Physical and mechanical properties of parallel strand lumber made from hot pre-pressed long strand oil palm trunk waste

Inayah Fridiyanti¹ and M Y Massijaya¹

¹Biocomposite Laboratory, Forest Products Department, Faculty of Forestry, Bogor Agricultural University, Bogor, West Java, Indonesia.
Email: fridiyanti.inay@gmail.com; mymassijaya@yahoo.co.id

Abstract. This research was focused on the utilization of oil palm trunk waste as a Parallel Strand Lumber (PSL) raw material. This research aimed to analyze the effect of adhesive types and glue spreads to the physical and mechanical properties of PSL. The adhesive types used were isocyanate and urea formaldehyde adhesives. The glue spreads used were 150 g/m² and 300 g/m². The research results showed that the moisture content of PSL ranged from 9.30% to 11.80%. The PSL density ranged from 0.64 to 0.78 g/cm³. The volume shrinkage ranged from 5.69 to 7.17%. Modulus of Elasticity (MOE) parallel to the grain and edge side ranged from 51.6 x 10⁹ to 98.3 x 10⁹ kg/cm², and 62.1 x 10⁹ to 99.9 x 10⁹ kg/cm², respectively. The Modulus of Rupture (MOR) parallel to the grain and edge side ranged from 269 to 724 kg/cm² and 342 to 728 kg/cm², respectively. The PSL hardness perpendicular to the grain, parallel to the grain and the edge side ranged from 135 to 300 kg/cm², 87 to 321 kg/cm², and 128 to 251 kg/cm², respectively. The compressive strength ranged from 181 to 231 kg/cm². The best adhesive and glue spreads of PSL was isocyanate with glue spread 300 g/m². PSL made from hot pre-pressed long strand of oil palm trunk waste bonded by isocyanate fulfill JAS 1152: 2007. However, those of bonded by urea formaldehyde failed to fulfill the standard. The physical and mechanical properties of PSL made from oil palm trunk were better compared to those of solid oil palm trunk.

Keywords: glue spreads, isocyanate, oil palm trunk, PSL, urea formaldehyde

1. Introduction

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. 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 oil palm agricultural waste [1]. 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 our 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. 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].

Adhesive used in the PSL production is one of the important components which influence significantly the properties of PSL [1]. The adhesive types and glue spreads used should be adjusted to the PSL manufacture requirements. The selection of adhesives in PSL manufacturing depends on end use, technology, dimensions, treatment, and design requirements [8]. For exterior applications preferable use weather and water-resistant adhesives such as isocyanates, whereas for interior applications can use urea formaldehyde adhesives [9]. Isocyanate adhesive is one of the best adhesives suitable for the manufacture of PSL, especially from oil palm trunk material [1]. According to research before the isocyanate adhesive has the advantage of being more tolerant of high moisture content, more stable in terms of board dimensions stability and the absence of formaldehyde emissions [10]. While the urea formaldehyde adhesive has the advantage of water soluble, good adhesion, and the price is cheap [11]. This allows the urea formaldehyde adhesive to be widely used in the composite products production.

Based on the problems described above, the objective of this research was to analyze the effect of isocyanate and urea formaldehyde adhesives and the influence of glue spreads on the physical and mechanical properties of Parallel Strand Lumber made from oil palm trunk waste.

2. Materials and Methods

2.1 Materials

The oil palm trunk used in this research were harvested from a plantation in Bunar area, Jasinga, Bogor, West Java, Indonesia. All together, fifteen (15) oil palm trunks of 25 to 30 years old (unproductive) were harvested. The adhesives used were isocyanate and urea formaldehyde adhesives. The equipment used was chain saw, band saw, circular saw, planner, moisture meter, hot press, tape measure, plastic, scales, oven, caliper, Universal Testing Machine (UTM), and camera.

2.2 Methods

2.2.1 Production of Parallel Strand Lumber

1. Harvesting

   Oil palm trunk that have reached 25 to 30 years old were harvested using chain saw.

2. Strand making

   Then the palm oil trunks were cut with the size of 120 cm long, 6 cm wide and 1 cm thick.

3. Drying and compacting

   The produced strand then dried and compacted using hot pressing technique for 60 minutes with a temperature of 150°C and pressure of 9.45 kg/cm². Drying and compaction process done until strand reach 0.6 cm thickness.

4. Glue spreading

   The strand that has been dried and then spreaded with isocyanate and urea formaldehyde adhesives. The glue spreads used were 150 g/m² and 300 g/m².

5. Mat forming

   The strand that has been spreaded by adhesive then arranged into sheets manually to be 4 cm in thickness, 6 cm in width, and 120 cm in length.

6. Hot pressing

   The obtained PSL mat then hot pressed according to the condition of each adhesive type. PSL bonded by isocyanate and urea formaldehyde adhesives were hot pressed in temperature of 150°C and 130°C, respectively. The pressure of hot press was 9.45kg/cm² for 40 minutes.
7. Conditioning
   After hot pressing, the produced PSL to be conditioning for at least 2 weeks to remove the residual stresses during the PSL production.

8. Trimming
   PSL that has been conditioned and then trimmed according to JAS 1152 : 2007 standard.

2.2.2 Testing Physical and Mechanical properties of PSL

The PSL was tested according to JAS 1152: 2007 standard. The properties tested include physical properties (moisture content, density, and volume shrinkage) as well as mechanical properties (MOE, MOR, hardness, and compressive strength).

1. Moisture content
   The sample test dimensions were 5 cm in width, 5 cm in length, and 4 cm in thickness. The water content was calculated from the initial weight (A) and the final weight (B) after oven dried for 24 hour at 103 ± 2º C to constant weight. The value of moisture content calculated using the formula:
   \[ MC = \frac{A - B}{B} \times 100\% \]  
   (1)

2. Density
   The sample test dimensions were 5 cm in width, 5 cm in length, and 4 cm in thickness. The density was calculated by weighting the sample (m), and calculated the sample volume (v) by multiplying the dimensions of length, width and thickness. Density calculated using the formula:
   \[ \rho = \frac{m}{v} \]  
   (2)

3. Volume Shrinkage
   The sample test dimensions were 5 cm in width, 5 cm in length, and 4 cm thickness. The samples were measured as initial volume at dry air condition (v₁), and then the samples were oven dried for 24 hours with temperature of 103 ± 2º C until the constant weight and then measured its dimension again by using caliper (v₂). Volume shrinkage calculated using the formula:
   \[ \text{Volume shrinkage} = \frac{(v_1 - v_2)}{v_1} \times 100\% \]  
   (3)

4. MOE (Modulus of Elasticity) and MOR (Modulus of Rupture)
   The samples size were 61 cm in length, 5 cm in width and 4 cm in thickness. The samples were tested with centralized load at the center of the panel, with a span length of 56 cm. Testing has been done in parallel to the grain and side edge. MOE and MOR calculated using the formula:
   \[ \text{MOE} = \frac{\Delta P L^2}{4 \Delta Y b h^3} \quad \text{MOR} = \frac{3 P_{\text{max}} L}{2 b h^2} \]  
   (4)

Where :
- MOE = Modulus of Elasticity (kg/cm²)
- MOR = Modulus of Rupture (kg/cm²)
- ΔP = Load under Proportion Limit (kg)
- ΔY = Deflection (cm)
- Pmax = Maximum load (kg)
- L = Span length (cm)
- B = Sample width (cm)
- h = Sample thickness (cm)
5. Hardness

The sample test dimensions were 4 cm in thickness, 5 cm in width, and 10 cm in length. Testing has done by load half a steel ball into the wood. Hardness calculated using the formula:

\[ H = \frac{p_{\text{max}}}{\text{Total area}} \]  

(5)

6. Compression strength Parallel to the grain

The sample test dimensions were 4 cm in thickness, 5 cm in width, and 20 cm in length was loaded in the parallel direction of the grain at the position of the vertical and load slowly until the test sample damaged. The load is the maximum allowable strength by the test sample (Pmax). The value of compression strength parallel to the grain calculated using the formula:

\[ CS = \frac{p_{\text{max}}}{\text{Total area}} \]  

(6)

2.2.3 Data analysis

The experimental design used in this research was a factorial completely randomized design with two factors. Factor A was adhesive types with two levels (isocyanate and urea formaldehyde) and factor B that was glue spreads with two levels (150 g/m² and 300 g/m²). All the physical and mechanical properties were conducted in 5 replications and processed by statistical programs.

3. Results and Discussions

3.1 Density

![Figure 1: Histogram of PSL density.](image)

Density is defined as the mass unity of volume in kilograms per cubic meter [12]. Figure 1 shows that the density values ranged from 0.64 to 0.78 g/cm³. Variations of density due to the difference in mass used and PSL volume variations. Strand which contains many vascular bundles who have thick cell wall and perfectly compacted can increase the density and produce a higher mass. PSL density bonded by isocyanate adhesive was higher (0.73 g/cm³) compared to those of bonded by UF adhesive (0.71 g/cm³). This is due to the chemical bonds that occur in the isocyanate adhesive. The isocyanate is capable of producing products that have better physical and mechanical properties, because isocyanate form the chemical bonds [13]. Statistical analysis with 95% confidence interval showed that the adhesive types and the glue spreads didn’t have significant effect on density. However, the interaction of the both factors produced significant effect. Solid oil palm trunk density ranged from 0.23 to 0.32 g/cm³ [1], while previous research stated that density values ranged from 0.31 to 0.52 g/cm³ [14]. PSL density in this research was higher compared than the solid oil palm trunk and hot pressing treatment increased remarkably the density of PSL.
3.2 Moisture content

Moisture content is defined as the percentage of water contained in wood. Wood strength will increase with the decrease in the water content of the wood below the saturation point of fiber [12]. Figure 2 shows that the moisture content of PSL ranged from 9.30% to 11.80%. Statistical analysis with 95% confidence interval, adhesive types and glue spreads influence significantly the PSL moisture content. However, the interaction of both factors did not significant. Utilization of higher glue spreads decreased the PSL moisture content. This was because the adhesive was able to fill the empty space in the strand so that the water was difficult to get in or get out from the PSL. According to [15], utilization of higher adhesives decreased the value of water content due to many adhesives will close space on the strand perfectly and not easily hydrolyzed. The moisture content of PSL bonded by UF adhesive was higher compared to those of bonded by isocyanate adhesive. This was due to isocyanate adhesive more resistant to water compared to those of UF adhesive which was not resistant to water because the water were able to hydrolyzed the UF adhesive and damaged the bond between the strand and UF adhesive. The average value of the moisture content was 10.69%, this value was lower than the previous study of 16.76% [14]. According to research before the value of moisture content of solid oil palm trunk was about 311.0% [16], this shows that the moisture content of the PSL was much better. The moisture content of PSL fulfilled JAS 1152: 2007 standard, JAS requires maximum moisture content by 15% [17]. PSL produced with hot pressing pre treatment succesfully reduced the moisture content of oil palm as well as prevented fungal attack.

3.3 Volume shrinkage

Figure 3. Histogram of PSL volume shrinkage.

Figure 2. Histogram of PSL moisture content.
Figure 3 shows that the volume shrinkage values ranged from 5.69 to 7.17% with an average of 6.15%. The previous research [16] stated that the volume shrinkage of solid oil palm trunk ranged from 17.5 to 39.1%, so the volume shrinkage value of this research was better compared to those of solid oil palm trunk. The volume shrinkage of PSL bonded by isocyanate adhesive smaller than those of bonded by UF adhesive. The previous research states that the isocyanate adhesive has the advantage of being more tolerant of high moisture content, more stable stability of the board dimensions and the absence of formaldehyde emissions [10]. However, the volume shrinkage did not differ significantly between PSL bonded by isocyanate and those of bonded by UF in this research.

3.4 Modulus of Elasticity

![Figure 4](image)

**Figure 4.** Histogram of PSL MOE parallel to the grain and edge side.

Figure 4 shows that the MOE values parallel to the grain ranged from 51.6×10³ to 98.3×10³ kg/cm², while the MOE edge side values ranged from 62.1×10³ to 99.9×10³ kg/cm². The average MOE values parallel to the grain and the edge side were 75.3×10³ kg/cm² and 75.9×10³ kg/cm², respectively. The variations of MOE values caused by uneven distribution of density in the parallel to the grain. The MOE values of the edge side were higher compared to those of the parallel to the grain. This was due to the effect of thicker PSL thickness when it was tested on edge side compared to those of parallel side. [1] reported that the MOE value of laminated wood of oil palm trunk was determined by the density and MOE of the constituent laminae. The PSL from oil palm trunk was higher compared to those of solid oil palm trunk. Statistical analysis with 95% confidence interval showed that the adhesive types produced a significant effect on parallel to the grain MOE values and glue spreads had a very significant effect on the edge side MOE values. PSL bonded by isocyanate adhesive at 300 g/m² glue spreads produced highest MOE. The isocyanate was capable of producing products that have relatively better physical and mechanical properties, because isocyanate form chemical bonds [13]. Isocyanate form a chemical bond with a strong polarity, not only having good adhesion potential but also the potential to form covalent bonds with substrates having reactive hydrogen groups. Chemically the isocyanate reacts with water contained in a strand to form a mechanically bonded polyurea glue [18]. Referring to the JAS 1152: 2007 standard that requires a minimum MOE value of 75×10³ kg/cm², PSL bonded by isocyanate adhesive at 300 g/m² glue spread fulfilled the JAS standard [17].
3.5 Modulus of Rupture

Figure 5. Histogram of PSL MOR parallel to the grain and edge side.

Figure 5 shows that MOR parallel to the grain and edge side ranged from 269 to 724 kg/cm² and 342 to 728 kg/cm², respectively. Variations in MOR values can be affected by the density and the number of adhesives. The greater number of adhesives used will increase the laminate's hardness properties as the adhesive plays an important role in strengthening the resulting laminated wood [19]. The strength of wood can also be affected by the pattern of lamina preparation. Preparation of palm wood lamina which put the stronger part in the outer position improved the mechanical properties significantly [1]. According to previous research that in the anatomical structure of oil palm trunk, the center portion of the trunk was dominated by the parenchymal base network while in the middle and the edge of the trunk were composed by thick-walled vascular bundles [20]. The average MOR values of parallel to the grain and the edge side were 519 kg/cm² and 492 kg/cm². The MOR values of PSL bonded by isocyanate adhesive at glue spreads of 150 g/m² and 300 g/m² fulfilled the JAS 1152: 2007 standard which requires a minimum MOR value is 300 kg/cm² [17]. Statistical analysis with 95% confidence interval showed that the adhesive types and the glue spreads had a very significant effect on the parallel to the grain MOR values as well as the edge side. The PSL MOR values was higher compared to those of solid oil palm trunk which has MOR ranged from 97 to 151 kg/cm² [1].

3.6 Hardness

Figure 6. Histogram of PSL hardness perpendicular, parallel and edge side.
Hardness is defined as the ability of boards to withstand scraping and destruction on its surface [21]. Figure 6 shows that the PSL hardness perpendicular to the grain, parallel to the grain and the edge side ranged from 135 to 300 kg/cm², 87 to 321 kg/cm², and 128 to 251 kg/cm², respectively. The mean values of perpendicular, parallel and edge side are 230 kg/cm², 182 kg/cm² and 194 kg/cm², respectively. The density of the strand affected the PSL hardness. According to [21] that the hardness is affected by the density, the size of the fiber, the interconnection between fibers and the arrangement of its wood fibers. From the three directions of testing, the highest value to the smallest PSL was the direction of perpendicular, edge side and parallel to the grain, respectively. This was due to the density in the strand on the core was lower compared to those of the outer strand of the PSL. The coating system affects the value of wood strength, such as the preparation of lamina wood palm placing the stronger part in the outer position [1]. The values of oil palm trunk hardness ranged from 64.3 to 137.3 kg/cm² [16]. PSL hardness was higher compared to those of solid oil palm trunk. Statistical analysis with 95% confidence interval showed that the adhesive types and the glue spreads have a very significant effect on hardness values.

3.7 Compression strength

![Histogram of PSL compression strength.](image)

Figure 7. Histogram of PSL compression strength.

Figure 7 shows that the compression strength ranged from 181 to 231 kg/cm² with an average of 211 kg/cm². The compressive strength of the fiber is required to determine the load that a pole can carry. Parallel compressive strength of the fiber is the ability of the board to withstand loads or pressures that try to reduce their size until the board is damaged [22]. The highest compressive strength resulted from PSL bonded by isocyanate adhesive at 300 g/m² glue spread. PSL which has more dense vascular bundles and higher fiber cells will has higher compressive strength. Statistical analysis with 95% confidence interval showed that the adhesive types, glue spreads, and interaction of the research factors influence compressive strength significantly. Previous research reported that the compressive strength solid oil palm trunk ranged from 38.8 to 141.8 kg/cm² [16]. The PSL compressive strength was better than those of solid oil palm trunk. This was proved that hot pressing pretreatment to the long strand increased the value of compression strength.

4. Conclusions

The adhesive types and glue spreads has no significant effect on the PSL physical properties except the values of moisture content. In general, the adhesive types and the glue spreads influenced significantly the PSL mechanical properties. The best adhesive types and glue spreads for PSL was isocyanate adhesive at a glue spread of 300 g/m². PSL made from hot pre-pressed long strand oil palm trunk waste bonded by isocyanate adhesive fulfilled JAS 1152: 2007, while those of bonded by UF adhesive failed
to fulfill the standard. PSL quality was better than those of solid oil palm trunk. Producing PSL using hot pressing pretreatment was successfully improve the mechanical properties of the produced PSL.

Acknowledgment
The authors gratefully acknowledge financial support from the Directorate of Higher Education, Ministry of Research, Technology and Higher Education of the Republic of Indonesia. The authors also thank for Bogor Agricultural University (IPB) for supporting research facilities.

References

[1] Darwis A, Massijaya MY, Nugroho N and Alamsyah EM 2014 *J. Ilmu Teknol. Kayu Lapis*. 12 (2): 157–168
[2] Nelson S 1997 *Structural composite lumber*. Engineered Wood Products: A Guide for Specifiers, Designers, and Users, S. Smulski (ed.), (Madison, Wisconsin (AS): PFS Research Foundation)
[3] Canadian Wood Council 1997 *Wood Reference Handbook* (Ottawa (CA): Canadian Wood Council)
[4] Bakar ES, Rachman O, Hermawan D, Karlinasari L and Rosdiana N 1998 *J. Teknologi Hasil Hutan* 11 (1): 1-12
[5] Bakar ES, Massijaya MY, Rahman O and Bahruni 2000 *Laporan Penelitian Hibah Bersaing VI Dirjen Dikti*. Bogor (ID): Jurusan Teknologi Hasil Hutan. Fakultas Kehutanan IPB
[6] Dungani R, Islam MN, Abdul Khalil HPS, Davoudpour Y, and A Rumidatul 2014 *Bioresources*. 9 (1): 455–471
[7] Sulistyono, Nugroho N and Surjokusumo S 2003 *Buletin Keteknikan Pertanian* 17(1):32-45
[8] Kurt R 2010 *BioResources* 5(3), 1868-1878
[9] Kurt R and Çavuş V 2011 *Wood Res* 56(1), 137-144
[10] Marra AA 1992 *Technology of Wood Bonding : Principles in Practice*. (New York (US): Van Nostrand Reinhold)
[11] Dungani R, Islam MN, Abdul Khalil HPS, Davoudpour Y, and A Rumidatul 2014 *Bioresources*. 9 (1): 455–471
[12] Iswanto AH, Sucipto T, Azhar I, Coto Z and Febrianto F 2010 *J. Teknologi Hasil Hutan* 3(1):1-7 (Medan (ID): Universitas Sumatera Utara)
[13] Sucipto T, AH Iswanto and I Azhar 2010 *J. Ilmu dan Teknologi Hasil Hutan* Vol 3(2) (Medan (ID): Universitas Sumatera Utara)
[14] Balfas J 2008 *Teknologi Pengolahan Batang Kelapa Sawit menjadi Produk Kayu Utuh (solid wood dan kayu lapis (plywood)*. (Bogor (ID): Badan Penelitian dan Pengembangan Kehutanan)
[15] Mawardi I 2009 *Jurnal Teknik Mesin* Vol 11(2). (Banda Aceh (ID): Politeknik Negeri Lokseumawe)
[16] Iswanto AH, Sucipto T, Azhar I, Coto Z and Febrianto F 2010 *J. Teknologi Hasil Hutan* 3(1):1-7 (Medan (ID): Universitas Sumatera Utara)
[17] [JAS] Japanese Agricultural Standard 2007 *Japanese Agricultural Standard for Glued Laminated Timber Notification No 1152* (Tokyo (JP): JPIC)
[18] Nuryawan A, Massijaya MY and Hadi YS 2008 *J. Ilmu dan Teknologi Hasil Hutan* 1(2): 60-66
[19] Persson M and Wogelberg S 2011 *Analytical models of pre-stressed and reinforced glulam beams: A competitive analysis of strengthened glulam beams* [Tesis] (Göteborg (SE): Chalmers University of Technology)
[20] Bakar ES 2003 *Forum Komunikasi Teknologi dan Industri Kayu* Vol 2. (Bogor (ID): Jurusan Teknologi Hasil Hutan Fakultas Kehutanan IPB)
[21] Mardikanto TR, Karlinasari L and Bahtiar ET 2011 *Sifat Mekanis Kayu* (Bogor (ID): IPB Pr)
[22] Tsoumis G 1991 *Science and Technology of Wood. Structure, Properties, Utilization* (New York (US): van Nostrand Reinhold)