Physical mechanical properties of plywood made from lesser known wood veneers bonded with phenol formaldehyde adhesive

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Abstract. Indonesia plywood production becomes the third-largest after wood particle and pulp production. However, this production is not supported by the continuous availability of wood as raw materials, so the use of less-known wood species such as mempisang wood can be considered as alternative raw materials for plywood. This study aims to develop plywood from mempisang wood and investigate the effect of glue spread on the physical and mechanical properties of plywood. The plywood consisted of three veneers glued with various glue spread of phenol-formaldehyde resin (250 g/m², 275 g/m², dan 300 g/m²) using single spread method. The plywood was hot-compressed at 130°C for 5 minutes with specific pressures at 10 kg/cm². Physical-mechanical properties of plywood were carried out based on JAS 233-2003. The higher of glue spread slightly improves the physical and mechanical properties of the mempisang plywood. The Moisture Content (MC), and Shear Strength (SS) values of the plywood satisfied the requirements for the JAS 233-2003 standard. The best level of glue spread of the plywood glued with 300 g/m² phenol-formaldehyde.

1. Introduction
Indonesia is well known as the biggest plywood producer and exporter. Indonesia plywood production reaches to 3.85 million m³ and becomes the third-largest after wood particle and pulp production [1]. Plywood is one of the most important composite products in Indonesia, also increasingly as a substitute for sawn timber and logs utilization. Meanwhile, wood resources were reduced due to the deforestation of natural forests. MoEF [2] reported that from 2015 to 2016, there had been deforestation of 0.63 million ha in Indonesia. The reduced wood supply can affect the deficiency of wood as raw materials for plywood production. As an alternative, the utilization of lesser-known wood was developed to overcome the problem of wood supply deficiency.

Indonesia is labeled as one of the mega biodiversity countries in the world. The wood species in the tropical rainforest of Indonesia, approximately 4000 potential wood species and only less than 10% that had been utilized [3, 5] According to Martawijaya et al. [5], there are about 133 wood species included in lesser-known species. The knowledge of basic properties become essential and needed to determine wood utilization even obtained efficiency the uses of wood. Therefore, it can complement also substitute the uses of commercial wood [6]. One of the lesser-known wood species that can be used mempisang (Alphonsea spp.) wood. The results of Supriadi and Abdurachman [6] showed that mempisang wood
has poor to excellent class on machining properties. Mempisang wood requires major caution on drilling and turning process on the lathe. Also, information about the utilization that wood as biocomposite products is still limited. Therefore, research on the utilization of mempisang wood as biocomposite products such as plywood should be explored. This study aims to develop plywood from mempisang wood and investigate the effect of glue spread levels on the physical and mechanical properties of the plywood.

2. Materials and Methods

2.1. Materials
Veneers mempisang wood with a thickness of 1.5 mm was obtained from Forest Products Research and Development Centre Bogor-Indonesia. The adhesive was used Phenol Formaldehyde (PF) resin from PT Pamolite Adhesive Industry (Jakarta, Indonesia).

2.2. Methods

2.2.1. Plywood manufactured
Mempisang wood veneers were oven-dried at 60°C for 48 hours to obtained less than 10% of moisture content. Three layers of veneers were manufacture into plywood. The core veneers were glued with PF resin at various glue spread levels (250 g/m², 275 g/m², dan 300 g/m²) using a single spread method. After the adhesives were spread and veneer arranged, the plywood was pressed using a hot-pressed machine at 130°C for 5 minutes with specific pressures at 10 kg/cm².

2.2.2. Physical and mechanical properties testing
The test of physical and mechanical properties was carried out based on JAS 233-2003 [7] and JIS A 5908-2003 [8]. The physical properties were tested, such as density, Moisture Content (MC), Water Absorption (WA), and Thickness Swelling (TS). The mechanical properties were tested modulus of elasticity (MOE), Modulus of Rupture (MOR), and Shear Strength (SS). The density and MC were measured based on JAS 233-2003 standard using 7.5 x 7.5 x 0.45 cm (in length, width, and thickness, respectively). The WA and TS test were based on JIS A 5908-2003 standard using 5 x 5 x 0.45 cm samples in length, width, and thickness, respectively. The mechanical properties (MOE and MOR) test was carried out according to JAS 233-2003 standard using 20 x 5 x 0.45 cm (in length, width, and thickness, respectively). The test was using UTM Instron (50 kN, USA) with a loading speed of 10 mm/minute for MOE and MOR, also 2 mm/min loading speed for the SS test. The samples for the SS test were 8 x 2.5 x 0.45 cm in length, width, and thickness, respectively.

2.2.3. Data analysis
The data were analyzed using Microsoft Excel and IBM SPSS Statistics (Statistical Product and Service Solution) ver 23. A simple completely randomized design with a single factor was used for data analysis. The factor analysis of variance tests of glue spread levels (250 g/m², 275 g/m², dan 300 g/m²) on physical and mechanical properties were evaluated. Duncan’s multi-range test was used for further analysis if the significance value of glue spread levels was significantly different p<0.05.

3. Results and Discussion

3.1. Physical properties of plywood
The density of plywood in this study tends to be same, ranged from 0.53-0.56 g/cm³ (Figure 1). Based on the analysis of variance showed in Table 1. The results showed that the glue spread level did not significantly affect density. There is no requirement of density on the JAS 233-2003 standard. The density of plywood in this study was higher than the density of plywood made from jabon veneers glued with PF resin mixed black liquor (PF-BL) (0.47-0.48 g/cm³) [9]. The results were also higher than 5 layers plywood made from pinus veneers wood (0.48-0.56 g/cm³) [10] and density of 5 layers plywood made from poplar veneers wood about 0.46-0.47 g/cm³ [11].
Figure 1. Density and MC of mempisang plywood glued with PF resin at various glue spread levels

The average MC of mempisang plywood in this study were 11.72-12.35% (Figure 1). The average MC of all mempisang plywood in this study met JAS 233-2003 standard, which requires a maximum value of 14%. The average MC was lower than three layers plywood made from jabon veneers wood glued with PF-BL (12.61-13.53%) [9]. Meanwhile, the average MC was higher than Suhasman and Agussalim [12], which MC of plywood made from sengon wood veneers reinforced with H₂O₂ ranged from 4.92-6.84%. Analysis of variance showed that glue spread levels did not significantly affect the MC of mempisang plywood (Table 1). However, the higher glue spread levels tend to reduce the MC of plywood.

Table 1. Analysis of variance (ANOVA) of glue spread levels on the physical properties of mempisang plywood

| Properties          | Significant |
|---------------------|-------------|
| Density             | 0.742ns     |
| Moisture content (MC)| 0.771ns     |
| Water absorption (WA)| 0.629ns     |
| Thickness swelling (TS)| 0.260ns     |

Note: ns: not significant at 95% confidence interval; **: significantly different at 95% confidence interval

According to Sulastiningsih et al. [13], lignocellulose materials such as wood have hygroscopic properties that can absorb and release water due to temperature, and Relative Humidity (RH) changes. Therefore, WA and TS of plywood are important to determine due to the dimensional stability of the products. The average WA of plywood ranged from 60.00-65.04%. The average WA of mempisang plywood at 300 g/m² glue spread level has lower than plywood with 250 g/m² and 275 g/m² glue spread level. It those due to the higher compatibility between hydrophilic fibers and adhesives of plywood glued with higher glue spread levels. Sreekala et al. [14] showed that weak compatibility between the surface of the fibre and the adhesive could cause a weak structure and not optimal. So, it facilitates higher water absorption. The average WA of plywood was lower than WA of plywood made from pine veneers wood glued with PF resin with value 107.6% [15].
Figure 2. WA and TS of mempisang plywood glued with PF resin at various glue spread levels

The average TS value was ranged from 13.72 to 21.35% (Figure 2). The TS value of all mempisang plywood in this study did not meet the requirement of JIS A 5908-2003 standard, which requires a maximum value of 12%. The average TS was higher than plywood made from eucalyptus wood veneers with PF resin, those reported by Almeida et al. [16] that the TS value was 7%. Silva et al. [15] also reported that the TS value of plywood made from pine wood with PF resin was 8.7%. The results of analysis of variance showed that glue spread levels did not significantly affect WA and TS value of mempisang plywood (Table 1). Therefore, the higher glue spread level tends to reduce the average of WA and TS value of plywood.

3.2. Mechanical properties of plywood

The MOE value of mempisang plywood ranged from 9.6 to 12.9 GPa (Figure 3). The results of the analysis of variance showed that glue spread has no significant effect on the MOE of the plywood (Table 2). However, the higher glue spread produces the higher MOE value of the plywood. It is due to the higher glue spread caused the resin spread and enter the wood pore on the surface and then hardened [17]. The MOE values in this study were higher than 5 layers of poplar plywood (2.1 GPa), and batai plywood (2.4 GPa) glued with UF resin [11,18]. In addition, the results of MOE value was also higher than 5 layers pinewood glued with PF resin that the values were 5.35 GPa [10].

The MOR values of mempisang plywood ranged from 45.35 to 60.39 MPa (Figure 3). The results of ANOVA showed that glue spread levels did not significantly affect on MOR values of plywood (Table 2). However, the higher glue spread level produce showed a higher MOR value. The MOR values of plywood in this study were higher than Bal and Bektas [11] that MOR values of poplar plywood (5.6 MPa) and Batai plywood (20.38 MPa) glued with UF resin [18]. Moreover, the MOR in this study also higher than pine plywood (56.7 MPa) with PF resin [10].

Figure 3. MOE and MOR of mempisang plywood glued with PF resin at various glue spread levels
Table 2. Analysis of variance (ANOVA) of glue spread levels on mechanical properties of mempisang plywood

| Properties            | Significant |
|-----------------------|-------------|
| Modulus of elasticity (MOE) | 0.291 ns   |
| Modulus of rupture (MOR)     | 0.051 ns   |
| Shear strength (SS)        | 0.138 ns   |

Note: ns: not significant at 95% confidence interval; **: significantly different at 95% confidence interval

The SS value in this study ranged from 1.60 to 2.17 MPa, with an average of 1.85 MPa (Figure 4). The SS of plywood in this study was higher than the 3 layers jabon plywood (0.72-1.15 MPa) using PF-BL resin by Karliati et al. [9] and sengon plywood reinforced with H_2O_2 (0.67-1.32 MPa) by Suhasman and Agussalim [12]. The SS value of mempisang plywood was also higher than 3 layers alder plywood glued with polyethylene adhesive (1.1-1.52 MPa) [19]. The results of the analysis of variance showed that the glue spread level did not significantly affect the SS values of plywood (Table 2). However, the SS values of mempisang plywood were increased in line with increasing the glue spread (Figure 4). It is following Khalil et al. [20], which states that the higher glue spread to a certain level can increase the SS value of plywood. The SS values of mempisang plywood in this study had met the requirements of JAS 233-2003 standard, which require a minimum value of 0.7 MPa.

Figure 4. SS of mempisang plywood glued with PF resin at various glue spread levels

4. Conclusion
The higher glue spread slightly improves the physical and mechanical properties of the mempisang plywood. The MC, and SS values of the plywood satisfied the requirements for the JAS 233-2003 standard. The best level of glue spread of the plywood glued with 300 g/m² phenol-formaldehyde.

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