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Original Article

Physical and Mechanical Properties of Glued Laminated Lumber of Pine (*Pinus merkusii*) and Jabon (*Anthocephalus cadamba*)[1]

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ABSTRACT

The aim of this research was to determine the physical and mechanical properties of glued laminated lumber (glulam) made from jabon (*Anthocephalus cadamba*) and pine (*Pinus merkusii*). Three layers of lamina from each wood species were bonded using isocyanate adhesive with a glue spread of 280 g·m^{-2} and then pressed using cold press with a specific pressure of 1.47 MPa. Samples had dimensions of 3 cm×6 cm×100 cm (thickness, width, and length, respectively). Glulam properties were tested based on Japanese Agricultural Standard (JAS) 234-2003. The results showed that the density of glulam was 0.36 g·cm^{-3} for jabon and 0.73 g·cm^{-3} for pine. The moisture content of all glulams fulfilled the JAS standard. The mechanical properties of pine glulam fulfilled the JAS standard in all tests, whereas jabon glulam fulfilled the standard in the modulus of rupture and shear tests.

Keywords: glued laminated lumber, isocyanate adhesive, *Anthocephalus cadamba*, *Pinus merkusii*

1. INTRODUCTION

Indonesian plantation forests are dominated by fast-growing tree species such as jabon (Anthocephalus cadamba) and pine (Pinus merkusii). These species have cutting cycles of 5~10 years, a diameter of less than 30 cm, and a specific gravity ranging from 0.4 to 0.7 (Hadi *et al*., 2015). With short cutting cycles, the proportion of sapwood is greater than that of heartwood (Fajriani *et al*., 2013). The high content of sapwood causes wood to have low density, modulus of elasticity (MOE), and modulus of rupture (MOR) (Clark *et al*., 2006). Wood for structural materials is required to have high strength at large dimensions.

One option to improve the utilization of wood, with no restriction on dimensions, could be to construct glued laminated lumber (glulam). Glulam is very efficient in the manufacturing process because the energy required to produce it from wood logs is less than required to produce steel or concrete. Moreover, Glulam is a composite material with more uniform distribution and higher values of mechanical characteristics than wood. (Kuzman *et al*., 2010).

Glulam used as a structural material, such as in buildings and bridge construction, is made from thin layers of lamina from small-diameter wood with

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low-medium quality and adhesive in accordance with the required size of the finished product (Lestari *et al*., 2015). The adhesives also have an important role in the quality of glulam because they allow adjustments in the physical and mechanical properties of the product (Sulistyawati *et al*., 2008). Isocyanate adhesive is one type of adhesive that is used in the production of glulam with cold pressing. The advantages of isocyanate adhesives are that they can be used in small amounts at low temperatures and in short press cycles (Marra, 1992). This study determined the physical and mechanical properties of glulam made from jabon and pine wood using isocyanate adhesives.

2. MATERIALS and METHODS

2.1. Preparation of Lamina

This research used jabon and pine wood from Ciampea, Bogor, Indonesia. Each log had a diameter of around 20 cm and was cut into laminas with dimensions of 1 cm×6 cm×100 cm (thickness, width, and length, respectively). The small clear specimen laminas were dried naturally and then kiln-dried to a moisture content of approximately 12%. The grading of lamina was performed by modulus of elasticity (MOE) prediction using a non-destructive device, namely Panther version MPK-5 with procedures as followed Surjokusumo *et al*. (2003):

1. Lamina to be sorted placed in two pedestals,
2. A load (P1) is placed over the lamina just above the deflectometer needle, measured magnitude of deflection (y1).
3. Standard load B (P2) is then added, the number on the deflectometer recorded (y2).
4. The load is lifted, the lamina is reversed and rearranged as before.

The larger the deflection value the smaller MOE value of the lamina and vice versa. The graded laminas were classified to be 2 grades, high MOE value and low MOE value. High MOE was put into the face/back layers and low MOE value was put into the core layers.

2.2. Preparation of Glulam

The laminas of the same species with high MOE values put into the face and back layers, and the laminas with low MOE value put into the core layer. Three laminas were bonded with isocyanate adhesive (PI-3100, a water soluble that consisted of base resin and hardener obtained from PT Polychemi Asia pacific, Jakarta). The glued system was using double spread method with a glue spread of 280 g·m^{-2} (Herawati *et al*., 2010), followed by cold pressing (specific pressure 1.47 MPa) for 3 hours and clamping for 24 hours. The three-layer glulams (3 cm×6 cm×100 cm; thickness, width and length, respectively) were conditioned for a month in room temperature with 23ºC to 30ºC with relative humidity 60% to 90% prior to testing. Five replications were made for glulam of each species.

2.3. Physical and Mechanical Test of Glulam

Examination of physical properties (including density and moisture content) and mechanical properties (MOE, modulus of rupture (MOR), and shear strength) were based on JAS (Japanese Agricultural Standard) 234-2003. For both wood species, five replication of small clear specimen of solid wood samples with around 12% of moisture content and the same size as the glulam samples were tested for physical and mechanical properties for comparison purposes. The mechanical tests were done using Universal Testing Machine (UTM) Shimadzu UH-100A. Data analysis was undertaken using a completely randomized block design. The block factor was wood species (i.e., jabon or pine), and the treatment factor was the type of adhesive (i.e., isocyanate or no adhesive in the case of solid wood). If from the analysis of variance the treatment factor was significantly different (P value < 0.05) or very significantly different (P value < 0.01), Duncan's multi-range test was used for further analysis.

3. RESULTS and DISCUSSION

3.1. Sorting and Preparation of Lamina

The range MOE value of laminas from jabon were 6,488 MPa to 9,458 MPa (for face-back layers) and 4,668 MPa to 6,141 MPa (for core layer), meanwhile from pine wood were 10,460 MPa to 11,762 MPa (for face-back layers) and 8,530 MPa to 9,635 MPa (for core layer). The MOE average value of laminas for face and back layers, and core layer is shown in Table 1. Moe of pine wood lamina was higher than MOE of jabon wood lamina, because wood density of pine was much higher than jabon and it was double value. The use of lamina with varying MOE values is understandable because in this study no minimum value restrictions or maximum used for glulam manufacture. Grade sorting of lamina was done to determine the lamina into 2 groups, and it would be placed for face-back layers and core layer (Komariah, 2015).

3.2. Physical Properties of Glulam

The physical properties, density and moisture content, of glulam and solid wood are shown in Table 2. The moisture content of glulam and solid wood from the two wood species ranged from 11.1~12.2%, these values reached equilibrium moisture content 10.6~20.5% (Simpson 1991), and also fulfilled the JAS 234-2003 standard (below 15%). Based on the analysis of variance (Table 2), neither the wood species nor the material affected the moisture content. Glulam and solid wood samples for each wood species were air dried conditioning for a month, and the moisture content of the products approached the equilibrium moisture content in Bogor (10.9% to 20%).

Table 1. Modulus of Elasticity Value of Lamina

Wood Species	Face and back layers (MPa)	Core layer (MPa)
Jabon	7.4 (0.9)	5.4 (0.7)
Pine	11.2 (0.6)	8.8 (0.6)

Remarks: Numbers in the parentheses are standard deviation values.

Table 2. Physical and mechanical properties of glulam and solid wood

Wood species	Material	Physical		Mechanical		
		Density ($g \cdot cm^{-3}$)	Moisture content (%)	MOE (×1000 Mpa)	MOR (Mpa)	Shear strength (Mpa)
Jabon	Solid	0.35 (0.01)	12.2 (0.9)	4.9 (0.3)	39.3 (1.9)	6.6 (0.5)
	Glulam	0.36 (0.03)	11.8 (0.5)	5.5 (1.1)	46.1 (4.4)	7.4 (0.9)
Pine	Solid	0.70 (0.01)	11.1 (0.5)	8.9 (0.5)	71.0 (3.4)	13.7 (0.4)
	Glulam	0.73 (0.04)	12.0 (0.5)	10.6 (0.7)	86.2 (8.6)	14.1 (0.2)
JAS Standard 234-2003			Max 15	Min 7.3	Min 29.4	Min 5.3

Remarks: Numbers in the parentheses are standard deviation values.

Table 3. ANOVA of the physical and mechanical properties of glulam

Parameter	Wood species	Material
Moisture content	NS	NS
Density	*	NS
MOE	*	*
MOR	*	*
Shear strength	*	NS

* Very Significant at $p \leq 0.01$.
NS = not significant.

The density of pine glulam was higher than that of jabon glulam, based on the analysis of variance (Table 3). The density value was significantly affected by wood species because the two species naturally have different densities. The densities of jabon and pine in this study were in line with observation of Hadi *et al*. (2013), who report that the density of jabon wood was 0.35 $g{\cdot}cm^{-3}$, and Hadi *et al*. (2016), who found the density of pine wood to be 0.68~0.70 $g{\cdot}cm^{-3}$. Further, the densities of solid wood and glulam for each species were not different from one another because the glue line of glulam was very thin and consequently could not substantially affect the density. According to Komariah *et al*. (2015), the similar densities of solid wood and glulam also indicate that the pressing process does not affect the density of glulam.

3.3. Mechanical Properties of Glulam

Table 1 shows that pine glulam had the highest value on the MOE test (10,594 Mpa) and fulfilled the JAS standard, which required minimal 7,355 Mpa, whereas the MOE for jabon glulam (5,462 Mpa) was below standard. Jabon wood had a low density (0.35 $g{\cdot}cm^{-3}$), which was also reported by Hadi *et al*. (2013), who found that jabon wood had a density of 0.35 $g{\cdot}cm^{-3}$, which did not fulfill the JAS 234-2003 standard. Nevertheless, the MOE values for both jabon and pine glulams were higher than those of the respective solid wood samples by as much as 12.75% for jabon and 19.34% for pine. In the MOR test, the pine glulam (86.2 Mpa) also had a higher value than the jabon glulam (46.1 Mpa), and both the jabon and pine glulam fulfilled the JAS 234-2003 standard (above 29.4 Mpa). Furthermore, the MOR of glulam was higher than that of its solid wood counterpart, by 17.21% for jabon and 21.41% for pine.

The enhanced MOE and MOR of glulam suggests that the glulam adhesive increased both values. The analysis of variance (Table 2) shows that MOE and MOR were significantly affected by wood species and material. The enhancement was also related to the density of the wood species. Pine has a higher density compared with jabon wood. According to Moody *et al*. (2010), the density of wood linearly affects the mechanical properties of the glulam; the higher the density of a wood species, the greater the mechanical properties of glulam as well.

In the shear strength test, pine glulam also had higher values than jabon glulam (Table 2). Pine is a conifer, and the wood has a simpler tissue structure; consequently, adhesive can more easily penetrate into its tissue. However, the shear strength of both wood species fulfilled the JAS 234-2003 standard of more than 5.3 Mpa. In addition, the shear strength for the two glulams was higher than the solid wood counterparts. According to the analysis of variance in Table 2, the shear strength value was only significantly affected by wood species, but not by material. This phenomenon indicates that the quality of the isocyanate adhesive is equal to the quality of solid wood.

4. CONCLUSION

1. The densities of glulam samples and their solid wood counterparts were not significantly different; jabon (glulam: 0.36 $g \cdot cm^{-3}$, solid: 0.35 $g \cdot cm^{-3}$) and pine (glulam: 0.73 $g \cdot cm^{-3}$, solid: 0.70 $g \cdot cm^{-3}$). All glulams had a moisture content that fulfilled the JAS 234-2003 standard, in a range of 11~12%.
2. All mechanical properties (MOE, MOR, and shear strength) of glulam were higher than the values for its solid wood counterpart. All glulams fulfilled the JAS 234-2003 standard for MOR and shear strength.
3. Overall, the results indicate that isocyanate is suitable for use with jabon and pine wood to produce a glulam superior to solid wood in terms of MOE and MOR.

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