The effect of drying temperatures and tannin-adhesive types on bending properties and shear strength of glued *Eucalyptus pellita* board

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Abstract. *Eucalyptus pellita* is usually harvested at young age for pulp and paper production. Therefore, it's wood quality needs to be improved when it is used for construction. One of which is through its conversion into laminated products. Nevertheless, several factors are assumed to influence the final quality of laminated products, i.e pre-drying temperatures used to prepare the samples and the adhesives types used. This paper aims to investigate the effect of both factors on the bending properties and shear strength of glued *Eucalyptus pellita* boards. The Pellita boards were exposed to 2 drying temperatures (50°C and 60°C) and further laminated by using 2 tannin-based adhesives (made from the mahogany and oil palm bark extracts). The results showed the modulus of elasticity (MOE) and modulus of rupture (MOR) of the glued boards with mahogany-tannin adhesives were, respectively, 33,333.15-39,160.15 kg/cm² and 214.30-640.77 kg/cm² higher than the boards laminated with the oil palm wood tannin adhesives. Nevertheless, the oil palm tannin adhesives improved the shear strength of laminated Pellita, approximately 15.06-16.45 kg/cm² higher than the boards laminated with mahogany-tannin adhesives. A further statistical test showed the tannin-types used for adhesives, and not the drying temperatures, that significantly affected the investigated mechanical properties of glued Pellita boards.

1. Introduction

*Eucalyptus pellita* is a native species to North Queensland, Papua New Guinea and Irian Jaya [1]. The species is a fast-growing species that have short rotation, straight stem, high tolerance to various types of soil and location, and high resistance to pest and diseases [2-4]. It is chosen for the development of plantation programs in Indonesia mainly for pulpwood production [4-6]. Nevertheless, the species also exhibits some properties that make it highly suitable as materials for poles, sleepers, flooring, paneling and general construction [7]. In Malaysia, the species has been used for construction and veneer and/or plywood production [5]. Indonesia has been recorded to export the sawn timber of this species at the price of US$ 300 per m³ [8].

Pellite is usually harvested at a very young age, between 5 and 7 years old, considering it is mostly used for pulp and paper production [9]. Therefore, its further utilization as construction and/or furniture materials will need some treatments or modifications to improve its properties and overcome the weaknesses often found in young plantation timber. One of the treatments or modifications that can be applied is the lamination technology which assembles several sawn timbers in particular orientation, glued together to create panel products. The technology improves the use of low to medium quality timbers as these materials can be combined together with high-quality timbers to create wooden products that meet the requirement for construction or furniture purpose. There are two kinds of laminated boards, which are glue-laminated (glulam) and cross-laminated timbers (CLT). The difference lies in the alignment of the board grains, where in CLT, the layers of wood are stacked in cross-wise but in glulam all grains are aligned in one direction [10].

There are several factors affecting the properties of the glue-laminated board, such as types of adhesives used, types of wood species being constructed and alignment of wood layers [11-13]. Nevertheless, very little attention has been given on the effect of technical process on the properties of laminated board, such as pressing time or treatment of the wood prior to the lamination process [14, 15]. One of the technical processes that are assumed to have an impact on the properties of laminated timber is the drying process the timbers are exposed to before being further glued together. Drying temperature applied could affect the uniformity of moisture distribution along the wood [16]. Therefore, it has potential to affect the bonding between the glue components and the wood surface. In addition, Pellita is not easy to dry wood. The low drying temperature is suggested to apply at the early phase of its drying, and it can be increased after the timber reaches fiber saturation point [17].

It is noted that, up to now, the study on the effect of drying temperature applied on the laminated board properties has not been carried out elsewhere. Therefore, this study was carried out with its main
aim to investigate the influence of different drying temperature and the adhesive used, as well as their interaction on several properties of laminated boards. Pellita is the subject of this research as the information on lamination technology for this species is still very limited.

2. Materials and Methods

2.1. Material Collection and Equipment

The main materials used for this research were 4000 mm-long sawn timber of 10-year old *Eucalyptus pellita*. The trees were collected from a research forest area in Wonogiri, Central Java, Indonesia which is managed by the Center for Forest Biotechnology and Tree Improvement (CFBTI) in Yogyakarta, Indonesia. The equipment used included a sawing machine, small band-saw, oven, fridge, caliper, moisture meter, ruler, measuring tape, and scale. Other supporting materials used include aluminum foil, writing tools, notebooks, and two types of tannin-based adhesives (made from the extracts of mahogany- and oil palm wood-barks).

2.2. Location and Time

The experiment was run in February-April 2019. All drying, gluing and mechanical testings were carried out in related laboratories of Forest Products Research and Development Center (FPRDC) in Bogor, Indonesia.

2.3. Research Procedures

2.3.1. Sample preparation

The long sawn timbers were cut to produce the small boards, each at length of 500 mm, a width of 100 mm and a thickness of 20 mm. The small boards were randomly checked and only boards with initial moisture content similar or above 15% were used for this experiment. Approximately 48 boards were selected for the study. Both ends of each selected board were further sealed with aluminum foil to prevent moisture evaporation from those parts.

2.3.2. Experimental methods

a) Drying

The prepared boards were divided into 2 groups, each consisted of 24 boards. The 1st group was exposed to drying process at 50°C and the other was exposed to 60°C. Both groups were dried until all boards reached the final moisture content of 10% or below. Afterward, all timbers were planned to obtain smooth surface prior to gluing process.

b) Gluing

The study used tannin-based adhesives which were made from the extract of mahogany and oil palm wood barks. The extraction process was carried out in an extractor. The bark powders were mixed with water with a ratio of 1:4 (w/w) for oil palm wood bark or 1:3 for mahogany wood bark. Each mixture was heated at 80°C for 3 hours. The extract obtained was filtered and separated from the powder. Extraction was repeated twice.

Each extract was further mixed with technical resorcinol (R) and formaldehyde (F). The resorcinol was added to activate the phenolic compounds within the bark. The adhesive formulation for the extract of oil palm wood bark was S:R:F = (1:0.25:1)%. Tapioca flour, as much as 2.5% from the adhesive ingredients, was further added [18]. The adhesives formulation from the extract of mahogany bark (M) was M: R: F = 1: (0.1-0.5): 1 [19].

The 24 boards from each drying group were divided evenly into 2 groups of adhesives. For each adhesive group, every two samples were glued with the prepared formula, resulting in 6 glued boards, each at a dimension of 500 mm (length) x 100 mm (width) x 400 mm (thickness). The adhesive was spread double, on each glue-line surface of the prepared samples. The amount of adhesive spread for each laminated board was (2 x 0.5 m x 0.1 m x 200 g/m2) = 20 gram.

c) Mechanical testing

The mechanical properties tested were the modulus of elasticity (MOE), modulus of rupture (MOR) and shear strength. The MOE and MOR test followed the British standard BS 373:1957, while the shear strength test followed ASTM D 143-94. Figure 1 shows the sampling procedure for the 3 properties. The sample dimension for MOE and MOR was 20 mm (width) x 20 mm (thickness) x 300 mm (length), and for shear strength was 50 mm (width) x 50 mm (thickness) x 63 mm (length) (Figure 2).
2.3.3. Data analysis

All data was tabulated in the table. Analysis of variance with 2 main factors, drying temperature and tannin-based adhesive types, was applied to investigate the significant effect of the main factors and their interaction on the bending properties and shear strength of glued Pellita. The results were then discussed.

3. Results and Discussion

Table 1 shows the bending properties of *E. pellita* boards dried under different temperatures and further glued with mahogany-bark tannin adhesive (M-adhesive) or oil palm wood bark tannin adhesive (P-adhesive). Briefly, Table 1 shows that the boards glued with M-adhesive have higher bending properties than those glued with P-adhesive. Higher values of MOE and MOR indicate the boards are more resistant to bend and get rupture. All MOE and MOR values obtained meet the JAS 234:2003 standard [23].

Higher drying temperature appears to reduce the bending properties of glued boards. Table 1 shows that the glued-boards made of samples previously exposed to 50°C have the highest bending properties for both types of tannin adhesive. This result could be due to the changes in wood components or structure as the effect of higher temperature applications. As the drying temperature increases, hemicellulose, lignin, and extractive substances start to decompose, cellulose becomes more crystalline and wood tends to be more hydrophobic [16, 21]. Nevertheless, further ANOVA result (Appendix 1) confirms only the types of tannin-adhesives applied that has a significant effect on the differences in the bending properties of glued Pellita boards.
Table 1. Bending properties of glued- *E. pellita* boards previously dried under 2 drying temperatures and glued with 2 tannin-based adhesive types

| Tannin-adhesive types | Drying temperature | MOE (kg/cm²) | MOR (kg/cm²) | MOE (kg/cm²) | MOR (kg/cm²) |
|-----------------------|--------------------|--------------|--------------|--------------|--------------|
|                       | 60°C               |              |              | 50°C         |              |
| Mahogany bark          |                    | 126,272.06 ± | 51,388.57 ±  | 135,102.07 ± | 1,473.77 ±    |
| Oil-palm wood bark     |                    | 87,111.91 ±  | 752.36 ±     | 99,529.37 ± | 833.01 ±     |

Table 2 shows the shear strength of glued-Pellita boards. Higher shear strength value indicates the bonding caused by a type of adhesive applied is stronger than the other one. This parameter is the main criteria used for analyzing the quality of an adhesive [22].

Different from the result obtained for bending properties, the boards glued with P-adhesive generally show higher shear strength values than those glued with M-adhesives with a different value of approximately 15.06 – 16.45 kg/cm². On the other hand, the differences in the drying temperatures applied did not show any differences in the shear strength values. This fact is unexpected because it was previously assumed that the drying temperatures applied could affect the bonding between the adhesives and the timber due to differences in the moisture distribution pattern within the board. Nevertheless, further ANOVA result (Appendix 2) confirms that the type of tannin adhesives is the only factor significantly affects the shear strength of glued-Pellita boards.

Table 2. Shear strength of glued-*E. pellita* boards exposed to different drying temperatures and glued with different tannin-based adhesive types

| Tannin-adhesive types | Drying temperature | Shear strength, kg/cm² | % damaged sample | Shear strength, kg/cm² | % damaged sample |
|-----------------------|--------------------|------------------------|------------------|------------------------|------------------|
|                       | 60°C               | 10.43 ± 7.44           | 12%              | 10.18 ± 5.62           | 8.33             |
|                       | 50°C               | 25.49 ± 17.99          | 16%              | 26.62 ± 8.12           | 1.67             |

Further Table 3 below is extracted from Santoso’s unpublished work [20] which helps to understand the superiority of P-adhesives in creating stronger bonding than the M-adhesives. It can be seen that the tannin-adhesive made with oil-palm wood bark extract has a higher viscosity, specific gravity, solid content and gelatinization time than that made from mahogany-bark extract. The adhesive with high solid content indicates a high resin content which also tends to be proportional directly to its viscosity, specific gravity and gelatinization time. Furthermore, high solid content also improves the resin penetration into the wood pores to create optimum bonding. As a final result, the adhesive with high solid/resin content results in better bonding quality [20]. Nevertheless, the shear strength of glued Pellita boards made with both types of tannin adhesives has not met the JAS standard 234:2003 [23]. Therefore, the formula used still needs to be improved.

Table 3. Comparison of several properties of tannin adhesives made from oil-palm wood bark and mahogany-bark extracts [20]

| Properties                  | Tannin-adhesive types | Oil-palm wood bark | Mahogany-bark |
|-----------------------------|-----------------------|--------------------|---------------|
| Viscosity, Poise            |                       | 12.43              | 11.48         |
| Specific gravity            |                       | 1.14               | 1.05          |
| Solid content , %           |                       | 17.87              | 15.36         |
| Gelatinization time, minutes|                       | 271                | 264           |
4. Conclusion
The study has shown that Pellita boards glued with M- adhesives have higher bending properties than those glued with P- adhesives. However, P-adhesive is potential to create a stronger bond between boards of E. pellita since the glued-boards have higher value of shear strength than those glued with M-adhesive. Statistical test results imply that only the types of tannin-adhesives used, not the drying temperature applied, had a significant effect on the bending properties and shear strength of glued Pellita boards.

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Appendix 1. ANOVA result for investigating the significant effect of drying temperatures and tannin-type adhesives on bending properties of laminated Pellita board

### Analysis of Variance for MOE, using Adjusted SS for Tests

| Source       | DF   | Seq SS   | Adj SS  | Adj MS | F   | P     |
|--------------|------|----------|---------|--------|-----|-------|
| Drying       | 1    | 2557249493 | 2557249493 | 2557249493 | 2,16| 0,159 |
| Tannin       | 1    | 11132515283 | 11620036471 | 11620036471 | 9,82| 0,006 |
| DT*Tannin    | 1    | 896811203  | 896811203  | 896811203  | 0,76| 0,395 |
| Error        | 18   | 21293286283 | 21293286283 | 21293286283 | 1182960349 | 0,76| 0,395 |
| Total        | 21   | 35879862262 | 35879862262 | 35879862262 | 1182960349 | 0,76| 0,395 |

S = 34394.2  R-Sq = 40,65%  R-Sq(adj) = 30,76%

### Analysis of Variance for MOR, using Adjusted SS for Tests

| Source       | DF   | Seq SS   | Adj SS  | Adj MS | F   | P     |
|--------------|------|----------|---------|--------|-----|-------|
| Drying       | 1    | 471082   | 471082  | 471082  | 2,52| 0,130 |
| Tannin       | 1    | 1098546  | 997007  | 997007  | 5,33| 0,033 |
| DT*Tannin    | 1    | 248006   | 248006  | 248006  | 1,33| 0,265 |
| Error        | 18   | 3369099  | 3369099 | 3369099 | 187172 | 1,33| 0,265 |
| Total        | 21   | 5186733  | 5186733 | 5186733 | 187172 | 1,33| 0,265 |

S = 432,634  R-Sq = 35,04%  R-Sq(adj) = 24,22%
Appendix 2. ANOVA result for investigating the significant effect of drying temperatures and tannin-type adhesives on shear strength of laminated Pellita board

Analysis of Variance for GeserRekat, using Adjusted SS for Tests

| Source      | DF | Seq SS | Adj SS | Adj MS | F     | P     |
|-------------|----|--------|--------|--------|-------|-------|
| Drying      | 1  | 1,0    | 1,0    | 1,0    | 0,01  | 0,924 |
| Tannin      | 1  | 1376,0 | 1353,8 | 1353,8 | 12,17 | 0,003 |
| DT*Tannin   | 1  | 2,6    | 2,6    | 2,6    | 0,02  | 0,879 |
| Error       | 18 | 2003,1 | 2003,1 | 111,3  |       |       |
| Total       | 21 | 3382,8 |        |        |       |       |

S = 10,5490  R-Sq = 40,79%  R-Sq(adj) = 30,92%