction compressive test (y axis) can be seen from figure 14:

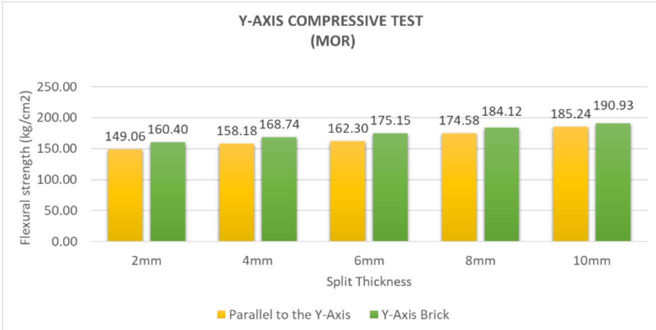

Figure 14. Diagram of the flexural strength value average of the y-axis compressive test on laminated petung bamboo towards the interfaces

Figure 14 shows an increase in the results of the MOR in the y-axis compressive test. In the parallel specimens of the y-axis increased 124,27%, and y-brick increased 119,03%.Chart of the MOR relationship of radial direction compressive test (z axis) can be seen from figure 15:

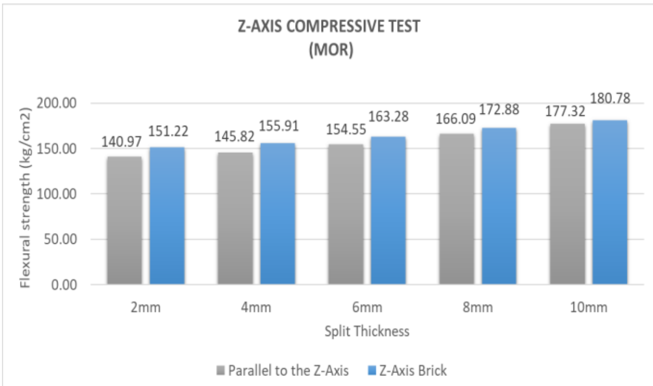

Figure 15. Diagram of flexural strength value average of z-axis compressive test on laminated petung bamboo towards the interfaces

Figure 15 shows an increase in the results of the MOR in the z-axis compressive test. In the parallel specimens of the z-axis increased 125,79%, and z-brick increased 119,55%.

3.4 Average Value of Test Results

The average values of all tests on the effect of the size and arrangement of petungbamboo split fibers towards the matrix interfaces with laminated bamboo split fibers are presented in Table 4-8.The average value for the perpendicular tensile test can be seen in table 4:

Table 4. Average Value of Tensile Strength

No	Test Type	Kg/cm^2	MPa
1.	Tensile Test of Y-Axis	50,64	4,97
2.	Tensile Test of Z-Axis	37,36	3,66

The average value for the tensile test strength of the Y-axis is greater than the Z-axis with a difference of 13,3 Kg/cm^{2}or equal to 1,3 MPa.The average value for the shear test can be seen in table 5:

Table 5. Average Value of Shear Strength

No	Test Type	Kg/cm^2	MPa
1.	Shear Test of Y-Axis	36,37	3,57
2.	Shear Test of Z-Axis	40,77	4,00

The average value for the shear test strength of the Z-axis is greater than the Y-axis with a difference of 4,4 Kg/cm^{2}or equal to 0,4 MPa.The average value for the compressive test can be seen in table 6:

Table 6. Average Value of Compressive Strength

No	Test Type	Kg/cm^2	MPa
1.	Compressive Test of X-Axis	468,75	45,97
2.	Compressive Test of Y-Axis	284,93	27,94
3.	Compressive Test of Z-Axis	269,46	26,43

The average value for the highest compressive test strength is on the X-axis, which is 468,75 Kg/cm^{2}or 45,97 MPa and for the lowest compressive test strength on the Z-axis is 269,46 Kg/cm^{2}or 26,43 MPa.The average value for the MOE of laminated bamboo testing can be seen in table 7:

Table 7. Average Value of the MOE

No	Test Type	Kg/cm^2	MPa
1.	Tensile MOE of Y-Axis	180,07	17,66
2.	Tensile MOE of Z-Axis	145,80	14,30
3.	Compressive MOE of X-Axis	4833,59	474,02
4.	Compressive MOE of Y-Axis	2648,44	259,73
5.	Compressive MOE of Z-Axis	2406,71	236,02

The highest average value for the MOE of laminated bamboo testing is in the X-axis compressive test, which is 4833,59 Kg/cm^{2}or 474,02 MPa and for the lowest MOE of laminated bamboo testing on the Z-axis tensile test which is 145.80 Kg/cm^2 or 14,30 MPa.The average value for the MOR of laminated bamboo testing can be seen in table 8:

Table 8. Average Value of the MOR

No	Test Type	Kg/cm^2	MPa
1.	Compressive MOE of X-Axis	281,25	27,58
2.	Compressive MOE of Y-Axis	160,88	15,77
3.	Compressive MOE of Z-Axis	170,87	16,75

The highest average value for the MOR of laminated bamboo testing is in the X-axis compressive test which is 281,55 Kg/cm^2 or 27,58 MPa and for the lowest MOR of laminated bamboo testing on the Y-axis compressive test is 160,88 Kg/cm^2 or 15,77 MPa.

3.5 Volume Fractions

The use of glue on laminated bamboo also affects the result of the strength. The density of glue on each thickness variation of the splits also varies.The thinner the split is used, the more PVAc glueis needed, whereas the thicker the split is used, the less PVAc glue is needed.The volume fraction of laminated bamboo can be seen in table 9:

Table 9. Volume Fraction of Laminated Bamboo

No	Specimen	Inf. (all) (cm^2)	Inf. (tested) (cm^2)	Vf (cm^3)	Vc (cm^3)	Glue (cm^3)	Fl (%)	Fr (%)	Inf. (Glue) (ml/cm^2)
1	2mm (S)	600	2,0	70	125	55	44,0	56,0	0,183
2	4mm (S)	400	2,1	77	125	48	38,4	61,6	0,252
3	6mm (S)	200	2,2	84	125	41	32,8	67,2	0,451
4	8mm (S)	150	2,3	91	125	34	27,2	72,8	0,521
5	10mm (S)	120	2,4	98	125	27	21,6	78,4	0,540
6	2mm (B)	590	2,7	72	125	53	42,4	57,6	0,242
7	4mm (B)	393	2,8	79	125	46	36,8	63,2	0,327
8	6mm (B)	196	2,9	86	125	39	31,2	68,8	0,577
9	8mm (B)	147	3,0	93	125	32	25,6	74,4	0,653
10	10mm (B)	118	3,1	100	125	25	20,0	80,0	0,657

Explanation:
(S) : Parallel Arrangement
(B) : Brick Arrangement
Inf : Interface
Vf : Volume of Fiber
Vc : Total Volume of Composite
Glue : PVAc
Fl : Glue Volume Fraction on Laminated Bamboo
Fr : Fiber Volume Fraction on Laminated Bamboo

Each cube specimen has a size of 5cm x 5cm x 5cm,therefore the volume is 125cm^3.

3.6 Discussion

The value of perpendicular tensile strength of laminated bamboo can be seen from figures 1 to 4, then the brick arrangement is better than parallel arrangement.

The testing direction of the Y-axis is better than the Z-axis because the interface on the Y-axis has many bamboo splits that are attracted by the test machine, while on the Z-axis there is only one split attracted to the test machine.

The value of laminated bamboo shear strength can be seen from figures 5 and 6, then the parallel arrangement is better than the brick arrangement. For the testing direction, the Z-axis is better than the Y-axis because the shape of the rectangular front splits so that when tested radially (z axis) there are many splits affected by force while on the Y-axis fewer splits are affected by force.

The value of laminated bamboo compressive strength can be seen from figures 7 to 15, then the brick arrangement is better than the parallel arrangement. The testing direction of the X-axis is the best compared to the Y and Z axes because on the X-axis the splits affectedby the force are in the direction of the laminated bamboo fiber.After testing, it can be seen that the data obtained is in line with the theory or previous research.

The mechanical properties of petung bamboo for perpendicular compressive strength of the fiber are 24,185 MPa. In this study the perpendicular compressive strength of the fiber is better, which is 26,43 MPa [7].The thicker the size of the bamboo splits used, the higher the value of the stress, modulus of elasticity, flexural strength, and volume fraction of laminated bamboo.Judging from the results of testing and analysis, laminated bamboo beams can be used as alternative substitutes for teak and mahogany wood, although not as strong as teak or mahogany wood [15].

3.7. Impact of Variation Changes

Judging from Table 9, the differences in the arrangement and size of laminated bamboo split fibers affect the strength of the matrix interface bond with laminated bamboo split fibers. Splits with thick sizes will be stronger, while thin splits are less strong.

The split arrangement in each testing also affects the results. In tensile test and compressive test, it is better for brick arrangement, while in shear test it is better for parallel arrangement.

In addition, variations in the testing direction (x, y, and z axes) also give different results depending on each test. In the tensile test, it is best tested tangentially (y axis), the shear test is best tested radially (z axis), and in the compressive test it is best tested in the direction of fiber (x axis).

IV. CONCLUSION

The glue interface in each cm^2affects the interface bond strength of laminated bamboo because the thicker the split, the higher the glue needs in mm/cm^2 and the greater the bond interface strength. This is because the homogeneity level increases and petung bamboo strength is stronger than the PVAc glue used. In addition, the thinner split requires more glue than a thick split, but with the same volume / weight in each specimen, the bamboo with the thickest split has the highest glue interface value so that the strength is the greatest.

The average of compressive test in this study was 341,05 kg / cm^2 and was entered into Strong Class III in BKI Wooden Vessels so that it was able to be used on ivory, leather, decks, masts, deck boards, spears, and construction above the draft on the vessel.

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