E-ISSN: 2528-388X
P-ISSN: 0213-762X

INERSIA
Vol. 19, No. 1, May 2023

Comparation Study of Wood Quality Influenced by Water Content with Ultrasonic Pulse Velocity Test Approach

Darmono*, Maris Setyo Nugroho, and Rama Aji Pupus Pamungkas

[a]Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Yogyakarta, 55281, Indonesia

Keywords:
Wood Quaility
Ultrasonic Pulse Velocity (UPV)
Water content

ABSTRACT

In general, the building evaluation requires a sample from the building being tested. However, this cannot be done in cultural heritage buildings such as Masjid Gedhe Mataram. Because of that reason, an Ultrasonic Pulse Velocity test (UPV) is applied. This test aims to determine the strength of the wood quality due to the influence of its water content using the ultrasonic pulse velocity direct method. In the UPV test, the results are in the form of wave propagation which is influenced by several factors such as the type and the water content of the wood. There were 3 types of tested wood, 9 specimens each. The types of tested wood were kruing (KR), sengon (S), and teak wood (JTB). The water content was set at 12%, 15%, 20%, 25%, and 30%.
The results showed a strong correlation between MoE and MoEd values of kruing wood with an R^2 value of 0.8405, a weak correlation of sengon wood with an R^2 value of 0.31, and a strong correlation of teak wood with an R^2 value of 0.9331. The differences in wood quality based on modulus of elasticity between bending testing and UPV were 0.9 - 4.43% for kruing wood, 3.23 - 23.4% for sengon wood, and 3.4 - 33% for teak wood.

1. Introduction

Wood has been used as building material since ancient time. This can be observed that so many cultural heritage buildings built in wood as the main material such as Masjid Gedhe Mataram. Until now Masjid Gedhe Mataram is still used as it should be. However, a building should be evaluated to assess its appropriateness. Considering the main material used in Masjid Gedhe Mataram is wood, there are some items could be used to assess the wood quality of the building. One of the most important factor of wood is the water content, the higher the wood water content the weaker the tested wood [1]. Generally to conduct such test needs samples from the building. However this can not be done for the cultural heritage buildings. To solve this problem, it needs another approach as an alternative, such as Ultrasonic Pulse Velocity test, a test being able to test the wood mechanical propertis without damaging the tested objects [2].

Non-destructive test is used to detect the failure of an object when it is being constructed or after it is used. Some methods being used are ultrasonic, radiography, magnetic particle, eddy current, dye penetrant, and visual methods. This assessment is depended on the non-destructive test technique to prepare accurate information of characteristic, capability or condition of the material. The researcher also argues that non-destructive test for wood is very different when compared to homogenous and isotropic materials such as metal, glass, plastic, and ceramic, because the non-wood materials have known mechanical properties and have been strictly controlled during manufacturing process [3][2]. For such materials, non-destructive test technique is only used to detect the existence of discontinuities, voids, and inclusions. Non-destructucite test technique for wood, however, is used to measure the appearing irregularities because of natural factors. The results of UPV test are wave propagation speed and MoEd score of the wood.

Beside the non-destructive test, the destructive test was also conducted as the flexural strengthtest, to compare with the UPV test. This study aims to analyse the wood

*Corresponding author.
E-mail: darmono@uny.ac.id

https://dx.doi.org/10.21831/inersia.v19i1.60759
Received May 16th, 2023; Revised May 28th, 2023; Accepted May 30th 2023
Available online May 31st, 2023

strength quality affected by the wood water content with the UPV approach. There were three wood types tested in this test, namely kruing, sengon, and teak woods.

2. Materials and Method

a. Materials and equipments

This study tested 3 wood types, namely kruing (KR), sengon (S), and teak woods (JTB). There were 9 specimens for each of the wood types, so the total specimens were 27. The dimension of the specimens was 5 cm x 5 cm x 76 cm [4]. The equipments used in this tudy were the Ultrasonic Pulse Velocity (UPV) and the Universal Testing Machine (UTM).

b. Testing Scheme

In order to make the implementation of the research more focused. a research flow chart is made as Figure 1.

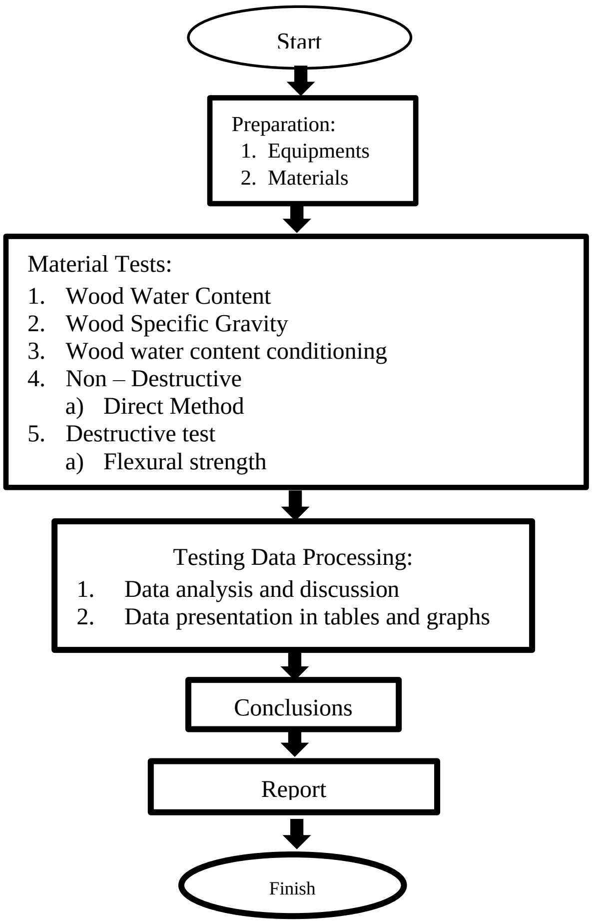

Figure 1. Reserach flow chart

c. Water content test

Wood water content is the amount of water existing in wood expressed in percentage of dry weight of its furnace [5]. Therefore before being tested, the tested wood should be dried to be in furnace dry condition (Figure 2). After the wood weight in the furnace dry condition is obtained, a wood weight plan is then established for the water contents of 12%, 15%, 20%, 25%, and 30%, can be observed on Table 1 to Table 3. The used of water content based on a testing have been conducted by [6] After a weight plan being set, the wood is soaked in water until a planned weight is obtained Figure 3. [7] To calculate the wood water content applys this equation formula (1):

$$MC\% = \frac{A-B}{B} \times 100 \qquad (1)$$

where MC is wood water content, A is soaked weight, and B is dry weight.

Figure 2. Wood drying

Figure 3. Wood soaking

Table 1. Table of weight plan for Kruing wood

Weight Determination for Kruing (KR) Wood						
Wood Code	Dry Weight (gr)	Wood Planned Weight				
		K.A 12% (gr)	K.A 15% (gr)	K.A 20% (gr)	K.A 25% (gr)	K.A 30% (gr)
KR 1	1275.7	1428.8	1467.1	1530.9	1594.7	1658.5
KR 2	1209.7	1354.9	1391.1	1451.6	1512.1	1572.6
KR 3	1257.3	1408.2	1445.9	1508.8	1571.7	1634.5
KR 4	1203.8	1348.3	1384.4	1444.6	1504.8	1565.0
KR 5	1291.6	1446.6	1485.4	1549.9	1614.5	1679.1
KR 6	1277.4	1430.7	1469.0	1532.9	1596.8	1660.6
KR 7	1227.2	1374.5	1411.3	1472.7	1534.1	1595.4
KR 8	1241.5	1390.4	1427.7	1489.8	1551.8	1613.9
KR 9	1216.4	1362.3	1398.8	1459.7	1520.5	1581.3

Table 2. Table of wieght plan for Sengon (S) wood

Weight Determination for Sengon Wood						
Wood Code	Dry Weight (gr)	Wood Planned Weight				
		K.A 12% (gr)	K.A 15% (gr)	K.A 20% (gr)	K.A 25% (gr)	K.A 30% (gr)
S1	504.5	565.0	580.1	605.4	630.6	655.8
S2	577.1	646.3	663.6	692.5	721.3	750.2
S3	479.9	537.5	551.9	575.9	599.9	623.8
S4	471.3	527.8	542.0	565.5	589.1	612.7
S5	494.5	553.8	568.7	593.4	618.1	642.9
S6	550.4	616.4	633.0	660.5	688.0	715.5
S7	608.9	681.9	700.2	730.7	761.1	791.5
S8	588.2	658.8	676.5	705.9	735.3	764.7
S9	629.5	705.1	723.9	755.4	786.9	818.4

Table 3. Table of weight plan for Teak wood (JTB)

Weight Determination for Teak Wood						
Wood Code	Dry Weight (gr)	Wood Planned Weight				
		K.A 12% (gr)	K.A 15% (gr)	K.A 20% (gr)	K.A 25% (gr)	K.A 30% (gr)
JTB1	1264.4	1416.2	1454.1	1517.3	1580.6	1643.8
JTB2	1186.5	1328.9	1364.5	1423.8	1483.2	1542.5
JTB3	1490.4	1669.2	1713.9	1788.4	1862.9	1937.5
JTB4	1335.0	1495.2	1535.2	1602.0	1668.7	1735.4
JTB5	1169.3	1309.6	1344.7	1403.2	1461.7	1520.1
JTB6	1306.3	1463.0	1502.2	1567.5	1632.8	1698.1
JTB7	1203.8	1348.2	1384.3	1444.5	1504.7	1564.9
JTB8	1163.2	1302.8	1337.6	1395.8	1454.0	1512.1
JTB9	1193.1	1336.3	1372.1	1431.7	1491.4	1551.0

d. Wood specific gravity test

The wood specific gravity test was conducted referred to Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials [8]. The wood specific gravity formula can be seen on formula (2) and the testing documentation shown in Figure 4.

$$\rho = K \times \frac{BKO}{V} \quad (2)$$

where ρ is specific gravity, BKO is oven dry weight, K is a conctant of 1000 (weight in gr and dimension in mm), and V is volume based on puncture diameter dan hole depth.

Figure 4. Wood specific gravity test

e. Ultrasonic Pulse Velocity Test

The specimens were tested by UPV test using direct method (Figure 5.) In this application the specimens were marked on the parts being tested, and before the test being conducted, the specimens were given gel and then two tranducers were placed, so the wave reading will be better. After gel was givern, the tranducers were placed on the tested wood so the reading results appeared. On the display unit. The UPV was conducted for the water content of 12%, 15%, 20%, 25%, and 30% [9]. The data in the form of wave velocity value were then used to calculate the wood stiffness value (elasticity modulus, MoEd) [10] [11] using the equation (3):

$$MoEd = \frac{V^2 x \rho}{g} \quad (3)$$

MoEd is dynamic elasticity Modulus (N/mm), ρ is wood specific gravity (g/cm^3), v is ultrasonic wave propagation velocity (m/det), and g is specific gravity constant (9,81 m/det^2).

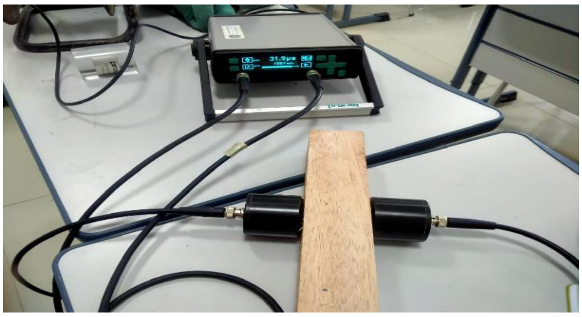

Figure 5. Ultrasonic Pulse Velocity Test

f. Flexural strength test

Based on the UTM test the following damage patterns were obtained as Figure 6 and Figure 7.

Notes:

1. The tested wood experienced a damage pattern of cross-grain tension where there are cracks on the crossing of grain direction.
2. The tested wood experienced a damage pattern of splinter tension where there are cracks forming flake shape on the wood surface.

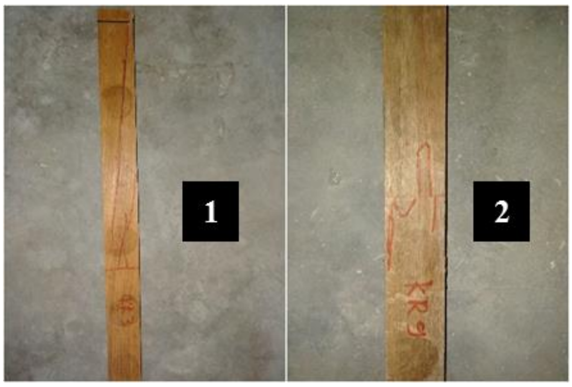

Figure 6. Damage pattern of kruing wood

Figure 7. Damage patterns of jati (left) and sengon (right) woods

The elasticy test applying UTM for Teak wood shows the damage pattern of splinter tension, where flakes exist on the wood surface [12].

a. The graph of plasticity test loading

Based on the obtained by elasticity test for kruing, sengon, and teak wood, the correlation graphs between existing load and deflection during the test can be seen on Figure 8 to Figure 16.

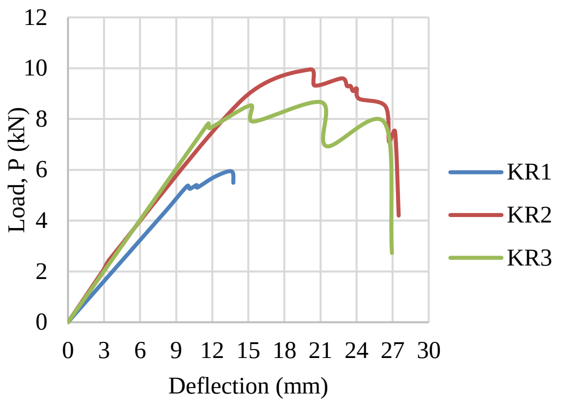

Figure 8. Correlation graph between load and deflection for kruing wood with 12% water content

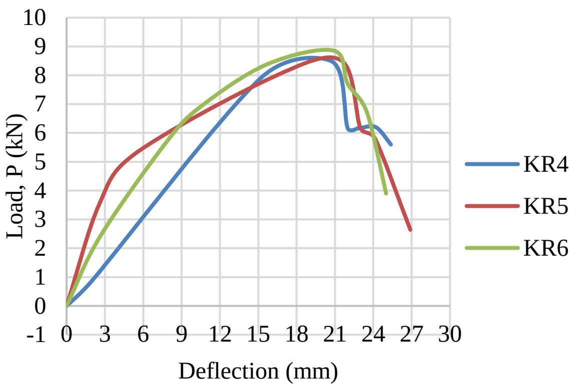

Figure 9. Correlation graph between load and deflection for kruing wood with 20% water content

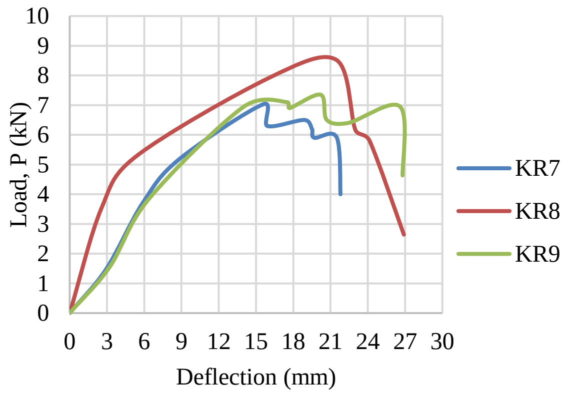

Figure 10. Correlation graph between load and deflection for kruing wood with 30% water content

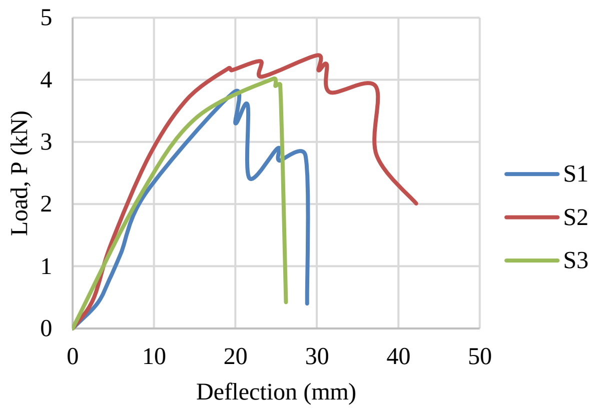

Figure 11. Correlation graph between load and deflection of sengon wood with 12% water content

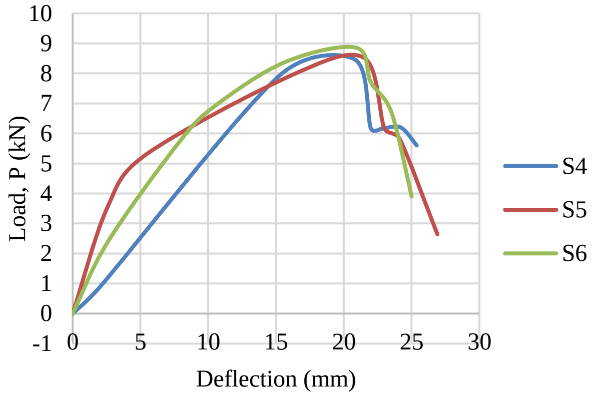

Figure 12. Correlation graph between load and deflection of sengon wood with 20% water content

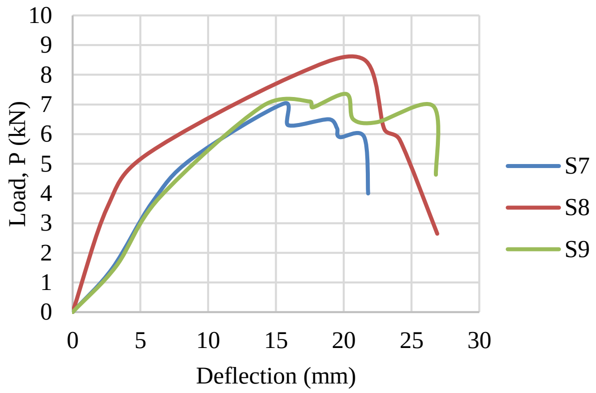

Figure 13. Correlation graph between load and deflection of sengon wood with 30% water content

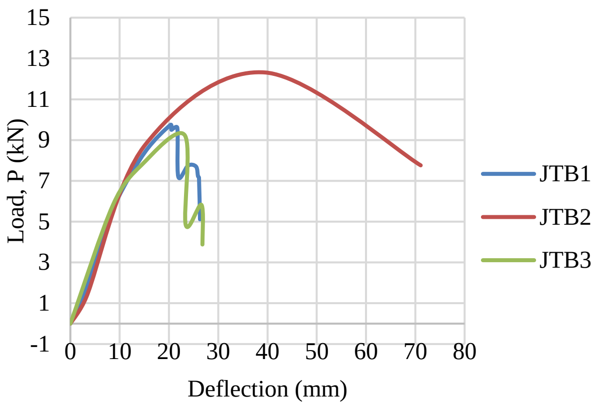

Figure 14. Correlation graph between load and deflection of jati wood with 12% water content

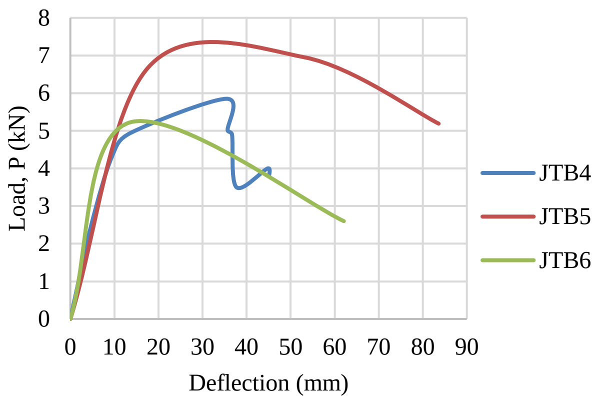

Figure 15. Correlation graph between load and deflection of jati wood with 20% water content

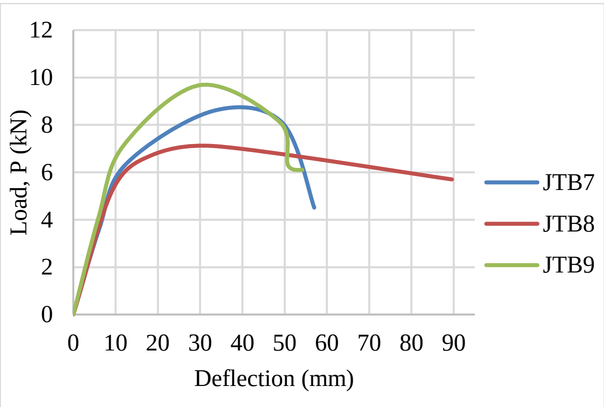

Figure 16. Correlation graph between load and deflection of jati wood with 30% water content

The test for flexural strength was conducted for 12%, 20%, and 30% water contents. The plasticity test was conducted referred to SNI [4]. This test uses UTM where the specimen is placed on a platform spanning 710 mm, the equipment is then pressed with a speed of 2.5 mm/minute (Figure 17 and Figure 18). By this test the plasticity elasticity modulus (MoE) and break plasticity stress (MoR) values are obtained. Those values can be calculated using the equations of (4) and (5):

$$MoE = \frac{PL^3}{4\Delta bh^3} \quad (4)$$

Where MoE is elasticity modulus (MPa), P is test maximum load (N), L is test span length, Δ is deflection (mm), b is test specimen width (mm), and h is test specimen height (mm).

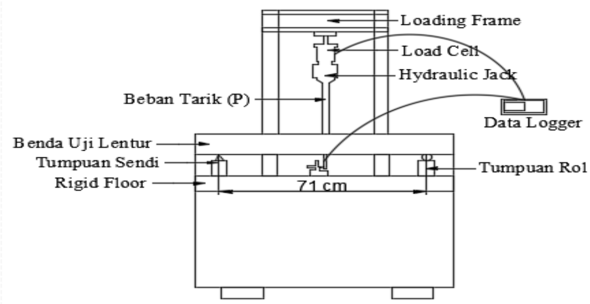

Figure 17. The UTM equipment

Figure 18. Flexural strengthtest

3. Results and Discussion

a. Water content test

The following tables show the results of the conducted tests for Kruing, Sengon, and Teak wood.

1) Water content test for Kruing wood

Table 4 shows the water content test results of Kruing wood. Figure 19 shows the actual water content resulted from soaking that has different values to the arranged water content. It could be caused by achieving the same as the arranged water content is difficult to be done.

2) Water content test for Kruing wood

Table 5 shows the conducted test results of water content for sengon wood. Figure 20 shows the actual water content resulted from soaking that has different values to the arranged water content. It could be caused by achieving the same as the arranged water content is difficult to be done.

3) The teak wood water content test

Table 6 shows is the teak wood water content test results. Figure 21 shows the actual water content resulted from soaking that has different values to the arranged water content. It could be caused by achieving the same as the arranged water content is difficult to be done.

Table 4. Kruing woods water content test results

Wood Code	Dry Weight (gr)	Soaked Weight (gr)	Water Content (%)
KR 1	1275	1450.4	13.76
KR 2	1209.5	1357.4	12.23
KR 3	1257	1412.5	12.37
Mean			12.79
KR 4	1203	1389	15.46
KR 5	1292	1492	15.48
KR 6	1277.5	1478	15.69
Mean			15.55
KR 4	1203	1467	21.95
KR 5	1292	1552	20.12
KR 6	1277.5	1569	22.82
Mean			21.63
KR 7	1227.5	1545	25.87
KR 8	1241.5	1556	25.33
KR 9	1216	1532	25.99
Mean			25.73
KR 7	1227.5	1605	30.75
KR 8	1241.5	1628	31.13
KR 9	1216	1602	31.74
Mean			31.21

Table 5. Sengon woods water content test results

Wood Code	Dry Weight (gr)	Soaked Weight (gr)	Water Content (%)
S1	504.5	569	12.78
S2	577	651.2	12.86
S3	480	540	12.50
Mean			12.71
S4	471.5	552.5	17.18
S5	494.5	578	16.89
S6	550	637.5	15.91
Mean			16.66
S4	471.5	568	20.47
S5	494.5	598	20.93
S6	550	664	20.73
Mean			20.71
S7	609	772	26.77
S8	588	736	25.17
S9	629.5	798	26.77
Mean			26.23
S7	609	799.5	31.28
S8	588	776	31.97
S9	629.5	822	30.58
Mean			31.28

Table 6. Taek wood water content test results

Wood Code	Dry Weight (gr)	Soaked Weight (gr)	Water Content (%)
JTB1	1265	1420	12.31
JTB2	1187	1335	12.52
JTB3	1490	1679	12.65
Mean			12.49
JTB4	1335	1545	15.73
JTB5	1170	1355	15.81
JTB6	1307	1520	16.34
Mean			15.96
JTB4	1335	1620	21.35
JTB5	1170	1410	20.51
JTB6	1307	1578	20.78
Mean			20.88
JTB7	1204	1512	25.58
JTB8	1163	1465	25.97
JTB9	1193	1502	25.90
Mean			25.82
JTB7	1204	1567	30.15
JTB8	1163	1515	30.27
JTB9	1193	1589	33.19
Mean			31.20

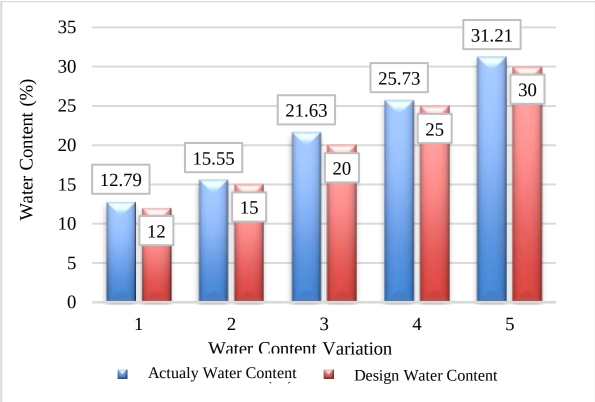

Figure 19. The graph of the test results of water content for kruing wood

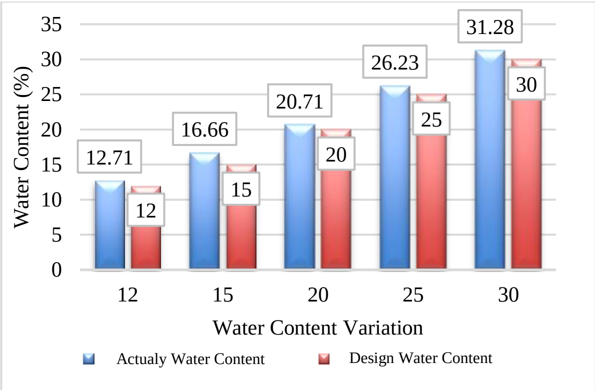

Figure 20. The graph of the test results of water content for sengon wood

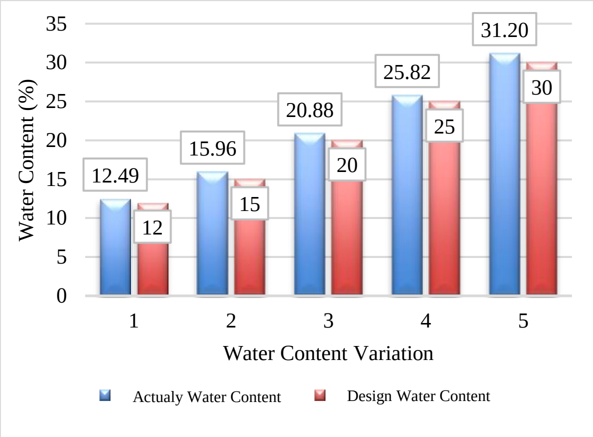

Figure 21. The graph of the test results of water content for teak wood

b. Specific gravity test

The specific gravity test results for Kruing, Sengon, and Teak Wood is displayed on Table 7 and Figure 22.

Table 7. Specific gravity test results

No.	Wood type	Wood Code	Mean
1	Kruing	KR	0.661
2	Sengon	S	0.295
3	Jati	JTB	0.632

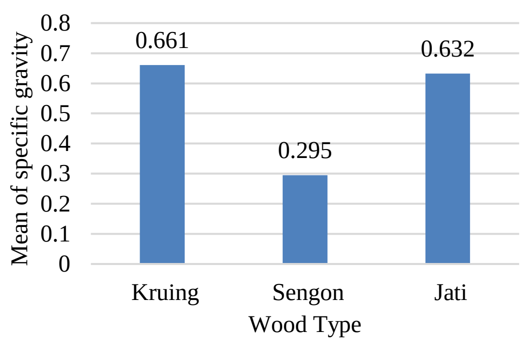

Figure 22. Graph of specific gravity test results

The graph shows the mean of specific gravity for kruing, Sengon, and Teak wood respectively 0.661, 0.295, and 0.63. Kruing wood has the highest specific gravity and the lowest specific gravity for sengon wood.

c. Ultrasonic Pulse Velocity Test

1) Wave propagation velocity value

a) Wave propagation velocity of Kruing wood

Table 8 and Figure 23. shows the wave propagation velocity test results of kruing wood for the arranged water content.

Table 8. The value of propagation velocity for kruing wood

Wood Type	Water Content (%)	Mean V (Km/s)
Kruing	12	1653.41
	15	1547.51
	20	1086.67
	25	1236.85
	30	899.21

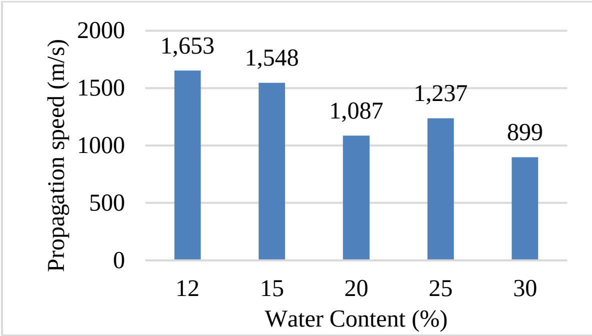

Figure 23. The propagation velocity graph of kruing wood

The wave propagation velocity for the water content of 12%, 15%, 20%, 25%, and 30% respectively 1653 m/s, 1.547 m/s, 1086.67 m/s, 1236.85 m/s, and 899.21 m/s. The decrease percentage of wave propagation velocity for the water content between 12% and 15% is 6.4%, for the water content between 15% and 20 % is 29.78%. For the water content of 20% and 25% an increase of wave propagation velocity 13.82% occurs, for the water content of 25% and 30% a decrease of 27.3% occurs. An increase of wave propagation velocity for the water content of 25% occurs. These could occur because of some causes such as innaccurate reading causing errors, and uneven distribution of vaselin coating on the tranducer surface and the specimens.

b) Wave propagation velocity of Sengon wood

Table 9 and Figure 24 shows the wave propagation velocity test results of sengon wood for the arranged water content.

Table 9. The value of propagation velocity for sengon wood

Wood Type	Water Content (%)	Mean V (m/s)
Sengon	12	1009.75
	15	1039.93
	20	823.06
	25	1335.63
	30	836.13

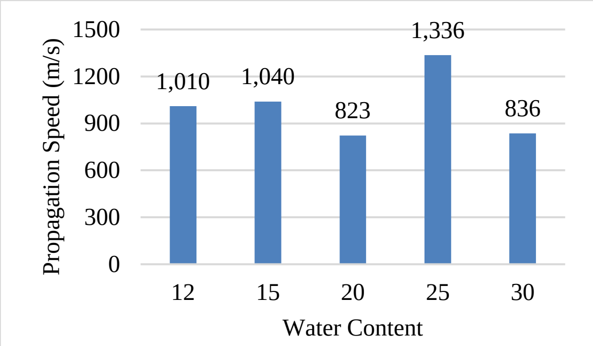

Figure 24. The propagation velocity graph of sengon wood

The wave propagation velocity for the water content of 12%, 15%, 20%,25%, and 30% respectively 1009.75 m/s, 1039.93 m/s, 823.06 m/s, 1335.63 m/s, and 836.13 m/s. An increase of 2.99% wave propagation velocity occurs for the water content of 12% and 15%, a decrease of 20.85% for the water content between 15% and 20%, an increase of 62.28% for the water content between 20% and 25 %, for the water content of 25% and 30% a decrease of 37.4% occurs. An increase of wave propagation velocity occurs for the water content of 25%. These could occur because of some causes such as innaccurate reading causing errors, and uneven distribution of vaselin coating on the tranducer surface and the specimens.

c) Wave propagation velocity of Teak wood

Table 10 and Figure 25. shows the wave propagation velocity test results of teak wood for the arranged water content.

Table 10. The value of propagation velocity for teak wood

Wood Type	Water Content (%)	Mean V (m/s)
Teak	12	1819.95
	15	1654.34
	20	1181.99
	25	1659.42
	30	1465.16

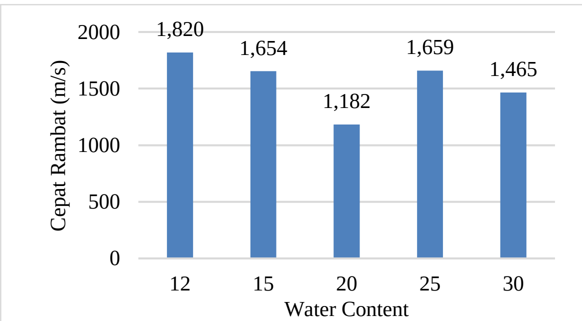

Figure 25. The propagation velocity graph of teak wood

The wave propagation velocity for the water content of 12%, 15%, 20%, 25%, and 30% respectively 1,82 km/s, 1.65 km/s, 1.18 km/s, 1.66 km/s, and 1.47 km/s. A decrease of wave propagation velocity of 9.1% occurs for the water content between 12% and 15%a decrease of 28.55% for the water content between 15% and 20%, an increase of 40.39% for the water content of 20% and 25%, and a decrease of 37.4% for the water content of 25% and 30%. An increase of wave propagation velocity occurs for the water content of 25%. These could occur because of some causes such as innaccurate reading causing errors, and uneven distribution of vaselin coating on the tranducer surface and the specimens.

2) MoEd Value

a) MoEd value of Kruing wood

Table 11 and Figure 26. shows the MoEd value of Kruing wood resulted from the conducted test of the arranged water content applying direct method.

Table 11. The MoEd value of kruing wood

Wood Type	Water Content (%)	MoEd (MPa)
Kruing	12	1814.7
	15	1763.5
	20	850.2
	25	1035.6
	30	547.6

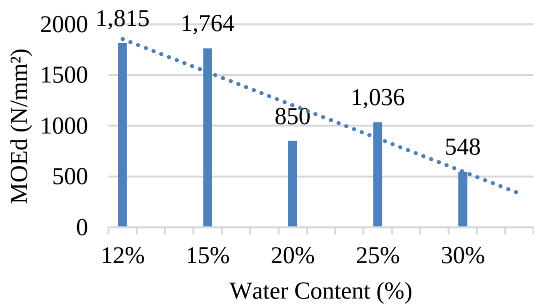

Figure 26. The MoEd value of kruing wood

The graph shows the MoEd value of Kruing wood for the water content of 12%, 15%, 20%, 25%, and 30% respectively 1814.7 MPa, 1763.5 MPa, 850.2 MPa, 1035.6 MPa ^{2}, and 547.6 MPa. The highest MoEd value of 1814.7 MPa for the water content of 12% and the lowest MoEd value of 547.6 Mpa for the water content of 30%.

b) MoEd value of Sengon wood

Table 12 and Figure 27. shows the MoEd value of Sengon wood resulted from the conducted test of the arranged water content applying direct method.

Table 12. The MoEd value of Sengon Wood

Wood Type	Water Content (%)	MoEd (MPa)
Sengon	12	315.0
	15	350.2
	20	211.9
	25	655.8
	30	218.0

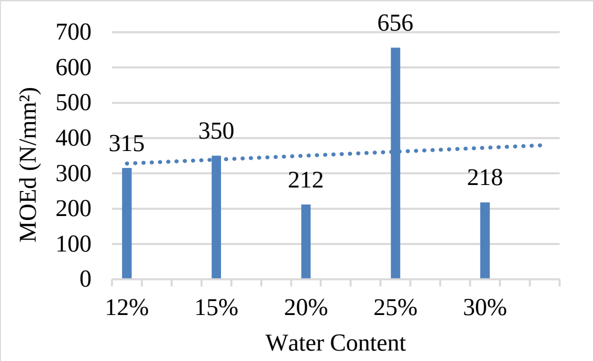

Figure 27. The graph of MoEd value for sengon wood

The graph shows the MoEd value of Sengon wood for water content of 12%, 15%, 20%, 25%, and 30% respectively 315 MPa, 350.2 MPa, 211.9 MPa, 655.8 MPa, and 218. MPa. The highest MoEd value is for 25% water content of 655.8 MPa and the lowest MoEd value is for 30% water content of 218 MPa.

c) MoEd value of Teak wood

Table 13 and Figure 28. shows the MoEd value of Teak wood from the conducted test for the arranged water content using direct method.

Table 13. The MoEd value of Teak wood

Wood Type	Water Content (%)	MoEd (MPa)
Teak	12	2129.3
	15	1867.1
	20	944.1
	25	1891.2
	30	1445.9

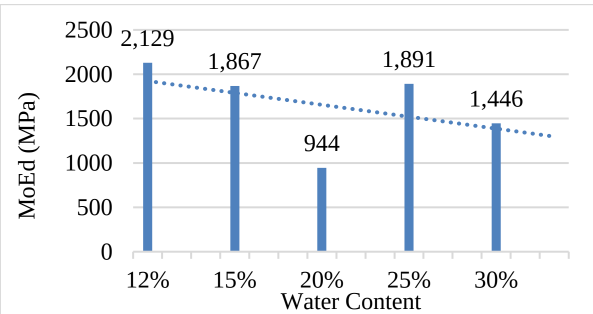

Figure 28. The MoEd value of teak wood

The graph shows the MoEd value of teak wood for the water contents of 12%, 15%, 20%, 25%, and 30% respectively 2129.3 MPa, 1867.1 MPa, 944.1 MPa, 1891.2 MPa, and 1445.9. MPa. The highest MoEd value is for 12% water content of 2129.3 MPa, and the lowest MoEd value is for 20% water content of 944.1 MPa.

d. Flexural strength test

1) Modulus of elasticity value (MoE)

a) MoE value of Kruing wood

The Table 14 and Figure 29. shows the MoE value of Kruing wood, from the conducted test for the arranged water content.

Table 14. The MoE value of kruing wood

Wood Type	Water Content (%)	MoE (MPa)
Kruing	12	6335.89
	20	5889.79
	30	5214.52

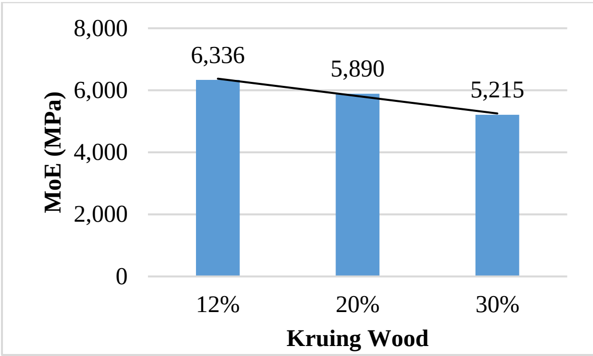

Figure 29. The graph of MoE value for kruing wood

The graph shows the MoE value of Kruing wood for the water contents of 12%, 20%, and 30% respectively 6335.89 MPa, 5889.79 MPa, 5214.52 MPa. The highest MoE value is for 12% water content of 6335.89 MPa and the lowest MoE is for 30% water content of 5214.52 MPa.

b) The MoE value of Sengon Wood

Table 15 and Figure 30. shows the MoE value of Sengon wood from the conducted test for the arranged water content.

Table 15. The MoE value for sengon wood

Wood Type	Water Content (%)	MoE (MPa)
Sengon	12	2344.04
	20	2142.34
	30	1567.15

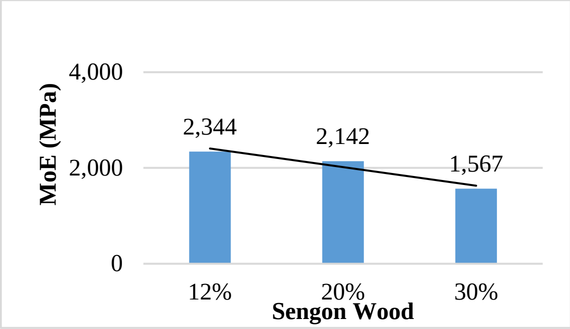

Figure 30. The graph of MoE value for sengon wood

The graph shows the mean MoE value of Sengon for the water contents of 12%, 20%, and 30% respectively 2344.04 MPa, 2142.34 MPa, and 1567.15 MPa. The highest MoE value is for 12% water content of 2344.04 MPa and the lowest MoE value is for 30% water content of 1567.15 MPa.

c) MoE value of Teak wood

Table 16 and Figure 31. shows the MoE value of Jati wood from the conducted test for the arranged water contents.

Table 16. The MoE value for Teak wood

Wood Type	Water Content	MoE (MPa)
Teak	12	4894.90
	20	2492.58
	30	2932.98

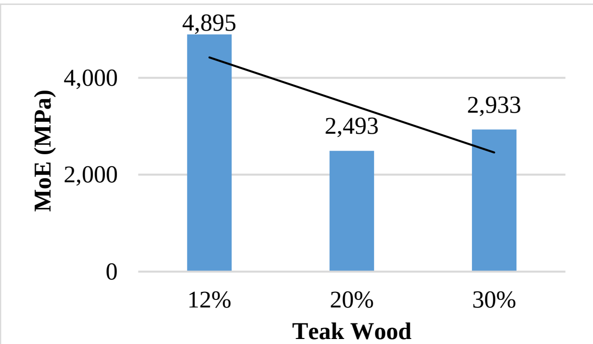

Figure 31. The graph of MoE value for teak wood

The above graph shows the mean MoE value of Teak wood for the water contents of 12%, 20%, and 30% respectively 4894.9 MPa, 2492.58 MPa, 2932.98 MPa. The highest MoE value is for 12% water content of 4894.9 MPa and the lowest MoE value is for 20% water content of 2492.58 MPa

e. Correlation Between MoE Value and MoEd Value Using *UPV*

Correlation test was conducted applying a computer program. The test aims to identify a trend of the graph, and to obtain a formula used to set the real value of the UPV test.

a) Correlation of Kruing Wood

Figure 32 shows the graph of the scatter plot.

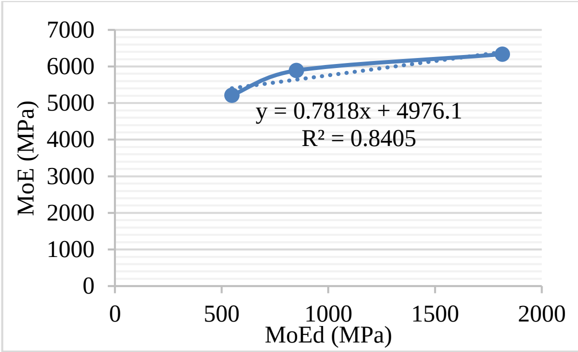

Figure 32. The Scatter Plot Graph for Kruing Wood

The graph shows a rightward trendline, meaning that there is a positive correlation. The R^2 value is 0.8405 so the two variables have a strong correlation. It is also obtained a formula of y = 0.7818 + 4976.1 meaning that the real MoE values of the UPV test results are 0.7818 times the MoEd value plus a constant of 4976.1, so the real value of the UPV test for kruing wood shown in Table 17.

Table 17. The Converted Table of MoEd Value for Kruing Wood

Water Content (%)	MoEd (MPa)	Converted MoE Value (MPa)
12	1814.69	6394.8
20	850	5640.6
30	547.6	5404.2

b) Correlation for Sengon Wood

Figure 33 shows a graph of the scatter plot.

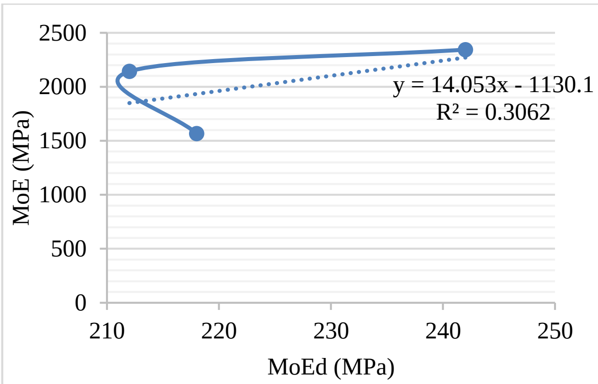

Figure 33. The scatter plot graph for sengon wood

The graph shows a rightward trendline, meaning that there is a positive correlation. The R^2 is 0.31 so the two variables have a weak correlation. It is also obtained a formula of y = 14.053 – 1130.1 meaning that the real MoE values of the UPV test 14.053 times the MoEd values minus a constant of 1130.1, so the real values of the UPV test for kruing wood shown in Table 18.

Table 18. The Converted Table of MoEd Value for Sengon Wood

Water Content (%)	MoEd (MPa)	Converted MoE Value (MPa)
12	242	2270.7
20	212	1849.1
30	218	1933.5

c) Correlation of Teak Wood

Figure 34 shows the graph of the scatter plot.

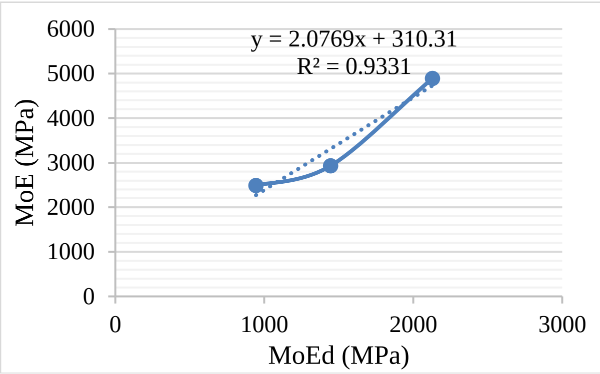

Figure 34. The scatter plot graph for teak wood

The graph shows a rightward trendline, meaning that there is a positive correlation. The R^2 svalue is 0.9331 so the two variables have a strong correlation. It is also obtained a formula of y = 2.0769 + 310.31 meaning that the real MoE values of the UPV test are 2.0769 times the MoEd values plus a constant of 310.31, so the real UPV test for kruing wood shown in Table 19.

Table 19. The Converted Table of MoEd Value for Jati Wood

Water Content (%)	MoEd (MPa)	Converted MoE Value (MPa)
12	2129.3	4733.7
20	944.1	3313.3
30	1445.9	2271.1

f. The Influence of Wood Water Content to Wave Propagation Velocity

This study conducted the UPV test for five water content variations. The results of the conducted tests are the wave propagation velocity will be smaller due to the larger water content of the wood. According to them, this is caused by th e UPV will be larger for solid materials (cell wall) when it is compared to liquid (water). On the other hand, for the water content above the fiber saturation point (25-30% water content), there is water inside both hollow and wall of the cell. It means atenuation (energy weakening) will be larger causing a decrease of wave propagation velocity on the wood [6].

g. The Influence of Wood water Content to Wood MoEd Value

This study conducted analysis of the influence of wood water content to the wood MoEd value for five water content variations. The results shows that the wood MoEd values will be smaller due to the larger wood water contents. The wood MoEd values are in line to the wave propagation velocity because the two are directly proportional. The decrease of the MoEd values for Kruing wood is -21 – 47.13%, for sengon wood is -200.48 – 66%, and for Teak wood is -100 – 49.43%. There are minus (-) values in the percentage canges showing that there are increases of the MoEd values.

h. Comparison of Flexural Strength Result and Ultrasonic Pulse Velocity

This study tested the flexural strength for three variation of water content. The analysis results in the wood MoE and MoR values. Table 20. show the water content and the wood MoE and MoR values of the tested:

Table 20. Comparison of Wood Quality Based on Modulus of Elasticity (MoE) and Modulus of Elasticity Dynamic (MoEd)

Wood Type	Water Content (%)	MoE (MPa)	MoEd (MPa)	Differences of MoE and MoEd (%)
Kruing	12	6335.39	6394.8	0.9
	20	5889.79	5640.6	4.43
	30	5214.52	5404.2	3.64
Sengon	12	2344.1	2270.7	3.23
	20	2142.34	1849.1	15.9
	30	1567.15	1933.5	23.4
Teak	12	4894.9	4733.7	3.4
	20	2490.75	3313.3	33
	30	2932.53	2271.1	29

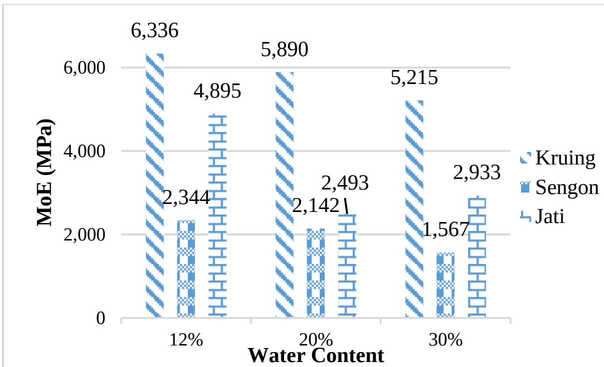

Figure 35. The Graph of MoE Value Comparison

Based on Figure 35, it could be identified that there is a decrease of the wood MoE value due to the wood water content. This conforms with the research [6] on the

Jatoba wood, there were decreases of the MoE value for the water contents of 12%, 20%, and 30% respectively in 17204 MPa, 15682 MPa, and 15257 MPa. This is shown on Kruing and Sengon wood, but this does not occur for Teak wood that the MoR and MoE values increase only for the water contents between 20% and 30%. This occurs for the random samples of Teak wood, the samples were originated from the different parts of trees. Each part of the trees has different mechanical properties also called anisotropic properties of wood. The MoE value of the Kruing wood decrease of 7.6-12.9%, while the MoE score decreases between -8 to 21.1% with the minus (-) score shows the increase of the MoR value. The MoE value of Sengon wood decreases of 9.4-36.7%, while the MoR value decreases of 12.9-24.2%. The MoE value of the Teak wood decreases between -15.1 and 96.57%, with the minus (-) value shows an increase of the MoE value, while its MoR value decreases of 9-13.4%.

4. Conclusions

A series of tests for Kruing, Sengon, and Teak woods concludes as follows.

1. Based on the MoE value of the jati wood, there was a quality decrease, at the beginning the quality code of E8 decreased to E5. Based on the MoE value of the sengon wood, the tested value was too low to be included in the existing quality codes. Based on the MoE value, the kruing wood experienced the quality decrease from E12 wuality code to E5.
2. Correlation between MoE value and MoEd value is directly proportional, shown in the scatter plot graph that tends to tilt to the right.
3. The MoE value for kruing wood compared to the converted MoEd value was 0.9 – 4.43%. The MoE value for sengon wood compared to the converted MoEd value was 3.23 – 23.4%. The MoE value for teak wood compared to the converted MoEd value was 3.4 – 33%.
4. The influence of water content on the MoEd value of Kruing wood decreases of -21 – 47.13%, for Sengon woof of -21 – 47.13%, and for Teak wood of -100 – 49.43%. The minus (-) value of the change percentages shows the increase of MoEd value.

5. References

[1] E. Setyowati, G. Hardiman, and T. W. Murtini, “Cultural Acculturation in the Mataram Mosque Building, Yogyakarta,” no. April, pp. A011–A018, 2017, doi: 10.32315/sem.1.a011.

[2] D. Darmono, M. S. Nugroho, S. Widodo, and F. Ma’arif, “Analysis Of Decreasing Wood Quality In Cultural Heritage Building Using The Non-Destructive Test Method (Case Study of the Mosque Cultural Heritage Building, Mataram, Special Region of Yogyakarta),” *INERSIA lnformasi dan Ekspose Has. Ris. Tek. Sipil dan Arsit.*, vol. 16, no. 2, pp. 191–199, Dec. 2020, Accessed: May 29, 2023. [Online]. Available: https://journal.uny.ac.id/index.php/inersia/article/view/36905

[3] William D Callister et al, *Materials Science and Engineering*, 10th ed. 2018. Accessed: May 30, 2023. [Online]. Available: https://ftp.idu.ac.id/wp-content/uploads/ebook/tdg/Teknologi Rekayasa Material Pertahanan/Materials Science and Engineering An Introduction by William D. Callister, Jr., David G. Rethwish (z-lib.org).pdf

[4] BSN, *SNI 03-3959-1995 Methods for testing the flexural strength of wood in the laboratory*. 1995, pp. 1–9.

[5] X. Arzola-Villegas, R. Lakes, N. Z. Plaza, and J. E. Jakes, “Wood moisture-induced swelling at the cellular scale—ab intra,” *Forests*, vol. 10, no. 11, p. 996, Nov. 2019, doi: 10.3390/f10110996.

[6] D. A. L. Silva, F. A. R. Lahr, O. B. De Faria, and E. Chahud, “Influence of wood moisture content on the modulus of elasticity in compression parallel to the grain,” *Mater. Res.*, vol. 15, no. 2, pp. 300–304, 2012, doi: 10.1590/S1516-14392012005000025.

[7] ASTM D4442-16, “Standard Test Methods For Direct Moisture Content Measurement Of Wood And Wood-Base Materials,” *Annu. B. ASTM Stand.*, vol. 4, no. 10, pp. 1–6, 2016.

[8] ASTM D729, *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*. 2008, p. 6. doi: 10.1520/D2395-17.2.

[9] L. Karlinasari, S. Suljokusumo, N. Nugroho, and Y. S. Hadi, “Non-Destructive Testing of Three Indonesian Plantations Wood Beam,” *J. Teknol. Has. Hutan, Fak. Kehutan. IPB*, vol. 19, 2006.

[10] BSN, *SNI ASTM C597:2012 Test method for speed of wave propagation through concrete*. 2012, pp. 1–10.

[11] P. R. A. Smith, “Non-Destructive Testing (NDT) – Guidance Document: An Introduction to NDT

Common Methods," *Br. Inst. NDT*, no. 2, p. 159, 2015, [Online]. Available: http://www.bindt.org/admin/Downloads/Apprenticeship-Guidance-Document.pdf

[12] W. Products, W. Materials, and H. M. Meters, "D4761-11 Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material," vol. i, no. 1, pp. 1–10, 2011.