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Analysis of Column Compressive and Adhesive Strengths of Laminated Wood From Pine Pallet Wood Waste and Mahogany as Reinforcement

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ABSTRACT

In Indonesia, the increasing demand for wood as an industrial material and the decline in its production rate, which is usually due to illegal logging, causes the emergence of less efficient wood waste. And one of the methods for efficiently utilizing these waste is through lamination. Accordingly, lamination is a technique that involves the gluing of two or more pieces of wood together. Therefore, the purpose of this study was to determine the value of the adhesive and compressive strength of laminated columns between pine pallet waste and mahogany wood reinforcement. The adhesive strength of 20, 30, 40, and 50 MDGL variations joined together using PVAc glue, as well as the compressive strength with variations of T0 (Pine-Pine-Pine-Pine-Pine), T1 (Mahogany-Pine-Mahogany), T2 (Mahogany-Pine-Mahogany-Pine), and T3 (Mahogany-Pine-Mahogany-Pine-Mahogany) were tested in this study. Furthermore, the adhesive and compressive strength tests were in accordance with the ASTM D905-03 standard and the SNI 03-3958-1995, respectively. The adhesive strength test was carried out at the Building Materials Laboratory, Civil Engineering and Planning Study Program, and Faculty of Engineering at the Yogyakarta State University, while the compressive strength test was performed at the Structural Laboratory, Civil Engineering Department, as well as the Engineering Faculty of Tidar University. Data were then analyzed using the one-way ANOVA test and the results of each variation's adhesive strength test were 1.359 MPa, 564 MPa, 1.699 MPa, and 1.558 MPa for the 20, 30, 40, and 50 MDGL MDGL variations respectively. Furthermore, the results of the compressive strength test with variations T0, T1, T2, and T3 were 6.158 MPa, 7.366 MPa, 7.135 MPa, and 6.923 MPa respectively. It was concluded that the highest adhesive strength was at 40 MDGL and the highest compressive strength was at variation T1 (Mahoni-Pinus-Mahoni).

1. Introduction

Wood is often used as a building material, it is the lightest compared to steel and concrete, and it is easier to use. In its use as a building material, wood is distinguished as either structural or non-structural. Structural wood in this aspect refers to woods that has the ability to handle load, while non-structural is simply the opposite [1].

As a construction material, wood must meet the requirements of toughness or load-bearing strength, as well as having good structural stability and stiffness. This material can serve as columns, beams, among others in construction. Following this, some important aspects of structural woods that needs to be considered are its physical and mechanical properties for effective use in construction. The physical properties of wood include density, specific gravity, moisture content, and the percentage of wood damage [2]. There are various kinds of mechanical properties, they include compressive strengths, namely parallel compressive strength to the fibers and perpendicular compressive strength to the fibers, tensile strength, shear strength, flexural strength which includes MOR and MOE [3]. Some other mechanical properties include bearing strength parallel to the grain, as well as strong support perpendicular to the grain. The mechanical properties of wood can be obtained by study and experimental tests in the laboratory [4].

Furthermore, other than for construction purposes, wood is also used in industrial activities, which usually have an

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impact on the material's productivity, and this in turn influences the amount of waste generated from the wood industry [5] [6]. However, only a small amount of wood waste is utilized optimally, i.e by reprocessing the waste into products with a sale value. Many types of wood can be used in structural materials, and some of these woods can be found in Java, namely *sengon* (silk tree), mahogany, suren, meranti, pine, and others [7].

Every day, the need for using pine pallets is becoming relatively high and this material can be used in various aspects [8] [9]. For example, it is used for securing and packaging goods when shipping out of town. [10] During the packaging and shipping process, pine pallets and wood waste are usually accumulated on the ground. As a result, the right step to take in reducing the need for wood is by utilizing pallet wood waste by transforming them into structural wood using the lamination method [11] [12].

Accordingly, the gluing technology system (laminated) in this study was used on a combination of pine pallets with mahogany reinforcement. The combination of these two materials will lead to a contrasting and aesthetically pleasing finished structural wood because pine pallets are lighter while mahogany is darker in color, and has great strength in withstanding load. With the high logging of mahogany forests and its long growth time, it is necessary to minimize the use of this material as a whole by utilizing lamination technology.

Laminated wood certainly has variations in thickness and segment sizes. Due to its property, which is slightly softer than mahogany's, a compressive and adhesive strength test was carried out. The variations of adhesive thickness on the laminates were to determine the highest strength value which was used as a coating reference in the compressive strength test. In addition, the result obtained from testing the various thickness variations used can be considered when recommending the required thickness for the laminated beams of pine pallets reinforced with mahogany wood as alternative raw materials in terms of technological and economic aspects [13].

Based on the description above, this study was conducted on laminated beams made from pine pallet waste and mahogany reinforcement. Pine pallet waste was selected because it is cheap and minimizes the accumulation of waste that is less efficient. Mahogany wood was also selected because of its strength against loads. It is expected that this study will provide a solution in utilizing pine pallet waste as a structural material and regenerating wood needs to reduce the exploitation of natural forests.

2. Method

2.1 Lamination

The difference between MSGL and MDGL is in the method of coating the adhesive. The MSGL gluing method is carried out by smearing the adhesive on only one side of the two surfaces to be glued. Meanwhile, in MDGL the adhesive is coated on both surfaces. When using the MDGL unit, a 10% additional adhesive from what would have been enough for MSGL is needed, and this is to overcome the loss of adhesive during the coating process on both sides. To use the MDGL method, the GPU calculation must be converted to the area unit used with the size of 2 inches = 317.5 cm^2 = 2048.3. The formula used to calculate the GPU is as Equation 1.

$$GPU = SA'/conversion \quad (1)$$

where GPU as Grams Pick Up (grams), S as the amount of adhesive added (MDGL), and A' as the area covered with adhesive (cm^2).

2.2 Compressive Strength

The wood compressive strength is the compressive force per unit area of the compressive field which can be determined by two methods. The compressive strength parallel to the grain direction is responsible for carrying the load acting on it as well as the load in the direction of the wood grain, while the compressive strength perpendicular to the grain direction is the strength of the wood, which carries the load acting on it and the load in the direction perpendicular to the wood fiber direction. Accordingly, the compressive strength method parallel to the direction of the wood grain was employed in this study. This refers to SNI 03-3958-1995 [14] with a direction parallel to the fibers calculated by the load per unit area of compression, as Equation 2.

$$fc// = p/(b \times h) \quad (2)$$

where f c// as the compressive strength parallel to the grain (MPa), P as the maximum test load (N), b as the width of the test object (mm), and h as the height of test object (mm).

2.3 Adhesive Strength

The adhesive strength test for the wood was carried out with regards to the ASTM D 905-03 [15] standard with dimensions (5.08 x 1.9 x 4.44 cm and a notch of 0.63 cm). Referring to the ASTM standard, the adhesive strength value is declared as good if the value is above 3.52 kg/cm^2. The formula used in determining the adhesive strength is as Equation 3.

$$\text{Adhesive strength} = \frac{P}{A} \quad (3)$$

where P is the maximum test load (N) and A is the shear area (mm^2).

2.4 Density

The wood density was determined using a straight comparison between the mass or weight of wood with a unit volume. The types of density considered are vertical and horizontal density. The equation used according to SNI 03-2105-2006 [16] is as Equation 4.

$$\rho = \frac{Wg}{Vg} \quad (4)$$

where ρ is the wood density (gr/cm^3), W_g is the wood wet weight (gr), V_g is the wood wet volume (cm^3).

2.5 Water Content

The water content value at the fiber saturation point was set at 25% to 30% in accordance with SNI 08-7070-2005 [17]. Wood with a high water content must first go through a drying process because excessive water leads to brittleness because the cells will in turn be q filled with lots of water. The formula for finding the water content is as Equation 5.

$$M = \frac{W_g - W_d}{W_d} x 100\% \quad (5)$$

where M is the water content (%), W_g is the wood wet weight (gr), and W_d is the oven dry wood weight (gr).

2.6 Wood Damage Percentage

When the amount of wood damage is greater than 50%, it is considered to have good wood adhesion. The percentage of wood damage in adhesive joints is calculated using Equation 6.

$$\text{PKK}\ (\%) = \frac{\text{LK}}{\text{LB}}\ x\ 100 \quad (6)$$

where PKK is the wood damage percentage (%), LK is the area of wood damage on the shear plane (mm^2), and LB is the shear area (mm^2).

2.7 Stress

The stress on an object, such as an iron wire, is defined as the force per unit cross-sectional area of the object. It is represented by the symbol σ (pronounced sigma) and mathematically represented as Equation 7.

$$\sigma = \frac{P}{Ao} \quad (7)$$

where P is the compressive force (N), A_o is the cross-sectional area (mm^2), and σ is the stress (N/mm^2).

2.8 Strain

Strain is defined as the ratio between the addition of length ΔL to the initial length Lo, it is formulated as Equation 8.

$$\varepsilon = \frac{\Delta L}{Lo} \quad (8)$$

where ε is the strain (without units), ΔL is the elongation (mm), and Lo is the initial length (mm).

2.9 Modulus of Elasticity

The force P acting on an elastic body does not exceed the elastic limit, therefore, the ratio between stress (σ) and strain (ε) is constant. This number (constant) is called the modulus of elasticity (E). In this regard, the modulus of elasticity is the ratio between the stress and strain experienced by an object. Mathematically, it is written as Equation 9.

$$E = \frac{\sigma}{\varepsilon} \quad (9)$$

where Σ is the stress (N/mm^2), ε is the strain (without unit), and E is the modulus of elasticity (N/mm^2)

2.10. ANOVA (Analysis Of Variance)

ANOVA is a multivariate analysis technique that functions as a differentiator with an average of more than two groups of data by comparing the variations. Subsequently, the one-way ANOVA is a parametric statistical technique used to test differences from several groups on average, where there is only one independent variable divided into several groups and one dependent variable. This one-way technique, which is usually used in experimental studies, was concluded by comparing the F value with the Fcrit value, if F is less than Fcrit then there is no significant difference in the existing data, but if F is greater than Fcrit, it means there is a significant difference.

2.11 Composition Calculation

The calculations used to test the adhesive strength of the 4 variations of laminated beams, namely 20 MDGL, 30

MDGL, 40 MDGL, and 50 MDGL with the following dimensions, are shown in Figure 1.

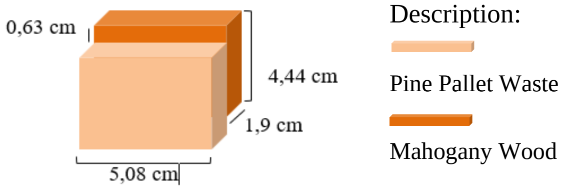

Figure 1. Dimensions of adhesive strength test objects.

The compressive strength of laminated beams with 4 variations was tested and graphically represented in Figure 2 to Figure 5

(a) Variation 1 (T0)

The size in this variation is 20 cm x 5 cm x 5 cm and the blade width of the test object was 1 cm with 5 segments/layer, as shown in Figure 2.

(b) Variation 2 (T1)

The size in this variation was 20 cm x 5 cm x 5 cm and the blade width of the test object was 1.67 cm having 3 segments/layers, as shown in Figure 3.

(c) Variation 3 (T2)

The variation had a size of 20 cm x 5 cm x 5 cm, while the blade width of the test object was 1.25 cm with 4 segments/layer. More details can be seen in Figure 4.

(d) Variation 4 (T3)

The variation's size was 20 cm x 5 cm x 5 cm, and the blade width of the test object was 1 cm with 5 segments/layer. More details of this variation and test object are shown in Figure 5.

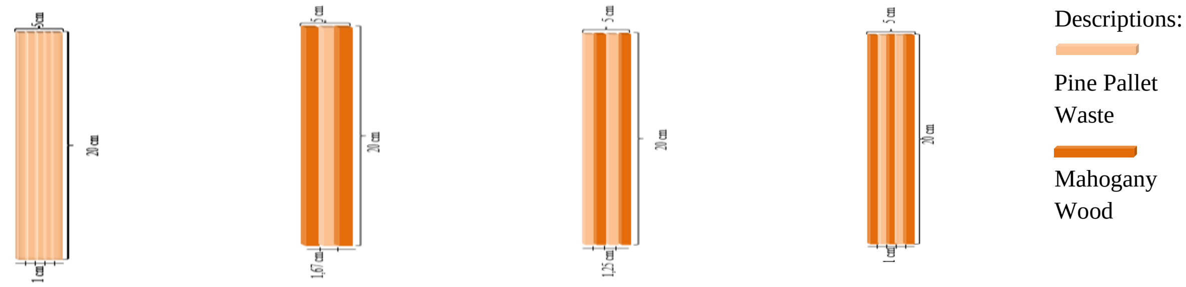

Figure 2. Variation T0. **Figure 3**. Variation T1. **Figure 4**. Variation T2. **Figure 5**. Variation T3.

2.12Test Scheme

In this study, the adhesive strength of joints on laminated wood pallets comprising of pine and mahogany with a size of 5.08 x 1.9 x 4.44 cm as well as a notch of 0.63 cm. The dimensions and the code of the adhesive strength of the test object are shown in Figure 6.

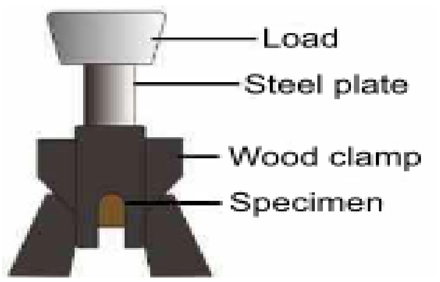

Figure 6. Scheme of adhesive strength test.

This test was carried out with a coating variation of 20 MDGL, 30 MDGL, 40 MDGL, and 50 MDGL. Each variation of the test object was repeated 4 times and the code of its adhesive strength is shown in Table 1.

The test object used for the compressive strength test on adhesive joints varied in thickness depending on the type of wood. The object size used for compressive strength is 5 x 5 x 20 cm. A schematic drawing of the compressive strength test can be seen in Figure 7.

Table 1. Code of adhesion strength test objects

Number	Test Object Code	Number of Test Objects
20 MDGL	20 R1, 20 R2, 20 R3, 20 R4	4
30 MDGL	30 R1, 30 R2, 30 R3, 30 R4	4
40 MDGL	40 R1, 40 R2, 40 R3, 40 R4	4
50 MDGL	50 R1, 50 R2, 50 R3, 50 R4	4

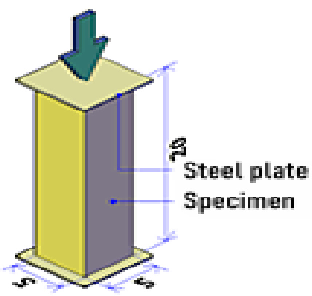

Figure 7. Compressive strength test [14].

This test uses 4 variations, each of which was repeated 5 times, hence, the total number of tests performed is 20. The compressive strength test object code is presented in Table 2.

Table 2. Code of test objects for compressive strength

Test Object Code	Size per Segment (cm)	Layer Segment	Number of Test Objects
T0	1	Pine-pine-pine-pine-pine	5
T1	1.67	Mahogany-Pine-Mahogany	5
T2	1.25	Pine-Mahogany-Pine-Mahogany	5
T3	1	Mahogany-Pine-Mahogany-Pine-Mahogany	5

The joint adhesive strength test (Figure 8) was carried out using a Universal Testing Machine (UTM) and variations in the amount of adhesive (20 MDGL, 30 MDGL, 40 MDGL, and 50 MDGL). The test mechanism for pine and mahogany pallet waste laminated wood is as follows:

1. Cut intact mahogany and pine pallets into lengths according to the plan, and give a specific code with respect to the variety of finishing. The code complies with Table 1, and the ASTM D 905-03 standard was referenced in the fabrication of test objects.
2. Mark the area where the adhesive will be applied with a pen.
3. Weigh the adhesive in accordance with a predetermined dose.
4. Spread the adhesive on the surface of the test object in accordance with the specified amount. Each variation of the test object was made in 4 repetitions.
5. Clamp the test object using clamps for 3 hours.
6. Leave the test object for 3 days until the adhesive is completely dry.
7. Place the test object on the UTM machine, giving a compressive load with a loading speed of 5 mm/min until it reaches the maximum load.
8. Obtain results on strength test.

Figure 8. Scheme of adhesive strength test.

In this study, the laminated beams' compressive strength was determined during their manufacturing process. The following are the steps for making a laminated beam test object from pine wood pallet waste and mahogany reinforcement:

1. Make the lamina blades using a sawing machine and planer according to the size planned.
2. Dry the lamina blade by natural drying, i.e by leaving the lamina blades in the open air to be exposed to natural winds.
3. Gather the wood by packing, hence, making the lamina a layer or component according to the specified size.
4. Gluing. This process was carried out using fox glue on the surface of the lamina slats after the material has been trimmed.
5. Compression. This process was carried out to ensure that the bamboo segments are properly and optimally merged.

The joint compressive (Figure 9) strength test was conducted using the UTM to determine the maximum or optimum amount of compressive strength in the laminated beams. The processes involved in performing this test are as follows:

1. Cut intact mahogany and pine pallets into sizes and layers as shown in Figure 2, Figure 3, Figure 4, and Figure 5. Also, assign a specific code to each finishing variation. The code should be in accordance with Table 2, and the test objects must be manufactured based on SNI 03-3958-1995.
2. Mark the area where the adhesive will be applied using a pen.
3. Weigh the adhesive according to the maximum yield.
4. Spread fox adhesive on the surface of the test object with respect to the specified amount. Each variation of the test object was made 5 times.
5. Clamp the test object using clamps for 3 days, hence, making the test object stick perfectly.
6. Place the test object on the UTM machine, clamp it with wooden clamps, and apply a compressive load with a loading speed of 1 mm/min until it reaches the maximum load.

Figure 9. Scheme of compressive strength test.

7. After the test is complete, the results on the joints of the laminated pine and mahogany pallets will then be obtained.

3 Result and Discussion

3.1 Water Content Test

Wood with a high water content must go through a drying process first, because excess water can cause brittleness due to the fact that the wood cells will be filled with lots of water. The water content for the adhesive strength test can be seen on the graph of the average water content (%) in Figure 10.

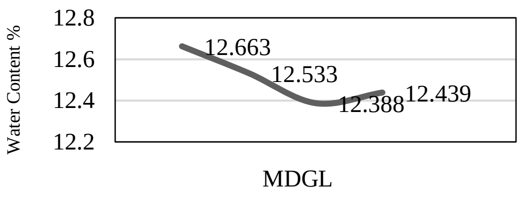

Figure 10. Water content graph for adhesive strength test.

From the test above, it was found that the water content in the 40 MDGL variation was 12.388%. This value was lower than that of the 50 MDGL, 30 MDGL, and 20 MDGL whose water content values were 12.439%, 12.533%, and 12.663% respectively. These results can affect the value of the adhesive strength because a low water content can produce a high adhesive strength value. Furthermore, the maximum water content in the compressive strength test according to SNI 03-3958-1995 was 20%. The water content for the compressive strength test can be seen in the graph of the average water content (%) in Figure 11.

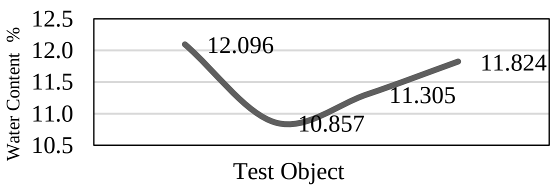

Figure 11. Water content graph for compressive strength test.

Based on the results obtained from testing the water content for each wood, it was found that the T1 variation with a value of 10.857% was lower than the T0, T2, and T3 variations, whose values were 12.096%, 11.305%, and 11.824% respectively. The results of the average water content of the lamination column met the water content standard for the use of lamination columns according to SNI 7973: 2013, where it was stated that the water content must not exceed 16%.

3.2 Density Test

The density of wood is affected by age when viewed from a horizontal direction. Usually, relatively young woods has a lower density. This test refers to SNI 03-2105-2006. The following is a graphical image of the average density value of each wood, as can be seen in Figure 12.

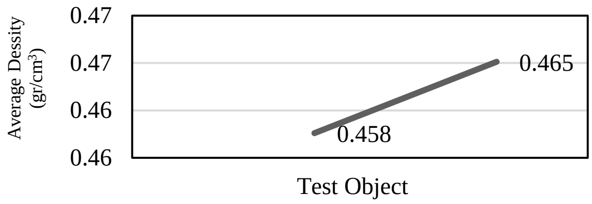

Figure 12. Graph of the average density for the adhesive strength test.

Based on the density test above, it was found that the density of mahogany wood was higher than that of pine wood, with a value of 0.458 gr/cm3 for pine and 0.465 gr/cm3 for mahogany. These results influenced the value of the adhesive strength. The average compressive strength can be seen in Figure 13.

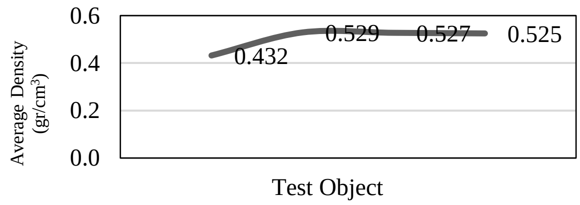

Figure 13. Graph of average density for compressive strength test.

Following this, the average density test for each wood was used in the compressive strength test. From this test, it was found that the density at T1 (0.529 gr/cm^3) with the mahogany-pine-mahogany variation was higher than T0 (0.432 gr/cm^3) with the variation of pine-pine-pine-pine-pine, which was the lowest value. These results served as a parameter for the compressive strength test of the laminated pine columns reinforced with mahogany wood.

3.3 Adhesive Strength Test Results

The adhesive strength test was carried out at the Building Materials Laboratory, Faculty of Engineering, Yogyakarta State University using the UTM. The test object was laminated beams of pine and mahogany pallets with adhesive coating variations of 20 MDGL, 30 MDGL, 40 MDGL, and 50 MDGL with 4 variations of each test object. The calculation results are shown in Table 3.

The following graphical image of the adhesive strength test can be seen in Figure 14.

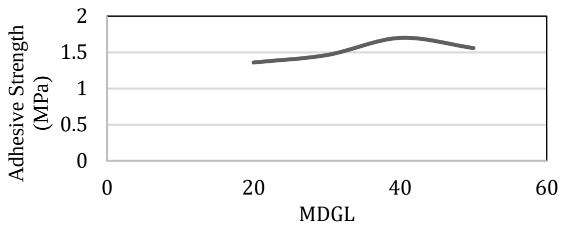

Figure 14. Graph of adhesive strength test.

Subsequently, the adhesive strength of the laminated column was calculated using a coating variation of 20 MDGL, 30 MDGL, 40 MDGL, and 50 MDGL yielded 1.358 MPa, 1.462 MPa, 1.699 MPa, and 1.558 MPa respectively. The results of the average adhesive strength test on the five test object variations in Figure 14 show that the 40 MDGL coating variation is the highest, while the lowest adhesive strength is at 20 MDGL.

Table 3. Adhesive strength test results

No	Name of Test Object	Max Load (N)	Dimensions of Test Objects			Adhesive Strength (MPa)	Average Adhesive Strength (MPa)
			Length (mm)	Width (mm)	Area (mm^2)		
1	20R1	1030	50.6	39.0	1970	0.523	1.358
2	20R2	3050	50.7	39.9	2019	1.511	
3	20R3	3510	50.8	39.6	2009	1.747	
4	20R4	3470	50.9	41.2	2097	1.655	
5	30R1	3750	50.0	37.5	1877	1.998	1.462
6	30R2	2910	50.1	37.2	1863	1.562	
7	30R3	2370	50.3	37.8	1899	1.248	
8	30R4	2060	50.8	39.0	1981	1.040	
9	40R1	2890	50.8	38.9	1976	1.462	1.699
10	40R2	3940	50.9	39.7	2019	1.952	
11	40R3	2990	50.8	39.9	2023	1.478	
12	40R4	3760	50.6	39.0	1973	1,906	
13	50R1	2750	50.6	37.1	1877	1.465	1.558
14	50R2	2670	50.1	37.2	1863	1.433	
15	50R3	2910	50.2	37.4	1876	1.551	
16	50R4	3420	50.3	38.1	1915	1.786	

* Source: Building Materials Laboratory, Yogyakarta State University, 2021.

Table 4. Oneway ANOVA test for adhesive strength test summary

Groups	Count	Sum	Average	Variation
20 MDGL	4	5.436	1.359	0.320
30 MDGL	4	5.848	1.462	0.173
40 MDGL	4	6.798	1.699	0.070
50 MDGL	4	6.235	1.558	0.025

ANOVA

Source of Variation	ss	df	MS	F	P-value	F crit
Variation	0.252	3	0.084	0.569	0.645	3.490
Error	1.769	12	1.462			
Total	2.021	15				

3.4 Wood Damage Percentage

The wood damage percentage at joints can only be found in 20R3, 20R4, 40R1, 50R4, and 50R5 with the highest percentage found in 40R1. The damage to 40R1 was 1.64%. The wood damage during the adhesive strength test of pine pallet laminate joints with mahogany tends to indicate that the form of failure on the test object is an adhesive failure. Figure 15 shows the highest wood damage value on the adhesive strength test.

3.5 Data Analysis of Adhesive Strength Test

The ANOVA analysis was carried out by comparing the F value with the Fcrit value. From Table 4, it can be seen that the F value (0.569) was smaller than that of the Fcrit (3.490), which indicates that although there are differences in the adhesive strength values between the 20 MDGL, 30 MDGL, 40 MDGL, and 50 MDGL variations, the difference does not have a significant effect.

Figure 15. Damage to wood adhesion test.

3.6 Compressive Strength Test Results

Following this, a compressive strength test was conducted t at the Structural Laboratory, Department of Civil Engineering, Faculty of Engineering, Tidar University, using UTM with the brand name JTM-CT-200 serial 9614-1. The results obtained from the adhesive strength test were 40 MDGL. Table 5 shows the results obtained from testing the compressive strength. The adhesive strength test results can be seen in Figure 16.

Table 5. Calculation of compressive strength test

No	Name of Test Object	Max Load (N)	Dimensions of Test Objects			Compressive Strength (MPa)	Average Compressive Strength (MPa)
			Length (mm)	Width (mm)	Area (mm^2)		
1	T01	53743	200	48.1	9620	5.587	
2	T02	59678	200	47.2	9440	6.322	
3	T03	63542	200	47.2	9440	6.731	6.158
4	T04	62884	200	48.1	9620	6.537	
5	T05	50620	200	45.1	9020	5.612	
6	T11	70414	200	47.1	9420	7.475	
7	T12	70315	200	48.1	9620	7.309	
8	T13	67783	200	47.2	9440	7.180	7.366
9	T14	64134	200	46.1	9220	6.956	
10	T15	77976	200	49.3	9860	7.908	
11	T21	68474	200	46.1	9220	7.427	
12	T22	79637	200	47.1	9420	8.454	
13	T23	63312	200	47.2	9440	6.707	7.135
14	T24	58955	200	48.4	9680	6.090	
15	T25	67175	200	48.0	9600	6.997	
16	T31	69033	200	46.2	9240	7.471	
17	T32	62736	200	47.1	9420	6.660	
18	T33	71039	200	49.5	9900	7.176	6.923
19	T34	57179	200	48.1	9620	5.944	
20	T35	67899	200	46.1	9220	7.364	

*Source: Structural Laboratory, Department of Civil Engineering, Faculty of Engineering, Tidar University, 2021

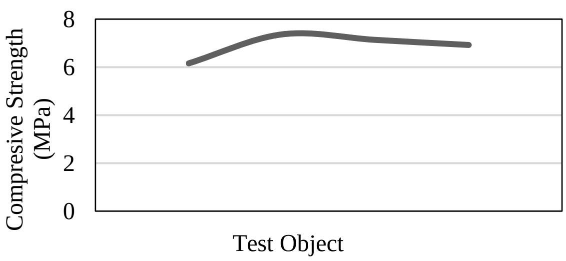

Figure 16. Graph of compressive strength

The km impact of the average compressive strength test on the variety of test objects, as shown in Figure 16, shows the highest compressive strength value on the T1 test object (Mahogany-Pine-Mahogany) with an average of 7.366 MPa and a thickness of 1.67 cm in each layer.

3.7 Forms of Wood Damage

Damage to wood with regards to compressive strength is dominated by compression, shear cracks, longitudinal cracks as well as horizontal cracks. Damage to wood in the compressive strength test is the failure of the joint adhesive, the laying of mahogany layers, and the composition such as the layer thickness on each test object. The damaged wood can be seen in Figure 17.

Figure 17. Compression and shear cracking damage.

3.8 Data Analysis of Compressive Strength Test

Lastly, from Table 6, it can be seen that the F value (3.462) is smaller than that of the Fcrit (3.238) which indicates that the compressive strength values between the variations T0, T1, T2, and T3 have significant differences.

3.9 Calculation of Stress, Strain, and MOE

The MOE calculation results for each compressive strength test object show that the highest E value is 1483.226 N/mm^2 and was found in the T1 variation. Based on these results, it can be seen that this study did not consider the wood quality based on SNI 7973-2013. Therefore, the obtained results cannot be used as structural materials but as non-structural wood because the water content is not more than 14% according to RSNI3 0608:2016.

4 Conclusions

Based on the results of this study, increasing the amount of coated adhesive leads to a significant increase in the adhesive strength between pine pallets and mahogany reinforcement. The average adhesive strength of the variations 20 MDGL, 30 MDGL, 40 MDGL, and 50 MDGL was 1.359 MPa, 1.462 MPa, 1.699 MPa, and 1.558 MPa respectively. However, the 40 MDGL variation has the highest adhesive strength due to the low water content and high density.

The compressive strength test results for the variation of T0 (Pine-Pine-Pine-Pine-Pine), T1 (Mahogany-Pine-Mahogany), T2 (Mahogany-Pine-Mahogany-Pine), and T3 (Mahogany-Pine-Mahogany-Pine-Mahogany) averaged 6.158 MPa, 7.366 MPa, 7.135 MPa, and 6.923 MPa respectively. The highest compressive strength was obtained in the T1 variation (Mahogany-Pine-Mahogany) with a thickness of 1.67 cm in each layer, while the lowest was in the T0 variation (Pine-Pine-Pine-Pine-Pine) with a thickness of 1 cm for each layer.

Table 6. Oneway ANOVA test on compressive strength summary

Groups	Count	Sum	Average	Variation
T0	5	30.789	6.157	0.280
T1	5	36.828	7.365	0.127
T2	5	35.675	7.135	0.779
T3	5	34.615	6.923	0.396

ANOVA

Source of Variation	ss	df	MS	F	P-value	F crit
Variation	4.116	3	1.372	3.462	0.041	3.238
Error	6.340	16	0.396			
Total	10.456	19				

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