The Compression Test and the Bending Test of Wooden Structural Material of Traditional Houses of Batak Karo, North Sumatera

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Keywords: Traditional House, Batak Karo, Wood Mechanical Properties, Compression Test, Bending Test, Earthquake Resistant.

Abstract: Traditional houses of Batak Karo, North Sumatra are known as the Traditional House of Siwaluh Jabu. The structure of the buildings uses wood materials, where such buildings has been proved to be more earthquake resistant. These traditional houses use several types of wood, namely Haudolok wood, Ingul wood, Pengki wood, and Simartolu wood. To know the mechanical properties of the wood structures, then a series of tests were done. This paper only is objected to discuss the results of compression and bending tests of the wood. The compression test was conducted to find out the relationship of the density with the elasticity modulus and the equivalent yield stress. Three-point and four-point bending tests were conducted to understand the relationship of the density with the elasticity modulus, the maximum bending stress, and the shear modulus. Teak wood and Jackfruit wood from Java were selected as control specimens. The test results showed that, in the compression test, the density has a very strong correlation with the modulus of elasticity and the equivalent of the melting stress. In both three-point and four-point bending tests, it shows that the density has a very strong correlation with maximum bending stress and strong correlation with shear modulus.

1 INTRODUCTION

Wood is one of the most common structural materials used in the construction of traditional earthquake resistant houses (Prihatmaji et al., 2011; Prihatmaji et al., 2012; Suara Merdeka, 2005). Wood materials are capable of deforming and tend to be stable when earthquake shaking as well as having a large damping and relatively light (LPMB, 1985; Mardikanto, 2011; Miller, 1999).

One of the buildings that use wood material as the main structure is the traditional house of Siwaluh Jabu, Batak Karo, North Sumatra. The selection of materials to build the traditional house of Siwaluh Jabu and the construction process that does not use nails, iron, or wire fastener, but using pegs and fiber ropes add the uniqueness of Traditional House of Siwaluh Jabu (Sembiring, 2010). Survey results show that the main structure of this traditional house uses four types of timber namely, Haudolok wood, Ingul wood, Pengki wood, and Simartolu wood (Nurdiah, 2011; Sembiring, 2010). A series of laboratory tests was done to know the mechanical properties of the wood used in making the traditional house of Batak Karo.

This paper is objected to discuss the results of the laboratory tests that covers the compression and bending tests of the wood. The compression test was conducted to find out the relationship of the density with the elasticity modulus and the equivalent yield stress. Three-point and four-point bending tests were conducted to understand the relationship of the density with the elasticity modulus, the maximum bending stress, and the shear modulus. Teak wood and Jackfruit wood from Java were selected as control specimens.

2 THEORY

The theoretical basis in this paper is limited to very closely related issues, i.e. the physical properties of wood, the mechanical properties of wood, and the mechanical test of wood (Miller, 1999; Suhardjono, 1994; SNI, 1961; SNI, 2000; Tjondro et al., 2013; Mardikanto, 2011; Yosafat, 2014; Yoshihara, 1998).

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2.1 Physical Properties

The physical properties of wood are hygroscopic, density, and specific gravity.

2.1.1 Hygroscopic

All of the physical properties of wood are strongly influenced by changes in the water content of wood. The amount of water contained in a piece of wood is called the water content of wood (Ka). The weight of wood on the dry state of the furnace is called dry wood furnace (Wo). The weight of water present in the wood is the difference between the weight of the wood before it is dried (wet weight / initial weight = Wb) minus the weight of the wood after it is dried by the furnace. The above formula can be written as follows.

$$Ka\ (\%) = \frac{Wb-Wo}{Wo} \times 100\% \qquad (2.1)$$

2.1.2 Density

In this study, the weight used was dry weight of the furnace / oven. So the wood density can be defined as the ratio between the oven dry weight and the volume of a piece of wood, i.e.:

$$R = \frac{Wo}{v} \qquad (2.2)$$

Where:

R : wood density (kg/m^3)
Wo : oven dry weight (kg)
v : volume (m^3)

2.1.3 Specific Gravity

Wood density is the ratio between wood density (on the basis of dry weight of the furnace and volume under various wood conditions) to the water density at 4^o C. The water has a density of 1 g / cm^3 or 1000 kg / m^3 at that standard temperature. Based on the number, the density (R) and specific gravity (BJ) are the same, but the specific gravity does not have units because the specific gravity is a relative value which can be determined by the following formula.

$$BJ = \frac{\text{Density}}{\text{Water Density at } 4^\circ \text{ C}} \qquad (2.3)$$

2.2 Physical Properties

The three wooden mechanical properties reviewed in this paper are compression strength, elastic modulus, and shear modulus.

2.2.1 Compression Strength

The compression strength of wood is the compression force per unit area of compression. The formula can be written as follows.

$$\sigma = \frac{P}{A} \qquad (2.4)$$

where:

σ : compression strength (kg/cm^2)
P : compression force (kg)
A : compression area (cm^2)

2.2.2 Elastic Modulus

The elastic modulus is a measure in which a material or structure will be damaged and deformed when placed under pressure. The elasticity modulus (E) can be calculated by dividing the stress (σ) by strain (ε) within the limit of linear elasticity on the part of the stress-strain curve. The formula E can be written as follows:

$$E = \frac{\sigma}{\varepsilon} \qquad (2.5)$$

2.2.3 Shear Modulus

The shear modulus (G) describes the tendency of an object to deform at a constant volume when the object is given opposing forces defined as shear stress to shear strain. The shear modulus can be calculated using the formula:

$$G = \frac{E}{2(1+v)} \qquad (2.6)$$

where:

E : elastic modulus (N/mm^2)
v : Poisson ratio

2.3 Mechanic Properties

Two kinds of test of mechanical properties in this paper are compression test and bending test.

2.3.1 Compression Test

The compression test is carried out both fully and partially in tangential and radial directions. To obtain the elastic modulus (E) from the test applies Eq. (2.5).

2.3.1 Bending Test

There are two kinds of bending tests that are three-point and four-point tests. A three-point bending test is performed to obtain the elasticity modulus (E) and MOR or maximum bending stress. To get the value of E, first, sought the deflection in the middle of the span by using the principle of the moment field as the load (Figure 1).

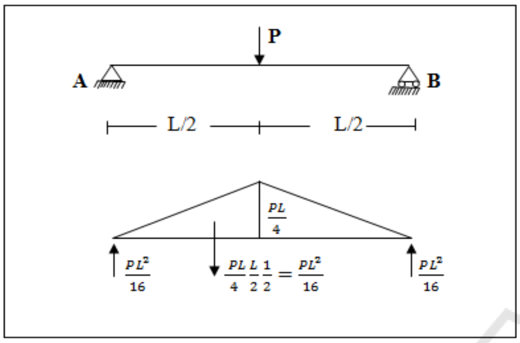

Figure 1. Principle of the moment area as a pointed force

$$\sigma_{Lentur\ max} = \frac{3PL}{2bh^2} \quad (2.7)$$

$$\delta = \frac{M}{EI} = \frac{PL^3}{48\ EI} \quad (2.8)$$

$$E = \frac{PL^3}{\delta\ 48\ I} \quad (2.9)$$

where:

δ = deflection
P = force
L = specimen length
E = elastic modulus
I = inertia moment

Then, a four-point bending test is performed to obtain the elastic modulus (E) and MOR or maximum bending stress. To get the value of E, first sought, the deflection in the middle of the span by using the principle of the moment field as the load (Figure 2). The deflection formula can be seen in Eq. (2.8).

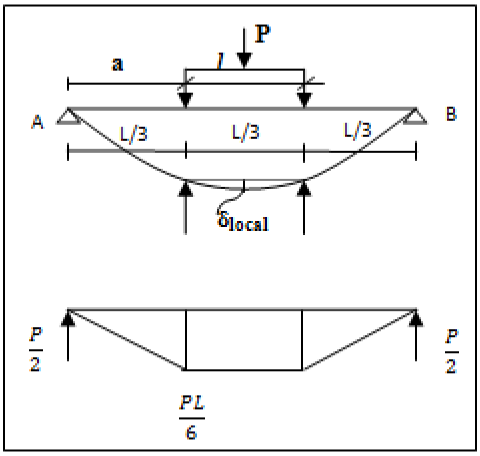

Figure 2. Sketch of loads for the four-point bending test

$$\sigma_{Lentur\ max} = \frac{PL}{bh^2} \quad (2.10)$$

$$\delta = \frac{M}{EI} = \frac{P.a.l^2}{16EI} \quad (2.11)$$

$$E = \frac{P.a.l^2}{\delta\ 16\ I} \quad (2.12)$$

3 METHODS

In this research, wooden test specimens from Sumatera are taken directly from Karo Regency, North Sumatera, while the wooden test specimens of Jackfruit wood and Teak wood using local wood taken from Yogyakarta. The specimens were tested using compression tests, three-point bending test, and four-point bending test. All tests were performed on specimens in the direction of radial and tangential fibers.

3.1 Compression Test

The specimens of compression tests are prepared in 4 (four) sizes with each size is 40 x 40 x 40 mm, 40 x 40 x 80 mm, 40 x 40 x 120 mm, and 40 x 40 x 160 mm. Each of these sizes is prepared for the specimen with the direction of radial and tangential wood fibers. Total test object used is as much as 120 pieces of specimen. The test scheme is carried out fully and partially in the tangential and radial directions as shown in Figure 3 which is then followed by a tested test using the test machine as shown in Figure 4

(Prihatmaji et. al, 2012). Type A denotes a full urgent test and type B denotes partial test. The push load is imposed on wooden specimens of type A and type B. For partial urgent test (type B), a steel plate of 40 mm width is placed in the center of the wooden specimen. The loading procedure at test is a static load at a speed of 0.5 mm / min, applied up to 4 mm deformation. The objective test is to obtain the elasticity modulus value and the yield stress equivalent of the six types of wood observed.

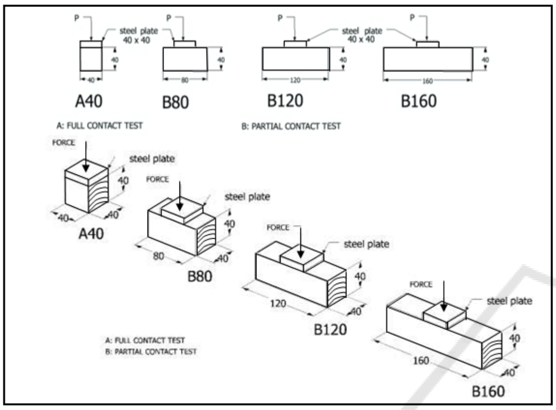

Figure 3: Specimens of compression test. Full (A40) Partial (B80, B120, and B160)

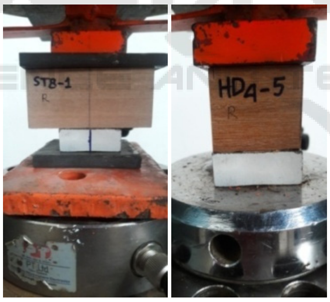

Figure 4: Photos of conducting tests

3.2 Bending Test

Wood specimens for three-point bending test and four-point bending test were prepared each with a size of 20 x 20 x 380 mm. The test specimens were prepared in the direction of radial and tangential wood fibers. For three-point bending test and four-point bending test, a total of 42 test pieces were used. Wood specimens for four-point shear test are prepared each with a size of 20 x 20 x 220 mm with a total of 24 test pieces. The test scheme and the testing process can be seen in Figures 5 and 6 (Prihatmaji et. al, 2012). Flexural testing is performed to obtain the elasticity modulus (E), maximum bending stress or MOR, and Shear Modulus (G) values.

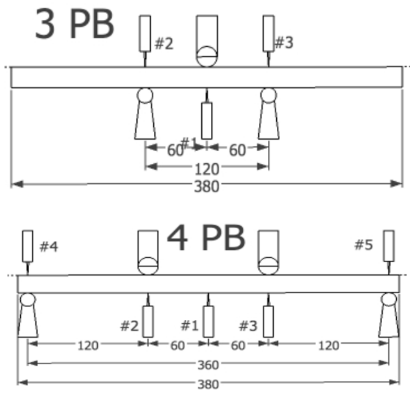

Figure 5: Three-point bending test (3 PB) and Four-point bending test (4 PB)

Figure 6: Photos of conducting tests. 3 PB (top). 4 PB (bottom)

4 RESULTS AND DISCUSSION

This part presents the results of the laboratory experiments and the discussion, both compression and bending tests.

4.1 Compression Test

From the graph of the compression test results in Figures 7 and 8, it can be seen that in the direction of the radial fibers and the direction of the tangential fibers of Haudolok wood has the highest urgency force among the 6 types of wood present, either at full test (type A40) or on partial testing (type B80, B120, B160). Exceptions occur in testing the direction of tangential fiber type B160 where the graphics results are inconsistent compared to other graphs. Haudolok wood has a lower pressing strength than wood of Jackfruit and Pengki wood.

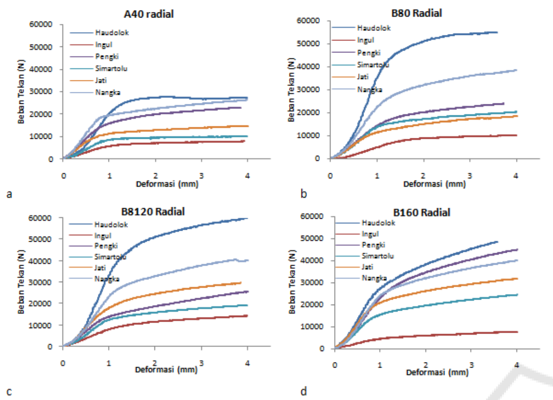

Figure 7: The results of the full compression test and the partial compression test in the radial fiber direction

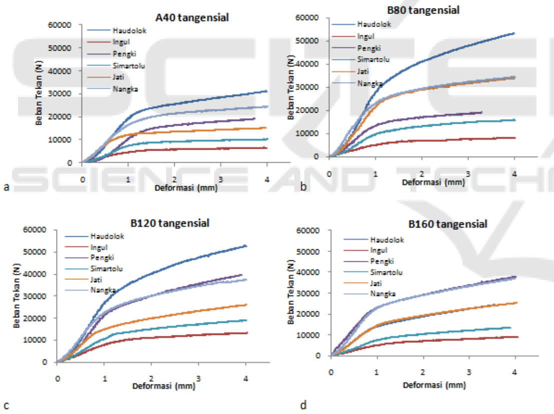

Figure 8: The results of the full compression test and the partial compression test in the tangential fiber direction

4.1.1 The Relationship of Density and Elastic Modulus

Figure 9 shows the relationship of density and Modulus of elasticity (E) in the direction of the radial fibers. From linear regression on each graph got value $R_{average}$ = 0.870. To facilitate an interpretation of the strength of the relationship between two variables, Sarwono (2006) gives the following criteria: 0: no correlation between two variables; > 0 - 0.25: the correlation is very weak; > 0.25 - 0.5: enough correlation; > 0.5 - 0.75: strong correlation; > 0.75 - 0.99: very strong correlation; and 1: perfect correlation. The correlation coefficient value of $R_{average}$ = 0.870 is at interval > 0.75 - 0.99 (very strong correlation) so it can be seen that the density has a very strong relationship with the modulus of elasticity (E). Ingul wood has the lowest density and E value, while Haudolok wood has the highest density and E value.

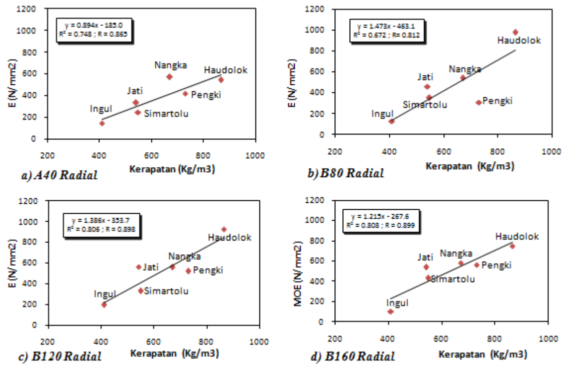

Figure 9: Graph of the relationship of density and elastic modulus in radial fiber direction

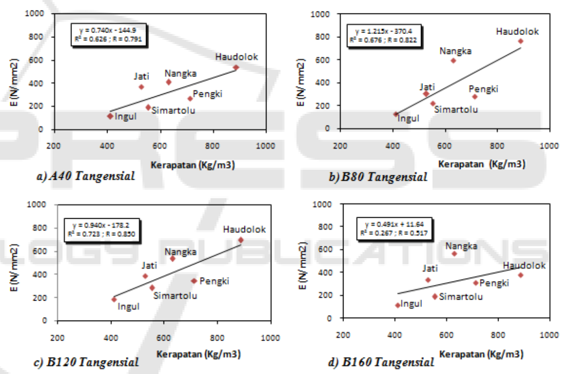

Figure 10 Graph of the relationship of density and Modulus of elasticity (E) in the direction of tangential fibers.

Figure 10 shows the relationship of density and Modulus of elasticity (E) in the direction of tangential fibers. From linear regression obtained value $R_{average}$ = 0.745. According to the criteria given by Sarwono (2006), the correlation coefficient value $R_{average}$ = 0.7451 is at interval> 0.5 - 0.75 (strong correlation) so it can be seen that the density has a strong relationship with the modulus of elasticity (E). In the tangential direction the Ingul wood has the lowest density and E value, while the Haudolok wood has the highest density and E value of type A40, B80 and B120. Haudolok wood on type B160 has a different behavior on the value of E, this is due to the porousness in the test specimen used.

4.1.2 The Relationship of Density and Equivalent Yield Stress

Figure 11 shows the relationship between the density and the equivalent yield stress of the radial fibers direction. From linear regression on each graph got correlation coefficient value $R_{average}$ = 0.912. The correlation coefficient value of $R_{average}$ = 0.9121 is at intervals> 0.75 - 0.99 (very strong correlation) so it can be seen that the density has a very strong relationship with the equivalent yield stress. Ingul wood has the lowest equivalent yield stress, while Haudolok wood has the highest equivalent yield stress.

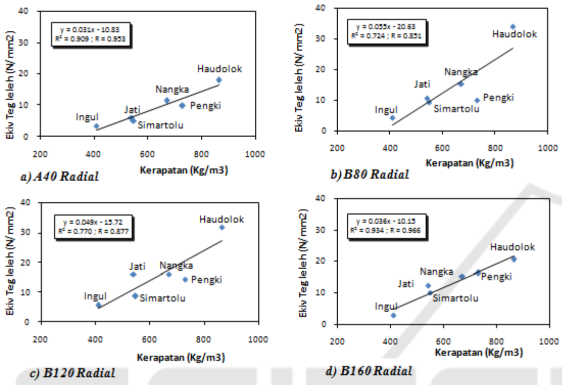

Figure 11: Graph of the relationship of density and equivalent yield stress in radial fiber direction

Figure 12 shows the relationship of density and the equivalent tensile stress to the tangential fiber. From linear regression on each graph got correlation coefficient value $R_{average}$ = 0.8365. The correlation coefficient value R = 0.8365 is at intervals> 0.75 - 0.99 (very strong correlation) so it can be seen that the density has a very strong relationship with the equivalent of the melting stress. In the tangential direction the Ingul wood has the lowest melting and equivalent value of the melting stress, while the Haudolok wood has the highest yield stress and equivalent yield stress in the A40, B80 and B120 types. Haudolok wood on type B160 has a different behavior on the equivalent value of yield stress, this is due to the porousness in the test specimen used.

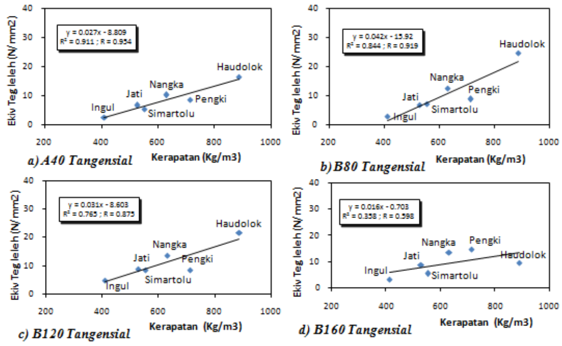

Figure 12: Graph of the relationship of density and equivalent yield stress in tangential fiber direction

4.2 Three-point Bending Test

The following description will show the relationship between density with elastic modulus, the equivalent yield melting stress, and the shear modulus of the three-point bending test results. Figure 13 shows the photos of the conducting test.

Figure 13: Photos of the conducting tests

4.2.1 The Relationship of Density and Elastic Modulus

Figure 14 shows the graph of the density relationship and σ maximum flexure in the direction of radial fibers. Linear regression on the graph yields a correlation coefficient R value of 0.787. The correlation coefficient value R = 0.787 is at interval> 0.75 - 0.99 (very strong correlation) so it can be seen that the density has a very strong relationship with σ maximum flexure. In the direction of Ingul wood radial fibers have the lowest density and σ maximum flexural value, while Haudolok wood has the highest density and σ maximum flexural value. Figure 12b. shows the graph of the density relationship and σ maximum flexure in the direction of tangential fibers. From the linear regression on the graph obtained correlation coefficient value R of 0.589. The correlation coefficient value R = 0.589 is at interval > 0.5 - 0.75 (strong correlation) so it can be seen that the density has a strong relation with maximal flexure. In the direction of Ingul wood tangential fiber has the lowest density and σ maximum flexural stress, while Pengki wood has the highest density, whereas wood of Jackfruit has the highest maximum flexural stress.

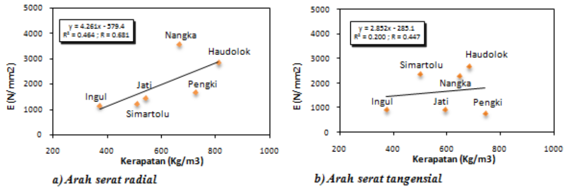

Figure 14: Graph of the relationship of density and elastic modulus

4.2.2 The Relationship of Density and Maximum Flexural Stress

Figure 15 shows the graph of the relation density and σ bending of the radial fiber direction. From the linear regression on the graph obtained correlation coefficient value R of 0.787. The correlation coefficient value R = 0.787 is at interval> 0.75 - 0.99 (very strong correlation) so it can be seen that the density has a very strong relationship with σ maximum flexure. In the radial fiber direction, Ingul wood has the lowest density and σ maximum flexural value, while Haudolok wood has the highest density and σ maximum flexural value.

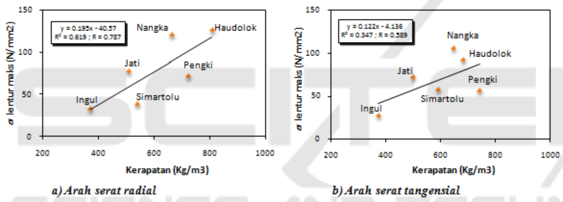

Figure 15: Graph of the relationship of density and maximum flexural stress

Figure 15 shows a graph of the density relationship and σ maximum flexure of tangential fiber direction. From the linear regression on the graph obtained correlation coefficient value R of 0.589. The correlation coefficient value R = 0.589 is at interval> 0.5 - 0.75 (strong correlation) so it can be seen that the density has a strong relation with maximal flexure. In the direction of Ingul wood tangential fiber has the lowest density and σ maximum flexural value, while Pengki wood has the highest density value, whereas wood of Jackfruit has the highest maximum flexural stress.

4.2.3 The Relationship of Density and Shear Modulus

Figure 16 shows the graph of the relation density and shear modulus (G) of the direction of the radial fibers. From linear regression on the graph got value of correlation coefficient R equal to 0.681. The correlation coefficient value R = 0.681 is at interval> 0.5 - 0.75 (strong correlation) so it can be seen that the density has a strong relation with G. In the direction of Ingul wood radial fiber has the lowest density and G value, while Haudolok wood has the highest density value, while wood of Jackfruit has the highest G value. Figure 14b. shows the graph of the relation density and shear modulus (G) of the direction of the tangential fibers. From the linear regression on the graph obtained correlation coefficient value R of 0.447. The correlation coefficient value R = 0.447 is at interval> 0.25 - 0.5 (enough correlation) so it can be seen that the density has a strong relation with G. In the direction of Ingul wood the tangential value has the lowest density and G value, while Pengki wood has the highest density value, while Haudolok wood has the highest G value.

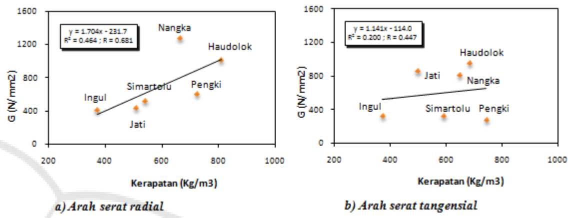

Figure 16: Graph of the relationship of density and shear modulus

4.3 Four-Point Bending Test

The following description will show the relationship between density with elastic modulus, the equivalent yield melting stress, and the shear modulus of the four-point bending test results. Figure 17 shows the photos of the conducting test.

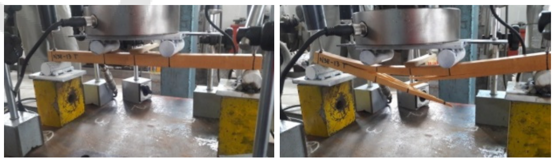

Figure 17: Photos of the conducting tests

4.3.1 The Relationship of Density and Elastic Modulus

Figure 18 shows the graph of the relation density and modulus of elasticity (E) the direction of the radial fibers. From the linear regression on the graph obtained correlation coefficient value R of 0.717. The correlation coefficient value R = 0.717 is at interval> 0.5 - 0.75 (strong correlation) so it can be seen that the density has a strong relationship with the modulus of elasticity (E). In the direction of Ingul wood radial fiber has the lowest density and E value, while

Haudolok wood has the highest density and E value. Figure 16b. shows the graph of the relation density and the modulus of elasticity (E) of the direction of the tangential fibers. From the linear regression on the graph obtained correlation coefficient value R of 0.272. The correlation coefficient value R = 0.272 is at interval> 0.25 - 0.5 (enough correlation) so it can be seen that the density has a fairly strong relationship with the modulus of elasticity (E). In the direction of Ingul wood tangential fiber has the lowest density and E value, while Haudolok wood has the highest E value, while Pengki wood has the highest density value.

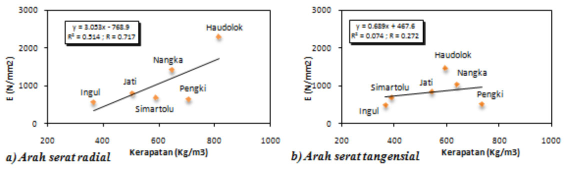

Figure 18: Graph of the relationship of density and elastic modulus

4.3.2 The Relationship of Density and Maximum Flexural Stress

Figure 19 shows the graph of the density relationship and σ maximum flexure of each type of wood in the direction of radial fibers. From linear regression on the graph got value of correlation coefficient R equal to 0.829. To facilitate an interpretation of the strength of the relationship between two variables, Sarwono (2006) gives the following criteria: 0: no correlation between two variables; > 0 - 0.25: the correlation is very weak; > 0.25 - 0.5: enough correlation; > 0.5 - 0.75: strong correlation; > 0.75 - 0.99: very strong correlation; and 1: perfect correlation. The correlation coefficient value R = 0.829 is at interval> 0.75 - 0.99 (very strong correlation) so it can be seen that the density has a very strong relationship with σ maximum flexure. In the direction of Ingul wood radial fibers have the lowest density and σ maximum flexural value, while Haudolok wood has the highest density and σ maximum flexural value.

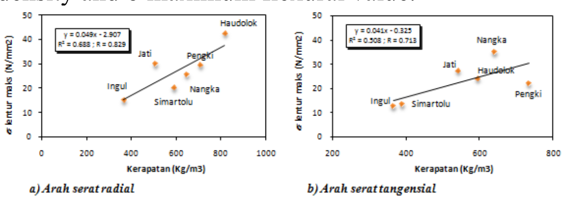

Figure 19: Graph of the relationship of density and maximum flexural stress

Figure 19 shows a graph of the density relationship and σ maximum flexure of tangential fiber direction. From the linear regression on the graph obtained correlation coefficient value R of 0.713. The correlation coefficient value R = 0.713 is at interval> 0.5 - 0.75 (strong correlation) so that it can be seen that the density has a strong relationship with maximal flexure. In the direction of Ingul wood tangential fiber has the lowest density and σ maximum flexural value, while Pengki wood has the highest density value, whereas wood of Jackfruit has the highest maximum flexural stress. Tests on radial fiber direction with R correlation coefficient value of 0.829 has a stronger density and flexural relationship is stronger than the test at the direction of tangential fiber with the value of correlation coefficient R of 0.713.

4.3.3 The Relationship of Density and Shear Modulus

Figure 20 shows the graph of the relation density and shear modulus (G) of the direction of the radial fibers. From the linear regression on the graph obtained correlation coefficient value R of 0.717. The correlation coefficient value R = 0.717 is at interval> 0.5 - 0.75 (strong correlation) so it can be seen that the density has a strong relationship with G. In the direction of Ingul wood radial fiber has the lowest density and G value, while Haudolok wood has the highest density and G value.

Figure 18b. shows the graph of the relation of density and shear modulus (G direction of tangential fiber) From the linear regression on the graph obtained correlation coefficient R of 0. 272 that is at interval > 0.25 - 0.5 (enough correlation) so it can be seen that the density has strong relation with G. In the direction of Ingul wood tangential fiber has the lowest density and G value, while Pengki wood has the highest density value, while Haudolok wood has the highest G value.

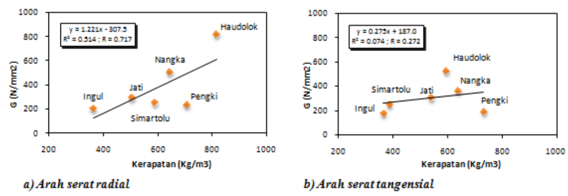

Figure 20: Graph of the relationship of density and shear modulus

5 CONCLUSIONS

The results and discussion in advance summarize the following.

- At the radial fiber direction test it is found that the density has a very strong correlation with the elastic modulus (E), whereas in the direction of the tangential fiber the density has a strong correlation with the elastic modulus (E). The density has a very strong correlation with the equivalent of the melting stress in both the radial and tangential fiber direction tests. The higher the density value the higher the value of E and the equivalent of the melting stress. Haudolok wood has a density value, elastic modulus (E), and the highest equivalent of melting stress, whereas Ingul wood has density value, elastic modulus (E), and lowest melting equivalent. According to the Indonesian Wood Construction Regulation (PKKI) 1961 NI-5, based on σ maximum bending of Haudolok and Jackfruit wood entering in strong class I (very good), teak wood entering strong class II (good), wood Pengki enter in strong class III (enough), the wood of Simartolu entered in strong class IV (less), and Ingul wood entered in strong class V (weak).
- In the 3-way bending test the radial fiber density direction has a strong correlation with the elastic modulus (E), whereas for the tangential fiber direction the density has a fairly strong correlation with the elastic modulus (E). The density has a very strong correlation with the maximum bending stress in the direction of the radial fibers, whereas in the direction of the tangential fiber the density has a strong correlation with the maximum bending stress. The density has a strong correlation with the shear modulus (G) in the direction of the radial fibers, whereas in the direction of the tangential fiber the density has a fairly strong correlation with the shear modulus (G).
- In the 4-way flexural test the radial fiber density has a strong correlation with the elastic modulus (E), whereas for the tangential fiber direction the density has a strong correlation with the elastic modulus (E). The density has a very strong correlation with maximum bending stress in the direction of the radial fibers, whereas in the direction of the tangential fiber the density has a strong correlation with the maximum bending stress. The density has a strong correlation with the shear modulus (G) in the direction of the radial fibers, whereas in the direction of the tangential fiber the density has a fairly strong correlation with the shear modulus (G).

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