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INCREASED MOE AND MOR VALUES OF DENSIFIED BOARDS USING MOE/MOR AND MOR/MOE RATIOS

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ABSTRACT

Densification is one of the effective techniques for improving the strength of low wood density. This technique is the process of pressing wood so that it increases in volume but decreases in density. This research focused on the densification of Sengon wood species (*Paraserianthes falcataria*) with a combination of two factors: compaction target (Factor I) and heating time (Factor II). Dunnet's test results showed that an insignificant increase for Modulus of Elasticity (MOE) occurred at the compaction target of 20%, while for MOR (modulus of Rupture) was at the compaction target of 20% with a heating time of 0. However, using the comparison method, the MOE values of densified boards calculated by the MOR unit increased, while the MOR values of densified boards calculated by the MOE unit decreased. Thus, a new phenomenon occurred that the actual increase in MOE and MOR values of densified boards was indicated by the increase and decrease in the comparative values.

KEY WORDS

Modulus of elasticity, modulus of rupture, MOE/MOR ratio.

Theoretically, wood is plastic and elastic, so it is easy to shape. With simple technology, wood density can be increased by densification. Wood with increased density will be more rigid and stiffer so that it can be used for specific applications, for example, as the material for floors, ceilings, and others.

Until now, the demand for wood in the market remains high because the community's need for wood is irreplaceable, either as a building material, furniture or others. In fulfilling the market demand for timber, producers are currently providing the market with various types of mixed wood because some commercial varieties of wood such as *Meranti* (Shorea sp.), *Kapur* (Dryobalanops), and others are highly difficult to obtain. The use of mild steel and aluminum as the construction material has been replaced by wood since both are limited in terms of availability (metals are non-renewable resources) and the price (metals are pretty expensive, especially for the common people).

Murhofik (2000) and Rilatupa (2000) in Wardhani (2005) have suggested that densification of Sengon and Aghatis woods up to 50% results in increased density of more than 100%, increased MOE and MOR values of 90% (Murhofik, 2000) and improved mechanical properties of 100-246% (Rilatupa 2000).

Densification on *Pulai* (*Alstonia scholaris*) wood species could increase the wood density up to 30% with a decrease in the thickness from 6.5% to 2.9% - 4.5%, indicating that densification affects the dimensional stability of wood (Farah, 2009).

This research used *Sengon* wood species, representing the type of wood from *Hutan Tanaman Industri* (*HTI*)[1]. *Sengon* grows faster and spreads widely in areas owned by companies or those by the community. *Sengon* has a low specific gravity of 0.33, so its density needs to increase (Martawijaya and Kartasujana, 1977).

Densification can also increase wood strength properties, such as flexural strength (MOE, MOR, and stress at the proportion limit), compressive strength, tensile strength, shearing strength, stiffness, and crushing strength more than 150% (USDA, 1999).

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[1] *Industrial Plantation Forest.*

The benefit of this research is to provide information on the increased MOE and MOR values after the densification process.

METHODS OF RESEARCH

The MOE and MOR values were calculated using the Universal Testing Machine (UTM) tool, while the effect of the treatments and the interaction of the two combined factors (compaction target and heating time) was analyzed using a completely randomized design of 2 (two) factors with 3x3 designs. Furthermore, the flexural values were calculated using the MOE/MOR ratio and changes in the stiffness values were calculated using the MOR/MOE ratio.

Preparation of Wood Samples. The *Sengon* tree (*Paraserianthes falcataria*) used in this research was about 80 cm in diameter. Samples were taken in a straight section in the middle of the stem. These samples were then made into boards with a thickness of 4 cm and a length of 2 m. Following the required samples, the wood used was between the radial and tangential planes about 10 cm from the pith and 10 cm from the edge of the stem. These boards were left and placed in the open air for about 3 months, to be then made into 1 (one) sample piece (control) sized 40 cm x 40 cm x 2.5 cm, 1 (one) sample piece sized 40 cm x 40 cm x 3.0 cm, and 1 (one) sample piece sized 40 cm x 40 cm x 3.5 cm. Before the densification process, the boards were air-dried until they reached 12-18% moisture content for approximately 6 (six) weeks.

The Process of Densification. Before densification, the sample boards were boiled for 45 minutes at 100^{o}C. The boards were added after water boiled. After the boiling was done, the boards were immediately wrapped in aluminum foil and put into a pressing machine. Pressing was done after the temperature reached 150^{o}C. There were 2 (two) factors combined, namely compaction target and heating time. The measures of compaction target were 2.5 cm (at 20% target), 3.0 cm (at 33% target), and 3.5 cm (at 43% target), while the measures of the heating time were 0 minutes (0'), 3 minutes (3') and 6 minutes (6'). Pressing was carried out so that when the compaction target thickness and heating time were reached, the pressing machine would automatically turn off, and the samples were taken out after 24 hours. After the densification process, the densified boards were air-dried again for about 6 (six) weeks until the moisture content reached 12-18%.

The Process of Making Test Samples. The mechanical properties tested were Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). The testing of mechanical properties in this research referred to the JIS Z 2113 (1963). The illustration of the shape and size of the tested samples can be seen in the following figure.

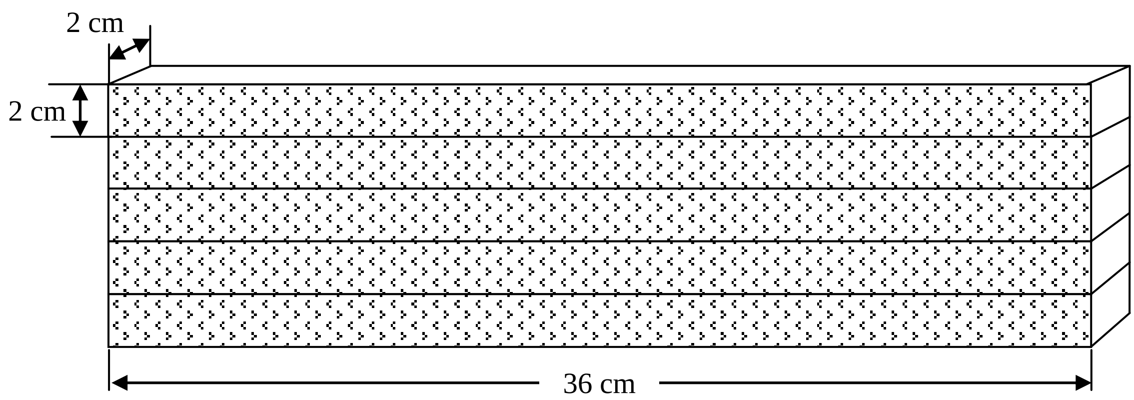

Figure 1 – Samples for MOE and MOR Tests

This research used a Completely Randomized Design with a two-factorial experiment, consisting of Factor I (compaction target of 20%, 33%, and 43%) and Factor II (Heating Time of 0', 3', and 6'), with 5 (five) replications respectively.

RESULTS AND DISCUSSION

The MOE value variance analysis showed that the densification process was influenced by the compaction target treatments, heating time, and the interaction of the two. However, based on Dunnet's advanced test results, the 20% compaction target did not show a significant difference.

Table 1 – Increased MOE Values Based on Dunnet's Test Results

Target & Time	μ1 (MOE)	μ2 (Control)	|μ2 - μ1|	DLSD	Increase (%)
20%	87,559.03	69,184.86	18,374.17	20,473.44	20.98
33%	105,169.66	69,184.86	35,984.79 *	20,473.44	34.22
43%	129,539.56	69,184.86	60,354.70 *	20,473.44	46.59
0'	93,234.54	69,184.86	24,049.68 *	20,473.44	25.79
3'	106,155.98	69,184.86	36,971.11 *	20,473.44	34.83
6'	122,877.73	69,184.86	53,692.87 *	20,473.44	43.70

Table 1 above indicates that, compared to the control values, the MOE values based on the compaction target treatments increased by 20.98% at 20% compaction target, 34.22% at 33% compaction target, and 46.59% at 43% compaction target. Meanwhile, based on the heating time, the MOE values increased by 25.79% at 0' heating time, 34.73% at 3' heating time, and 43.70% at 6' heating time. The increase in the MOE values is logically due to the increased compaction targets so that the wood becomes stiffer and more rigid.

|μ2 - μ1| is the absolute value showing a significant increase and decrease. If μ1 > μ2 > DLSD, the increase is significant and if μ1 < μ2 > DLSD, the decrease is significant. As shown in the table above, the increased MOE value at the 20% compaction target was not significant because the difference of |μ2 - μ1| is less than the DLSD value.

The increased MOE values in Table 1 can be depicted in the following histogram.

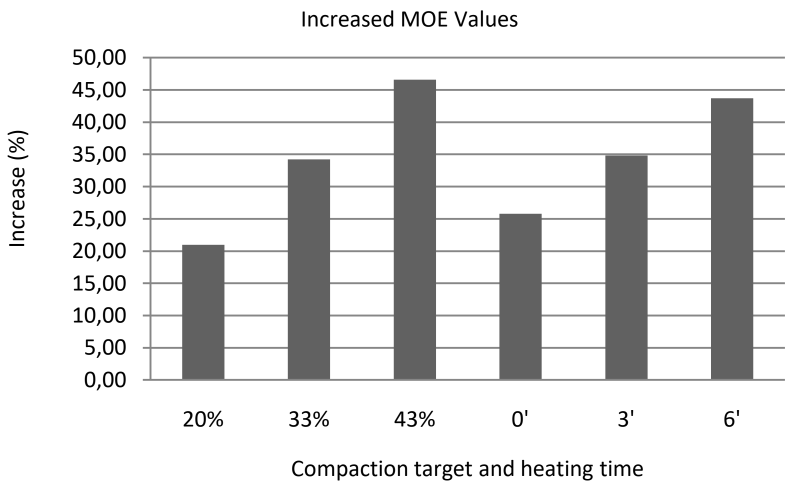

Figure 2 – Increased MOE Values Based on Compaction Target and Heating Time

Table 2 – Increased MOR Values Based on Dunnet's Test Results

Target and Waktu	μ1 (MOR)	μ2 (Control)	|μ2 - μ1|	DLSD	Increase (%)
20%	554.99	520.7	34.28	59.53	6.18
33%	582.65	520.7	61.94 *	59.53	10.63
43%	656.79	520.7	136.08 *	59.53	20.72
0'	540.44	520.7	19.74	59.53	3.65
3'	609.4	520.7	88.69 *	59.53	14.55
6'	644.58	520.7	123.88 *	59.53	19.22

The MOR value variance analysis showed that the densification process was only not influenced by the compaction target treatments. All the criteria analyzed, based on the variance of heating time, the interaction of the two (compaction target and heating time), and others, had a significant effect. However, based on Dunnet's advanced test results, the increased MOR values at the 20% compaction target and the 0' heating time did not show a significant difference.

Table 2 confirms that, compared to its control value, the MOR values based on the compaction target treatments increased by 6.18% at 20% compaction target, 10.63% at 33% compaction target, and 20.72% at 43% compaction target. Meanwhile, based on the heating time, the MOR value increased by 3.63% at 0' heating time, 14.55% at 3' heating time, and 19.22% at 6' heating time. The increased MOE values stimulate the increase in the MOR values because the relationship between MOE and MOR is powerful to a certain extent. It is said to a certain extent because *it is logically very unlikely for wood to be very stiff and flexible at once*. This research further discussed this matter using the MOE/MOR and MOR/MOE ratios.

As explained in the previous, |μ2 - μ1| is the absolute value showing a significant increase and decrease. If μ1 > μ2 > DLSD, the increase is significant and if μ1 < μ2 > DLSD, the decrease is significant. The table above reveals that the 20% compaction target and the 0' heating time showed an insignificant increase.

The increased MOR values in Table 2 can be depicted in the following histogram.

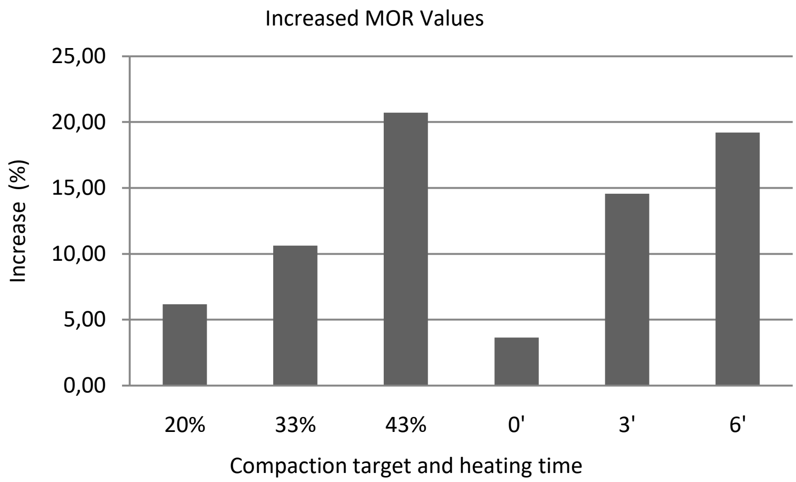

Figure 3 – Increased MOR Values Based on Compaction Target and Heating Time

Each type of wood or object has an ideal equilibrium ratio of MOE/MOR due to its flexibility and stiffness in a particular composition differentiating one another. This perfect equilibrium will change in densified wood, where the results of densification can cause the wood to be more flexible or stiffer. This value cannot be the same because any object, including wood, is very unlikely to be very flexible and stiff at once. The MOE-MOR equilibrium can be illustrated as follows:

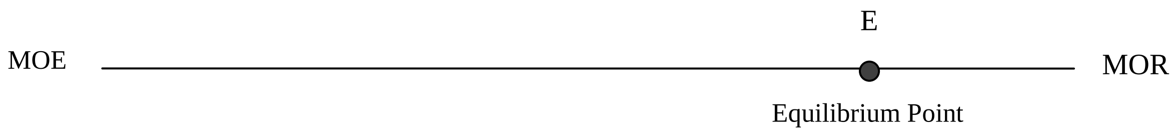

Figure 4 – Illustration of MOE-MOR Equilibrium

The illustration above shows that the equilibrium point (E) changes according to the increase occurring. If the MOE value increases after the densification, the E point will move to the right, while if the MOR value increases after the densification, the E point will move to the left.

The MOE and MOR values can be ratioed for several reasons as follows:

- The calculation of MOE and MOR uses the same unit (kg/cm^2);

- Data are taken using the same sample;
- The calculation of MOE and MOR uses the same data.

Changes in the MOE values due to densification can be seen from the MOE/MOR ratios presented in Table 3 below.

Table 3 – MOE/MOR Ratios as a Benchmark of Changes in MOE Values

Target and Time	MOE	MOR	MOE/MOR	MOE ↑ / ↓
Control	69,184.86	520.7	132.9 MOR	Control
20%	87,559.03	554.99	157.8 MOR	↑
33%	105,169.66	582.65	180.5 MOR	↑
43%	129,539.56	656.79	197.2 MOR	↑
0’	93,234.54	540.44	172.5 MOR	↑
3’	106,155.98	609.4	174.2 MOR	↑
6’	122,877.73	644.58	190.6 MOR	↑

Table 3 depicts that MOE values of the densified boards increased compared to those of the control boards. The MOE values increased from 132.9 MOR at the control to 157.8 MOR at 20% target, 180.5 MOR at 33% target, and 197.2 MOR at 43% target based on the target compression. Similarly, based on the heating time, the MOE values increased from 132.9 MOR at the control to 172.5 MOR at 0’ time, 174.2 MOR at 3’ time, and 190.6 MOR at 6’ time.

Here is the MOE/MOR histogram of the densification results.

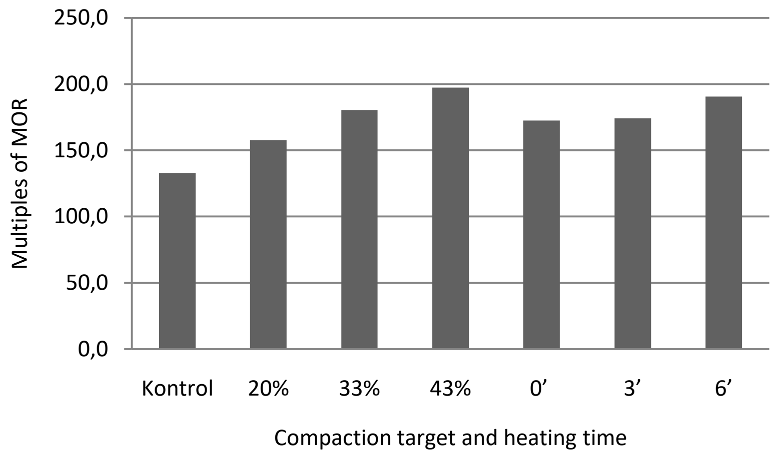

Figure 5 – Multiplies of MOE/MOR Values Based on Compaction Target and Heating Time

Changes in the MOR values after densification can be seen from the MOR/MOE ratios presented in Table 4 below.

Table 4 – MOR/MOE Ratios as a Benchmark of Changes in MOR Values

Target and Time	MOE	MOR	MOR/MOE	MOR ↑ / ↓
Control	69,184.86	520.7	0.0075 MOE	Control
20%	87,559.03	554.99	0.0063 MOE	↓
33%	105,169.66	582.65	0.0055 MOE	↓
43%	129,539.56	656.79	0.0051 MOE	↓
0’	93,234.54	540.44	0.0058 MOE	↓
3’	106,155.98	609.4	0.0057 MOE	↓
6’	122,877.73	644.58	0.0052 MOE	↓

Table 4 shows that MOR values of the densified boards decreased compared to those of the control boards. The MOR values decreased from 0.0075 MOE at the control to 0.0063 MOE at 20% target, 0.0055 MOE at 33% target and 0.0051 MOE at 43% target based on the target compression. Likewise, based on the heating time, the MOR values of the densified board decreased from 0.0075 MOE at the control to 0.0058 MOE at 0' time, 0.0057 MOE at 3' time, and 0.0052 MOE at 6' time.

Here is the MOR/MOE histogram of the densification results.

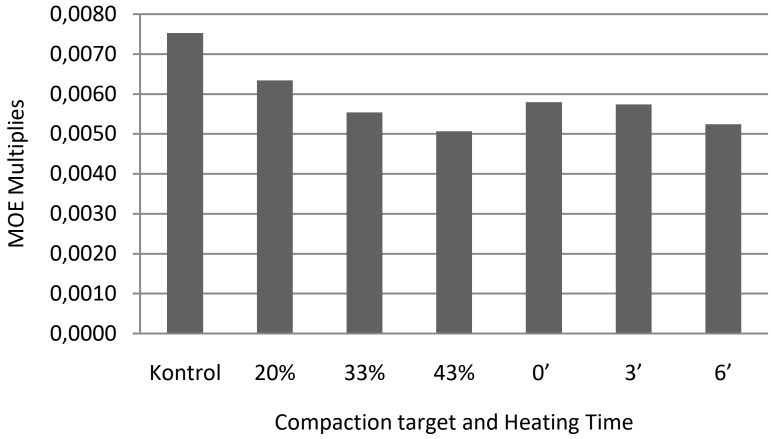

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Figure 6 – Multiplies of MOR/MOE Values Based on Compaction Target and Heating Time

CONCLUSION

Based on Dunnet's advanced test results, the simultaneous increase in the MOE and MOR values compared to the control is relative because, if viewed from the MOE/MOR and MOR/MOE ratios, there could be a decrease in either the MOE or MOR.

The increased MOE value with the MOR unit and the increased MOR value with the MOE unit are easy to understand, as shown in Table 3 and Table 4.

This research indicates that the increased MOE values with the MOR unit presented in Table 3 can decrease the MOR values with the MOE unit, as shown in Table 4.

The ratio method, both MOE/MOR and MOR/MOE, can immediately reveal the increase and decrease in the MOE and MOR values.

The increase or decrease obtained is not relative but absolute because if the MOE value increases, the MOR will decrease and vice versa.

This calculation method can explain that no objects, including wood, are logically able to be increased in stiffness and flexibility at the same time.

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