Basic properties of parallel strand lumber from oil palm trunk wastes (*Elaeis guineensis* Jacq.) bonded by isocyanate adhesive

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Abstract. This research was conducted to produce high quality Parallel Strand Lumber (PSL) made from oil palm trunk waste bonded by isocyanate adhesive. The basic properties tested were the physical properties (moisture content, density, volume shrinkage) and mechanical properties (Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)). The thicknesses of long strand were 0.3 cm and 0.6 cm, while the widths were 2 cm, 4 cm, and 6 cm. Based on the statistical analysis using anova assessment, the width of long strands influence significantly volume shrinkage, MOE and MOR. Meanwhile, the long strand thickness affected significantly MOE and MOR.
The PSL moisture contents were 10.73 to 11.95%. The densities were 0.62 to 0.63 g/cm^3.The volume shrinkages were 1.18 to 1.98%. The PSL MOEs were 1.75 x 10^4 to 2.6 x 10^4 kg/cm^2 and the MORs were 117 to 246 kg/cm^2. In general, PSL made from oil palm trunk waste failed to meet the minimum requirement set forth by JAS 1152 (2007).
Keywords: isocyanate, oil palm trunk, waste, physical and mechanical properties.

1. Background

The oil palm plantation is very important for Indonesia whose number and size of oil palm plantation area increase from year to year. Since the 1980s oil palm plantations have continued to increase significantly. This increase in the number of oil palms is directly increase proportionally to the waste produced by the plantations.

Oil palm has a productive lifespan is up to 30 years. Several researches proved that after 30 years the productivity of oil palm classified as unproductive. In most cases, the unproductive oil palm trees will be rejuvenated by being cut and replaced with new oil palm crops. The result of this rejuvenation is the oil palm waste that is generally only chipped or burned in the plantation area. Therefore, appropriate technology is needed to utilize the oil palm waste, especially oil palm trunk and frond. The unproductive oil palm will be felled and most of the oil palm biomass including trunk are left to rot on plantation areas and considered to be the oil palm agricultural waste [1, 2].

Up till now, oil palm trunk waste has not been utilized optimally in Indonesia. On the other hand, utilization of wood as biocomposite products raw material increased but not supported by sufficient wood supply from the forests. Utilization of oil palm trunk waste as raw material of composite products such as Parallel Strand Lumber (PSL) is one of an effective and smart solution. In addition, PSL made from oil palm trunk waste is classified as a green product [1].

As a substitute for sawn timber, PSL has the advantage not only of high utilization of wood/raw material but also in strength, size availability, and dimensional stability [2]. PSL can be used for structural applications such as poles, beams, and columns [3].

Previous research stated that the portion of oil palm trunk that is suitable for use as a lightweight construction material is 1/3 of the outer part while the remaining 2/3 is not feasible because it is too soft [4, 5]. In addition, oil palm trunk has low properties such as specific gravity, low durability, poor dimensional stability, low strength and machining properties [6]. The weaknesses of oil palm trunk in physical and mechanical (basic) properties led the limitation of waste oil palm trunk utilization for furniture and buildings applications. Our previous researches shown that the basic properties of oil palm wood improved significantly after hot pressed. Wood compaction is one of the efforts to increase the strength and durability of low-density timber by pressing wooden boards to become more solid [7].

Production of Parallel Strand Lumber (PSL) made from oil palm trunk waste is one of the alternative utilization of oil palm trunk waste. The PSL is ideally developed as a substitute for the main products made of wood because it has advantages such as abundant raw materials supply as agricultural waste, moreover it has high economic value considering the use of oil palm trunk and the produced PSL classified as green products. In addition, the advantages of using composite products including PSL are improving the properties of strength and stiffness, providing a choice of more diverse geometric shapes, allowing for adjustment of laminate quality to desired levels and improving dimensional accuracy and shape stability.

This research was conducted to produce high quality PSL made of oil palm trunk. The results of this research are expected to provide an appropriate alternative technology in the utilization of oil palm trunk waste into PSL and can be a solution in reducing the volume of oil palm trunk waste so as to increase the income of the community around the area of oil palm plantations, and can provide alternative raw materials for wood processing industries.

2. Method

2.1. Materials

The oil palm (*Elaeis guineensis* Jacq.) waste raw material used in this research were collected from oil palm plantation in Jasinga area, Bogor regency, West Java province and the age ranged was 25-30 years. The adhesive used was isocyanate adhesive.

2.2. Samples preparations

Oil palm trunks were cut in 1.20 m length. The oil palm trunk was subsequently split into sortimens, the sortimens were dried using hot pressing techniques to avoid drying defects due to the high levels of oil palm moisture content. Then the sortiments are converted to the form of a long strand using band saw. The long strand dimensions were 1.2 m in length, 0.3 cm and 0.6 cm in thicknesses and 2 cm, 4 cm, and 6 cm in width.

The produced long strand then dried using hot pressing technique at a temperature of 110^{o}C until the long strand reaches a water content of 7%. Long strand that has been dried was sprayed by isocyanate adhesive with glue spread of 300 g/m^2 by double spread method. Adjusted strands were formed into sheets and cold pressed with a specific pressure of 15 kg/cm^2 for 3 hours. After cold pressing process, the obtained PSL was conditioned for 1 week to remove residual stresses during the cold pressing. The target size of the produced PSL were 1.2 m in length, 6 cm in width and 4 cm in thickness, and the target density was 0.65 g/cm^3.

2.3. Testing for basic properties of PSL

Testing of physical properties

The physical properties of the PSL tested according to JAS 1152 (2007) for density, moisture content, and volume shrinkage properties. The density sample dimensions were 5 cm in length, 5 cm in width, and 4 cm in thickness. The value of density was calculated by the equation:

$$\rho\ (g/cm^3) = \frac{\text{Mass}}{Volume}$$

Testing of moisture content was calculated based on baseline weight (A) and oven dry weight (B). The value of moisture content was calculated by the equation:

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

The samples of volume shrinkage dimensions were 5 cm in length, 5 cm in width, and 4 cm in thickness. Initial volume as baseline of the samples determine by measured the samples dimensions using caliper at room temperature (V1) and then measured again after oven dried (V2). The value of volume shrinkage (VS) was calculated by the equation:

$$VS\ (\%) = \frac{V1 - V2}{V1} \times 100\%$$

Testing of mechanical properties

The mechanical properties of the PSL were tested according to JIS A 1152 (2007) standard. The mechanical properties tested were Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). The sample dimensions were 61 cm in length, 5 cm in width, and 4 cm in thickness. The samples were tested with centralized load at the center on the PSL, with a span length of 56 cm. Testing was conducted in parallel to the grain position using Universal Testing Machine (UTM). MOR test was performed together with MOE testing using the same sample. The value of MOE and MOR were calculated by the equation:

$$MOR\ (kg/cm^2) = \frac{3\ Pmax\ L}{2\ bh^2} \qquad MOE\ (kg/cm^2) = \frac{\Delta P\ L^3}{4\ \Delta Ybh^3}$$

Where:
MOE = Modulus of Elasticity (kg/cm^2)
MOR = Modulus of Rupture (kg/cm^2)
ΔP = Loading under Proportion Limit (kg)
ΔY = Deflection load (cm)
P = Maximum load (kg)
L = Span length (cm)
b = Sample width (cm)
h = Sample thickness (cm)

2.4. Data analysis

The experimental design used in this research was a factorial completely randomized design with two factors. Factor "A" was strand thickness with two levels (0.3 and 0.6 cm) and factor "B" was strand width with three levels (2, 4, and 6 cm). All the physical and mechanical properties were conducted in 5 replications and processed by statistical analysis.

3. Results and discussion

The research results of the analysis of variance the basic properties of PSL for moisture content, density, volume shrinkage, MOE, and MOR properties can be seen in table 1 below.

Table 1. Research results of the analysis of variance the basic properties of PSL.

Treatment	Diversity analysis (α = 0.05)				
	Moisture content	ρ	Volume shrinkage	MOE	MOR
Long Strand width	0.2502	0.9787	0.0452	0.000	0.000
Long Strand thickness	0.5192	0.8873	0.4880	0.000	0.000
Thickness and width	0.7085	0.8797	0.9114	0.006	0.000

4. Density

Density is one of the physical properties which shows the ratio between the mass of the body to its volume (the number of substances of volume unity) [8]. Density can be used as a good indicator in its strength estimation. Density may affect hygroscopic properties, swelling and shrinkage properties, mechanical properties, acoustic properties, electrical, and others related to subsequent woodworking [9].

Analysis of variance test results (table 1) showed that the thickness and width of the long strand did not give a significant effect on the density. The target density to make the produced PSL was 0.65 g/cm^3 and overall shows almost uniform results (figure 1). The samples density values obtained were 0.62 to 0.63 g/cm^3 which indicating a very good homogeneity of the produced PSL through a very good processing. However, the resulting PSL density is smaller than the target density of 0.65 g/cm^3. This phenomenon happen due to the influence of spring back which caused actual PSL thickness was slightly thicker compared to those of the thickness target. The PSL density made of oil palm trunk was higher compared to those of the whole palm kernel, namely 0.26 – 0.45 g/cm^3 [10]. Density is a very good indicator for predicting the timber or composite products strength. The higher of density and specific gravity the higher the strength properties.

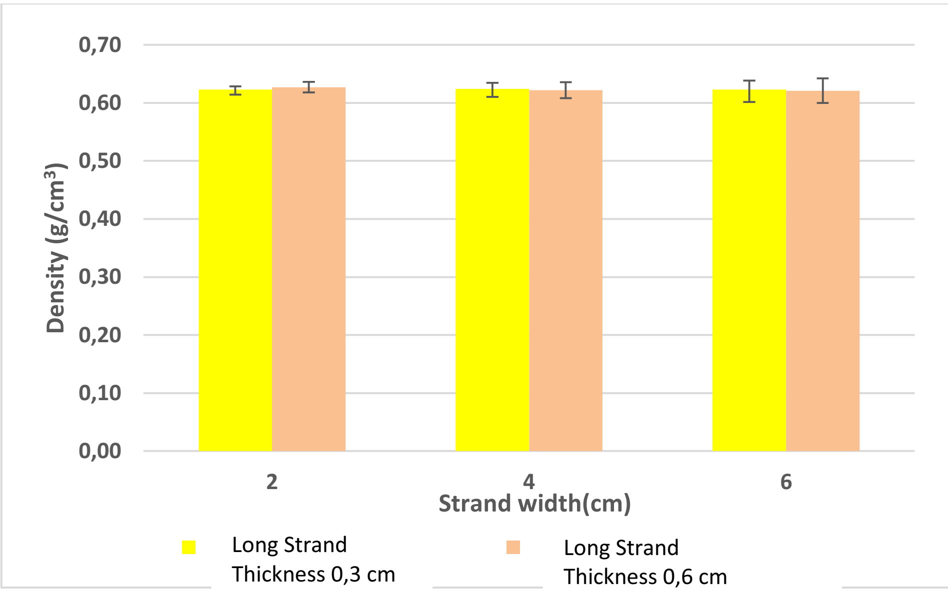

Figure 1. Histogram of PSL density in each thickness and width of long strand.

5. Moisture content

The moisture content indicates the amount of water contained in the board. Moisture content as weight of water expressed as percent weight of free water to dry weight of the PSL sample [11]. Analysis of variance test results (table 1) showed that the thickness and width of the long strand did not give a significant effect on moisture content. The research results (figure 2) show the overall PSL moisture contents were 10,73 to 11,95%. The maximum moisture content set by Japan Agricultural Standard for Glued Laminated Timber Notification No. 1152 [12] is 15%, so that the produced PSL fulfill the standard. The moisture content of the PSL can affect its strength. The mechanical properties of PSL were influenced significantly by changes in moisture content below the fiber saturation point. Above the fiber saturation point, changes in moisture content do not affect its properties because changes in water content have not occurred in the cell wall [1], [13].

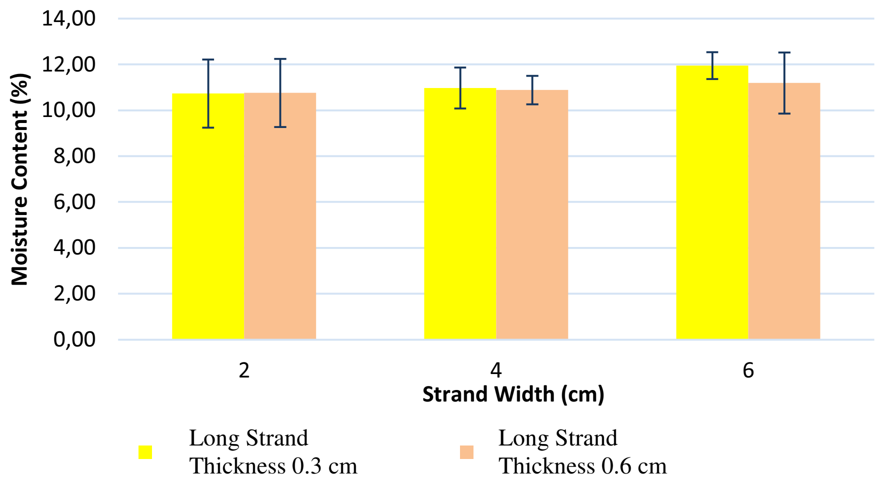

Figure 2. Histogram of PSL moisture content at each thickness and width of the long strand.

6. Volume Shrinkage

The volume shrinkage is a measure of the PSL stability dimension which is very important to be evaluated if it will used for construction component and furniture raw material purposes. The test result (figure 3) showed that the largest volume shrinkage was the PSL made of the biggest size of long strand (0.6 cm thickness and 6 cm width), while the smallest volume shrinkage was the PSL made of the smallest long stand (0.3 cm thickness and 2 cm width). Based on the analysis of variance test (table 1), the long strand width treatment influenced significantly the volume shrinkage.

The small PSL volume shrinking values indicate good dimensional stability. Volume shrinkage of PSL made from oil palm trunk was smaller than the shrinking volume of palm oil palm trunk which in the ranged of 17.5 - 39.1% [10]. The large volume shrinkage of the oil palm trunk prohibit it used as a construction raw material in form of solid oil palm trunk because its low dimensional stability. The high volume changes (swelling and shrinkage) indicate that the dimensional stability of the product is not good, and vice versa. If dimensional stability is poor, the composite board cannot be used for exterior use or for long periods of time, since its mechanical properties will soon decline drastically in the future [14].

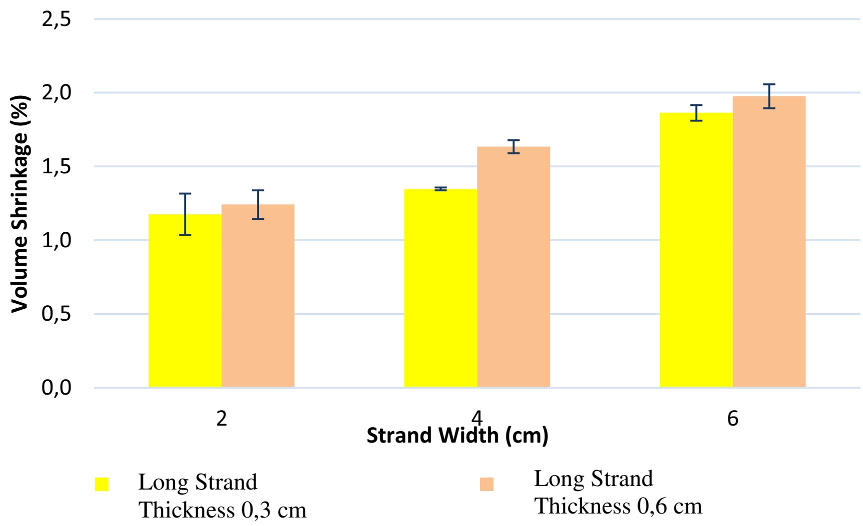

Figure 3. Histogram comparison of volume shrinkage at each thickness and width of long strand.

7. Modulus of Elasticity (MOE)

MOE test results (figure 4) show that PSL with 0.3 cm thickness and 2 cm long strand width resulted the largest average MOE value, namely 2.6 x 10^4 kg/cm^2 which was higher compared to those of oil palm trunk. The average MOE oil palm trunk was 1.57 x 10^3kg/cm^2 [15]. Static bending (MOE and MOR) firmness relates to the strength properties of timber described as a measure of the ability of the wood to withstand loads perpendicular to the longitudinal axis of the fiber. The analysis of variance testing (table 1) shows the thickness and width of the long strand influence MOE significantly. The average MOE value of PSL made of 0.3 cm thickness and 2 cm width strand indicates that the flexibility of the PSL was higher compared to the other PSL. It was designed that the width of produced PSL was 12 cm, so if it was made of 2, 4, 6 cm strand width, it required 6, 3, and 2 strand, respectively for one layer. Based on the calculation above, PSL made of 2 cm width and 0.3 cm thickness required higher portion of isocyanate adhesive compared to those of others, this reason made it resulted higher MOE compared to those of others. Eventhough, the produced PSL resulted higher MOE compared to its raw material, the produced PSL failed to fulfill the JAS Standard. According to Japan Agricultural Standard for Glued Laminated: Timber Notification No. 1152 [12], the minimum MOE value for construction timber is 7.5 x 10^4kg/cm^2, so all the produced PSL fail to meet the minimum value.

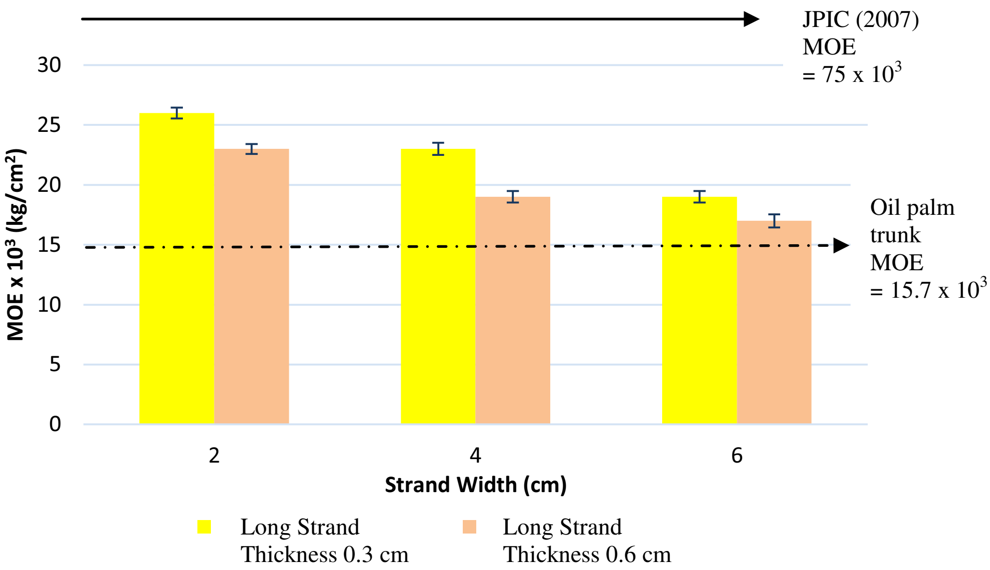

Figure 4. Histogram of MOE value of each thickness and width of long strand.

8. Modulus of Rupture (MOR)

Based on the research results of the MOR test (figure 5), the PSL made of 0.3 cm thickness and 2 cm width strand resulted the largest average MOR value of 179 kg/cm^2, this MOR value was higher compared to those of oil palm trunk MOR which ranged of 97 – 151 kg/cm^2. Based on the analysis of variance test results, the thickness and width of the long strand influence MOR significantly. The MOR indicated the maximum load that can be retained by a material per unit area until the material is broken/damaged. Referring to Japan Agricultural Standard for Glued Laminated: Timber Notification No. 1152 [12], the minimum MOR value for construction timber is 300 kg/cm^2, so that all the produced PSL failed to meet the minimum value the JAS standard. The low MOE and MOR values of the PSL should be improved by improving the bond of the oil palm trunk such as adhesive impregnation to improve the strength bonding among parenchyme and vascular bundles.

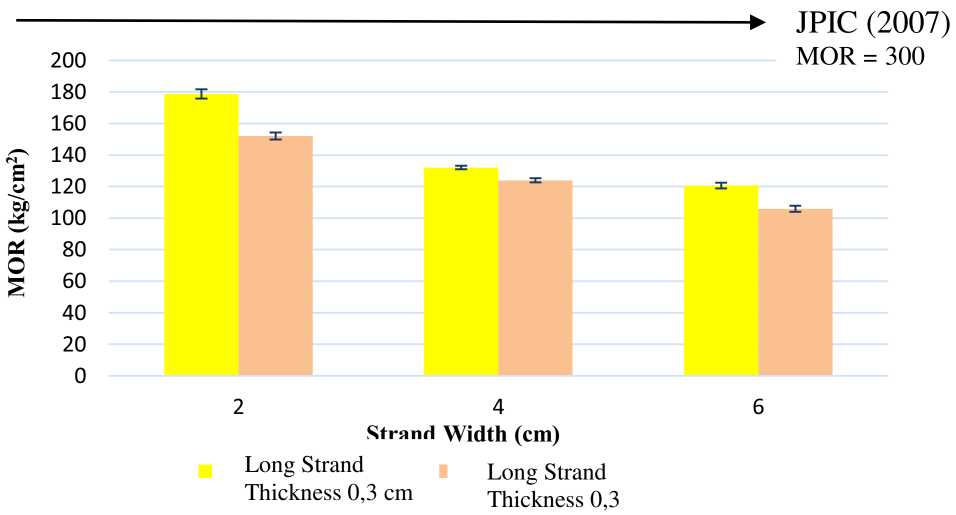

Figure 5. Histogram of MOR values of each thickness and width strand.

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9. Conclusions and suggestions

Parallel Strand Lumber (PSL) made from oil palm trunk waste were suitable to be used for furniture products and housing components. However, it should be improved significantly if it will be used as a construction component that withstands heavy loads. The PSL made from long strand of 2 cm width and 0.3 cm thickness resulted the highest MOE and MOR values. However, it failed to fulfill Japan Agricultural Standard for Glued Laminated: Timber Notification No. 1152. Further research should pay attention to improve MOE and MOR properties, significantly.

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