Some properties of laminated veneer lumber manufactured from oil palm trunk

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Abstract. Indonesia is the largest oil palm producer in the world and it was predicted that around 7 million metric tons was left in the field as a replanting waste, including palm frond and trunk. The utilization of this waste as a raw material of composite products may overcome the problem. The objective of this study was to determine the physical and mechanical properties of Laminated Veneer Lumber (LVL) made of oil palm trunk. Laboratory scale five-ply LVls glued with urea formaldehyde adhesive were fabricated with five types of layer compositions i.e five-ply LVL with all layers made of oil palm trunk veneers (OP), five-ply LVL with face and back layers made of jabon veneers (J2), five-ply LVL with face, back and center core layers made of jabon veneers (J3), five-ply LVL with face and back layers made of mahoni veneers (M2), and five-ply LVL with face, back and center core layers made of mahoni veneers (M3). Results showed that the physical and mechanical properties of laminated veneer lumbers made from oil palm trunk were affected by layer compositions. Incorporating jabon or mahoni wood veneers in the structure of oil palm LVL improved the physical and mechanical properties of LVL.

1. Introduction

The increasing demand for timber has led to a shortage of timber supply in wood industries. To anticipate the shortage, a wide range of alternative substitute materials are being explored. Oil palm (Elaeis guineensis Jacq.) trunk appears to be the most potential substitute material. Indonesia is the largest oil palm producer in the world, with the total crude palm oil production of 36.59 million ton in 2018 [1]. It was revealed that in 2018 at least 12.76 million hectares of land are being planted with oil palm [1]. Further, Badan Pusat Statistik [1] reported that over the years oil palm plantation is significantly increasing.

The productive live span of oil palm tree is between 25-30 years. Thus, it would be replanting after this period. It was predicted that around 7 million metric ton was left in the field as a replanting waste [2], including palm frond and trunk. The utilization of this waste as a raw material of composite products, however, can give additional economic value of the useless by products. A wide range of research have been conducted to investigate the properties of composite products made of oil palm trunk [3–11]. It was suggested that oil palm LVL is suitable for panelling and non-structural purposes [8]. Furthermore, the strength of soft inner part of oil palm trunk could be improved by applying Close System Compression (CSC) method for resin impregnation and densification [9]. Low molecular weight phenol formaldehyde treatment with different resin solid content and initial moisture content of veneer improved the physical properties of oil palm veneer LVL [10]. The inclusion of rubberwood...
veneer significantly improved the bending and compression strength of the LVL [7]. This study examined the physical and mechanical properties of laminated veneer lumber made of oil palm trunk with combined layers of jabon (Anthecephalus cadamba Miq.) and mahoni (Swietenia macrophylla King.) wood.

2. Materials and Methods

2.1. Materials

The materials used in this study were oil palm trunk (Elaeis guineensis Jacq.) collected from Malimping, Banten Province, jabon wood (Anthecephalus cadamba Miq.) and mahoni wood (Swietenia macrophylla King.) collected from Sukabumi, West Java Province, Indonesia. A commercial liquid urea formaldehyde was used as adhesive.

2.2. Methods

2.2.1. Preparation of oil palm trunk veneer

The oil palm trunk logs with average diameter of 36 cm and 140 cm in length were converted into veneer using rotary peeling machine with targeted veneer thickness of 5.5 mm. Rotary veneers were then cut into 40 cm long by 42 cm wide and then air drying at room temperature for one day and followed with sun drying to about 16% moisture content. Oil palm trunk veneers were then hot pressed at temperature of 120ºC with specific pressure of 10 kg/cm² for 1 minute.

2.2.2. Preparation of wood veneer

The logs of jabon wood and mahoni wood with average diameter of 28 cm and 125 cm in length were converted into wood veneer using rotary peeling machine with targeted veneer thickness of 2 mm. Rotary veneers were then cut into 40 cm long by 42 cm wide and then air drying at room temperature for one day and followed with sun drying to about 16% moisture content. Afterwards, it oven dried at temperature of 80ºC for 48 hours to about 10% moisture content.

2.2.3. Laminated Veneer Lumber (LVL) fabrication

Laboratory scale five-ply LVLs with the dimension of 40 cm x 40 cm x thickness were fabricated with five types of layer compositions i.e. five-ply LVL with all layers made of oil palm trunk veneers (OP), five-ply LVL with face and back layers made of jabon veneers (J2), five-ply LVL with face, back and center core layers made of jabon veneers (J3), five-ply LVL with face and back layers made of mahoni veneers (M2), and five-ply LVL with face, back and center core layers made of mahoni veneers (M3). To manufacture five-ply LVL, the urea formaldehyde adhesive (100 UF resin: 10 wheat flour: 10 water: 0.5 hardener) was applied to each face of the veneers, targeting a total spread rate of 200 g/m² per glue line. After the adhesive was applied, the assembly of five veneer sheets was cold pressed together parallel to each other for 15 minutes, with a nominal dimensions of 40 cm x 40 cm x thickness for each LVL board. The assembly then was further hot pressed at temperature of 120ºC and specific pressure of 10 kg/cm² for 7 minutes. Five replications for each type of LVL were prepared. The LVLs produced were conditioned for two weeks before testing.

2.2.4. Testing

The laminated veneer lumbers were cut into desired specimen dimensions and measured for density, moisture content, thickness swelling, water absorption, delamination, Modulus of Rupture (MOR), Modulus of Elasticity (MOE), compression strength, and hardness. The tests were performed using the American Standard ASTM D 1037-93 [12] and Japanese Standard for Laminated Veneer Lumber [13] for evaluating properties of LVL.

2.2.5. Data analysis

A completely randomized design was used in the experiment with the layer compositions as the treatment factor. Five replications were prepared for each treatment. The effects of combined wood
species on physical and mechanical properties of LVLs were computed by analysis of variance using Minitab Statistical and Qualitative Data Analysis Software.

3. Results and Discussion

3.1. Physical properties and bonding quality of laminated veneer lumbers

The mean values of physical properties and bonding quality of laminated veneer lumbers (LVLs), the results of analysis of variance (ANOVA), and the results of HSD are presented in Table 1.

3.1.1. Moisture content

Average value of moisture content of OP LVL is given in Table 1. The moisture content of laminated veneer lumbers made from oil palm trunk varied from 12.10% to 12.43% with an average of 12.28%. These values are still within the range of air-dried moisture content and meet the Japanese Standard requirement for laminated veneer lumber since the values are below 14%. The results of ANOVA in Table 1 showed that moisture content of LVL was not affected by layer compositions. The previous study Sulaiman et al. [4] reported that LVL made from oil palm trunk glued with urea formaldehyde had moisture content of 9.81% while those glued with phenol formaldehyde had moisture content of 9.90%.

3.1.2. Density

As shown in Table 1, the density of laminated veneer lumbers produced in this study varied from 0.500 g/cm³ to 0.591 g/cm³ with an average of 0.535 g/cm³. The results of ANOVA in Table 1 showed that density of LVL was significantly affected by layer compositions. It was observed that the values of LVL density increased with increasing number of wood veneer incorporating in the LVL structure. The lowest density of LVLs was produced from OP LVL while the highest density of LVLs was produced from M3 LVL. In Table 1 it can be seen that there is no different in density between OP LVL with J2 LVL and J3 LVL. Incorporating mahoni veneer in the structure of OP LVL, however, increased the density of OP LVL by 12% and 18.2% for M2 LVL and M3 LVL, respectively. This is in agreement with [7] who found the increased density as the incorporated rubberwood veneers in the LVL. The entirely oil palm trunk veneers LVL had the lowest density (0.545 g/cm³), while the highest found in the LVL with the inclusion of three layers of rubberwood veneers (0.589 g/cm³) [7]. It was argued that the incorporating of wood veneers in the layers could give a more uniform and denser LVL [7].

The previous study [4] reported that LVL made from oil palm trunk glued with urea formaldehyde had density of 0.57 g/cm³ while those glued with phenol formaldehyde had density of 0.37 g/cm³. Other previous study reported that the density of three-layer oil palm trunk LVL glued with either EPI or PVAc had density around 0.52-0.55 g/cm³ [5]. The density of 0.597 g/cm³ was found in the LVL from the bottom part and peripheral zone of oil palm trunk adhered with urea formaldehyde [8]. It was the highest density observed in the study compared to another portion and zone of the trunk. The density of seven-ply LVL made of poplar wood veneers glued with phenol formaldehyde was 0.419 g/cm³ while the density of eucalyptus LVL was 0.616 g/cm³ [14]. From this information it can be seen that the density of LVL is governed by the density of wood veneer raw materials. This finding is in agreement with that reported by Sulastiningsih et al. [15], that the density of wood composite product is governed by the density of its raw materials, the use of adhesive and the pressure applied during wood composite manufacture, which produced a denser product.

3.1.3. Thickness swelling

Thickness swelling is one indicators of dimensional stability and it performs as an important property of composite products. The thickness swelling of laminated veneer lumbers made from oil palm trunk varied from 6.08% to 9.22% with an average of 8.38%. The data on thickness swelling of LVL were subjected to analysis of variance and the results showed that thickness swelling of LVL was significantly affected by layer compositions. It was observed that the lowest value of thickness
swelling was resulted from five-ply oil palm trunk LVL which included three mahoni wood veneers in the LVL structure as face, back and center core layers (M3). The percentage of thickness swelling decreased with the addition of wood veneer layer in the OP LVL. This is in agreement with [8] who found the similar trend, where thickness swelling increased as the density decreased. Thickness swelling of seven-ply LVL made of poplar and eucalyptus glued with phenol formaldehyde were 2.09% and 2.59% respectively [14], while thickness swelling of five-ply LVL made of gmelina glued with phenol formaldehyde was 2.09% [16]. A recent study Masseat et al. [10] reported that the low molecular weight phenol formaldehyde treatment with 45% solid content at 15% initial moisture content resulted in 0.76% of oil palm veneer thickness swelling. Impregnation with phenol formaldehyde or non-resin (chemical) is the most commonly method to improve the oil palm trunk physical properties [11].

3.1.4. Water absorption

The results of ANOVA in Table 1 showed that water absorption values were significantly affected by layer compositions. The water absorption of laminated veneer lumbers varied from 64.13% to 85.88% with an average of 76.77%. It was observed that water absorption of laminated veneer lumbers decreased as the number of wood veneer increased in the LVL structure. Previous study also recorded the similar trend, where the water absorption increased as the density decreased [8]. The highest water absorption value, 94.33%, was found in the LVL made of top portion and inner zone, while the lowest, 63.03%, was found at bottom portion and peripheral zone [8]. It was also reported that the lowest and highest values of thickness swelling were found in the LVL made of bottom portion and peripheral zone (2.99%) and top portion and inner zone (5.62%) of the oil palm trunk, respectively [8]. Water absorption of seven-ply LVL made of poplar and eucalyptus glued with phenol formaldehyde were 59.56% and 23.23% respectively [14], while water absorption of five-ply LVL made of gmelina glued with phenol formaldehyde was 15.23% [16].

| Properties               | OP    | J2    | J3    | M2    | M3    | ANOVA results |
|--------------------------|-------|-------|-------|-------|-------|---------------|
| Moisture content, %      | 12.10 | 12.37 | 12.43 | 12.15 | 12.35 | 0.80**        |
|                          | (0.46) | (0.23) | (0.24) | (0.23) | (0.51) |               |
| Density, g/cm³           | 0.500 | 0.507 | 0.518 | 0.560 | 0.591 | 33.86**       |
|                          | (0.006) | (0.009) | (0.009) | (0.018) | (0.024) |               |
| Thickness swelling, %    | 8.99  | 9.22  | 8.44  | 9.16  | 6.08  | 6.62**        |
|                          | (0.94) | (1.48) | (1.24) | (1.18) | (0.74) |               |
| Water absorption, %      | 84.75 | 85.88 | 74.97 | 74.14 | 64.13 | 8.18**        |
|                          | (12.65) | (2.10) | (4.15) | (3.11) | (7.12) |               |
| Delamination,%           | 0     | 0     | 0     | 0     | 0     |               |

Each value was the average of five specimens
Values in parentheses are standard deviations
Values followed with the same letter within the same row are not significantly different
** not significant
** highly significant

3.1.5. Delamination

The bonding quality of any composite product is very important. The simple way to determine the bonding quality of multilayers composite product in this study is delamination test. The results of the warm water delamination test showed that there was no delamination in all samples and, therefore, the bonding quality of the LVLs made from oil palm trunk and in combination with jabon veneer and mahoni veneer were considered acceptable and meet the Japanese Agricultural Standard requirement
for laminated veneer lumber. Comparatively, the eight-ply oil palm trunk LVL made of bottom portion and peripheral zone and top portion and peripheral zone had superior bonding quality compared to the rubberwood LVL [8].

3.2 Mechanical properties of Laminated Veneer Lumbers
The mean values of mechanical properties of laminated veneer lumbers (LVLs), the results of analysis of variance (ANOVA), and the results of HSD are presented in Table 2.

3.2.1. Modulus of Rupture
The LVL produced with different layer compositions showed higher MOR values than the entirely oil palm veneer layers LVL. The MOR of laminated veneer lumbers (Table 2) varied from 227.2 kg/cm² (22.28 MPa) to 417.6 kg/cm² (41 MPa) with an average of 362.6 kg/cm² (35.6 MPa). The data on MOR of LVL were subjected to analysis of variance and the results showed that MOR of LVL was significantly affected by layer compositions. It was observed that the MOR values increased with the increase in number of wood veneers incorporated in the oil palm LVL structure. Incorporating wood veneers in the structure of OP LVL increased the MOR of OP LVL by 65.7% for J2 LVL, 83.8% for J3 LVL, 70.6% for M2 LVL and 78% for M3 LVL respectively. Additionally, a study by [7] reported that the inclusion of two and three layers of rubberwood veneers escalated the MOR of the oil palm trunk LVL to about 19.8% and 45.6%, respectively.

Table 2. Mechanical properties of laminated veneer lumbers, the results of ANOVA and HSD.

| Properties          | OP  | J2  | J3  | M2  | M3  | ANOVA Results |
|---------------------|-----|-----|-----|-----|-----|---------------|
| MOR, kg/cm²         | 227.2bc | 376.4a | 417.6a | 387.5a | 404.4a | 7.73**        |
|                     | (43.4) | (73.3) | (62.6) | (68.2) | (59.30) |               |
| MOE, kg/cm²         | 36428bc | 33531bc | 43192b | 53643a | 43241b | 15.05*        |
|                     | (5574) | (4853) | (4352) | (1247) | (5006) |               |
| Compression strength, kg/cm² | 164.1d | 222.6c | 236.7c | 274.7b | 317.4a | 100.24**      |
|                     | (9.12) | (15.24) | (5.79) | (15.73) | (15.1) |               |
| Hardness, kg/cm²    | 178.7c | 199.1bc | 232.4b | 234.8b | 273.1a | 18.16**       |
|                     | (8.2) | (21.3) | (14.0) | (13.5) | (30.3) |               |

Each value was the average of five specimens
Values in parentheses are standard deviations
Values followed with the same letter within the same row are not significantly different
* not significant
* significant
** highly significant

The seven-ply LVL made of jabon veneers glued with phenol formaldehyde at glue spread rate of 200 g/m² with various adhesive compositions had MOR values varied from 38.33 MPa to 69.75 MPa [17]. Another study reported that laminated board made from oil palm trunk glued with isocyanate adhesive at glue spread rate of 300 g/m² had MOR values varied from 20.2 MPa to 56.98 MPa [18]. The MOR of eight-ply LVL made of three hybrid poplar clones glued with phenol formaldehyde at glue spread rate of 200 g/m² varied from 77.64 MPa to 95.82 MPa [19]. The MOR of five-ply LVL made of gmelina glued with phenol formaldehyde at glue spread rate of 220 g/m² was 61.39 MPa [16] while the MOR of seven-ply LVL made of surian glued with urea formaldehyde was 72.18 MPa [20]. The MOR of mahoni solid wood was 623 kg/cm² or 61.1 MPa [21] while the MOR of jabon solid wood was 691 kg/cm² or 67.77 MPa [22]. Another study recorded for static bending parallel to the grain the MOR of eight-ply MOR of oil palm trunk ranged from 11.05 to 19.29 MPa and 13.04 to 24.63 MPa for the edgewise position [8]. A markedly low MOR value was reported for static bending in perpendicular to the grain of oil palm trunk, ranged from 1.33 to 1.95 MPa [8].
3.2.2. Modulus of Elasticity
The assessed treatment was different with respect to the MOE. The MOE values of laminated veneer lumbers varied from 33531 kg/cm² or 3289 MPa to 53643 kg/cm² or 5261 MPa with an average of 42007 kg/cm² or 4120 MPa. The data on MOE of LVLs were subjected to analysis of variance (ANOVA) using completely randomized design and the result showed that the MOE of LVLs was affected by layer compositions. It was observed that the highest MOE was resulted from five-ply oil palm LVL which included two mahoni wood veneers in the LVL structure which used as face and back layers (M2). Similarly, an increase in the MOE value was found in the oil palm trunk LVL with the inclusion of two and three layers of rubberwood veneers to 61.8% and 80.4% compared to the entirely oil palm trunk layers, respectively [7].

The seven-ply LVL made of jabon veneers glued with phenol formaldehyde at glue spread rate of 200 g/m² with various adhesive compositions had MOE values varied from 5295.71 MPa to 8428.70 MPa [17]. Other study reported that laminated board made from oil palm trunk glued with isocyanate adhesive at glue spread rate of 300 g/m² had MOE values varied from 2.28 GPa to 10.01 GPa [18]. The MOE of eight-ply LVL made of three hybrid poplar clones glued with phenol formaldehyde at glue spread rate of 200 g/m² varied from 6773.78 MPa to 8363.78 MPa [19]. The MOE of five-ply LVL made of gmelina glued with phenol formaldehyde at glue spread rate of 220 g/m² was 12.86 GPa [16]. The MOE of seven-ply LVL made of surian glued with urea formaldehyde was 8569.86 MPa [20]. The MOE of mahoni solid wood was 92000 kg/cm² [21] while the MOE of jabon solid wood was 68000 kg/cm² [22]. These values were superior than the eight-ply oil palm trunk LVL in the previous study [8].

The MOE in parallel to the grain of oil palm trunk LVL ranged from 405.83 to 712.84 MPa and 816.47 to 1501.11 MPa, for flatwise and edgewise position, respectively [8]. For static bending in perpendicular to the grain, the MOE was around 106.68 to 117.39 MPa and 154.71 to 205.27 MPa for the edgewise and flatwise position, respectively [8].

3.2.3. Compression strength.
As shown in Table 2, the compression strength values of laminated veneer lumbers varied from 164.1 kg/cm² (16.1 MPa) to 317.4 kg/cm² (31.1 MPa with an average of 223.6 kg/cm² (21.93 MPa). The ANOVA showed that the compression strength of laminated veneer lumbers was affected by layer compositions. Incorporating wood veneers in the structure of OP LVL increased the compression strength of OP LVL by 35.6% for J2 LVL, 44.2% for J3 LVL, 67.4% for M2 LVL and 93.4% for M3 LVL respectively. Similar trend was also reported by [7], who found the escalated compression strength of oil palm trunk LVL with the inclusion of rubberwood veneers, compared to the nine-ply oil palm trunk LVL. The inclusion of two and three layers of rubberwood in the LVL gave compression strength values of 26.6 MPa and 31.6 MPa, respectively [7].

The highest compression strength value of oil palm LVL in this study was higher than the compression strength of five-ply LVL made of gmelina [14]. It was reported that the five-ply gmelina LVL glued with phenol formaldehyde at glue spread rate of 220 g/m² was 103.29 kg/cm² or 10.13 MPa [14]. Additionally, the compression strength of M3 LVL (317.4 kg/cm²) was comparable to the compression strength of mahoni solid wood (360 kg/cm²) [21] and jabon solid wood (374 kg/cm²) [22]. It suggests that the inclusion of rubberwood veneers as face, core and back layers of the oil palm trunk LVL raised the compression strength.

3.2.4. Hardness
The results of ANOVA (Table 2) showed that the hardness of laminated veneer lumbers was affected by layer compositions. The hardness of laminated veneer lumbers varied from 178.7 kg/cm² to 273.1 kg/cm² with an average of 243.1 kg/cm². Based on the data in Table 2 it can be seen that OP LVL has the lowest hardness value. In addition, it was observed that the hardness of LVL increased with the increase in the number of wood veneers incorporating in LVL structure. The hardness of five-ply OP LVL increased by 11.4% for J2 LVL, 30.1% for J3 LVL, 31.4% for M2 LVL and 32.7% for M3 LVL.
respectively. The side hardness of mahoni solid wood was 271 kg/cm² [21] while the side hardness of jabon solid wood was 268 kg/cm² [22].

4. Conclusion
The study concluded that the physical and mechanical properties of laminated veneer lumbers made from oil palm trunk were affected by layer compositions. Incorporating jabon or mahoni wood veneers in the structure of oil palm LVL improved the physical and mechanical properties of LVL. The results of the current study indicated that the produced LVL made from oil palm trunk in combination with jabon or mahoni veneer glued with urea formaldehyde adhesive meet the Japanese Agricultural Standard requirement for laminated veneer lumber.

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