Modified Grain Orientation of Laminated Veneer Lumber Characteristics of Three Fast-Growing Tropical Wood Species

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Laminated veneer lumber (LVL) and modified grain orientation of LVL (LVB) are composite products made from veneer that are predicted to replace construction timber. The purpose of this study was to determine the physical and mechanical properties of LVL and LVB of mahoni (*Swietenia macrophylla*), manglid (*Manglietia glauca*), and gmelina (*Gmelina moluccana*) and to compare their characteristics. The results showed that the physical and mechanical properties of LVL and LVB generally meet the standards for use in construction. Differences in the properties of LVL and LVB occurred in the properties of hardness and screw tests, while the other properties were similar. The parallel fiber direction was better in terms of adhesive strength, while the compaction density was slightly higher than LVL. The LVL flexural strength was better than LVB in flat and edge test directions. This difference correlates with the adhesive strength in the shear strength test due to the different orientation of the fiber directions.

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INTRODUCTION

The use of wood is dependent on its shape and characteristics (Kamala *et al.* 1999). The important role of wood results in higher demand, thereby threatening the existence of forest resources (Shukla and Kamdem 2008). One of the efforts to increase the supply of wood is to establish forest plantations. Plantation forests are expected to substitute wood produced from natural forests, but the amount of plantation wood is relatively small. It needs to be increased by modifying products, for example, making composite products (Shukla and Kamdem 2008; Hua *et al*. 2022).

Laminated veneer lumber (LVL) is a composite product developed for plantation forest wood (Aydin *et al*. 2004). LVL requires small diameter logs of various wood qualities, especially fast-growing wood (Lam 2001). Veneer-based composites have many advantages over conventional solid wood, such as good dimensional stability, high uniformity and strength, good stress distribution, lower processing costs, availability in larger sizes, and better appearance (Kamala *et al.* 1991; Wong *et al.* 1996).

The mechanical and physical properties of composite veneer products are determined by the characteristics of the constituent materials, manufacturing process, adhesive, and use of the product (Lam 2001). Laminated veneer lumber can be used for structural and non-structural applications (Ozarska 1999), so it can replace the dominance of concrete and steel, which are less environmentally friendly (Ozarska 1999; Lam 2001).

The development of LVL requires the characterization of wood growing in plantations. Mahoni (*Swietenia macrophylla*), manglid (*Manglietia glauca*), and gmelina (*Gmelina moluccana*) are often found in plantation forests in Indonesia. These fast-growing woods are widely used for raw wood, and very little is used for buildings (Kamperidou *et al*. 2018). One type that is widely used as sawn timber, bioenergy, and pulp is gmelina (Dvorak 2004). The use of fast-growing wood for glulam and LVL of the gmelina species produces quite good quality (Sasaki *et al.* 1993; González *et al.* 2004).

Most research has focused on laminated beams (González *et al.* 2004) and the mechanical properties of LVL as flanges on I-Beams (Sasaki *et al.* 1993). More research is needed in other aspects besides looking for other fast-growing wood species that have the potential to be developed as LVL. Moreover, it is necessary to develop LVL dimensional stability in the width direction. This form can be called modified grain orientation of laminated veneer lumber (LVB). LVB is similar to LVL, except that only in the middle (several layers) the direction of the veneer crosses to the length so that it will increase its stability.

This study compared the physical and mechanical properties of LVL and LVB in mahoni, manglid, and gmelina. The addition of a cross layer to several layers is discussed.

EXPERIMENTAL

Material Preparation

Gmelina (*Gmelina moluccana*), mahoni (*Swietenia macrophylla*), and manglid (*Manglietia glauca*) wood of 8- to 10-years were obtained from community forests around Cibugel Village-Tanjungsari Sumedang. The logs were peeled through rotary spindles at PT SGS Tangerang Industry with a thickness of 2 mm. The veneer was dried to a moisture content of 5%. Phenol formaldehyde (PF) was used as a base adhesive with the addition of accelerator and filler (cassava flour). The complete adhesive formulation used based on weight comparison is in Table 1 and the basic properties of wood material in Table 2.

Table 1. Composition of Adhesive Mixture Based on Weight Ratio

No	Adhesive component	Specification	Weight comparation	Percentage	
1	Resin Based	Phenol Formaldehyde	50	100	84
2	Filler	Tepung Lencana Merah (cassava flour)	5	10	8.4
3	Accelerator	H451 ($CaCO_3$)	4.5	9	7.56
Component Total			59.5	119	100

Note: Viscosities after mixing: 20 poises.

Phenol formaldehyde (PF) used is a commercial adhesive from PT. Dover chemical (product code: regular PF) has a viscosity of 100 to 70 poise (at 30 °C) and a solids content of 41 to 43%, The molecular weight of phenolic resin was about 2000 to 3000. Likewise, H451 (product code) is the accelerator of the active ingredient calcium carbonate ($CaCO_3$). Meanwhile, cassava flour is a kind of industrial tapioca flour which functions as a filler with a particle size ranging from 50 to 60 mesh.

Table 2. Basic Properties of the Wood Material

Properties	Wood Species		
	*Swietenia macrophylla**	*Gmelina moluccana***	*Manglietia glauca****
Density	0.53 - 0.67	0.33 – 0.51	0.37-0.43
MOE	9200 N/mm^2	4560 – 6990 N/mm^2	5370 – 5470 N/mm^2
MOR	62.3 N/mm^2	19.4 – 34.7 N/mm^2	37.5 – 45.8 N/mm^2

*Abdurrohim *et al.* 2005; ** Krisdianto *et al*. 2013; ** Abdurrohim *et al*. 2004

Board Production

Two board types were made, namely laminated veneer lumber (LVL) and so-called modified grain orientation of laminated veneer lumber (LVB). LVL has all veneer layers in its structure oriented in the length direction of board, whereas LVB has some of the veneer layers oriented perpendicular in the board. The compositions of veneer layers are described in Table 3.

The panel was made at a plywood factory in the Tangerang area (PT Sumber Graha Sejahtera). Three panels were made for each wood species with dimensions of 244 cm long × 122 cm wide × 2 cm thick. The layers were glued using phenol formaldehyde (PF) resin, which was applied on one face of the veneer with a glue spread amount of 210 g/m^2 using a glue roller. The panels were pressed in two steps; they were cold-pressed at 8 kgf/cm^2 for 15 min, which was followed by hot-pressing at 8 kgf/cm^2 and 90 to 95 °C for 20 min. The use of this temperature (90 to 95 °C) corresponds to factory standards, which so far use fast-growing wood. From several tests carried out the use of temperatures above 100 °C always encountered problems. For example, when the hot press was finished, blisters occurred on several surfaces of the veneer sheets. To avoid this, the use of temperatures of 90 to 95 °C was considered effective if immediately after the hot press the panel sheets were stacked in several layers and given weight left for 24 h for optimal curing, after which they were cut into their final dimensions.

Table 3. Composition of Veneer Layers Structure of Board

Board Type	Layer Number										
	1	2	3	4	5	6	7	8	9	10	11
LVL	//	//	//	//	//	//	//	//	//	//	//
LVB	//	//	//	⊥	//	⊥	//	⊥	//	//	//

Note: // = parallel; † = Cross section

Evaluation Test

Prior to testing, the boards were conditioned in a room with a relative humidity (RH) of 65% and a temperature of 25 °C. The moisture content (MC), delamination, formaldehyde emission, shear and modulus constant tests were conducted in accordance with the Japanese Agricultural Standard (JAS) for LVL 2013. The modulus of elasticity (MOE) and modulus of rupture (MOR) in bending was carried out by flat and edge position. Ten replication samples for screw tests were determined under air-dried conditions accordance with the Japan Industrial Standard (JIS A5908). The physical test that was used for the specific gravity determination and hardness was ASTM D143 (2003).

Statistical Analysis

The normality and the presence of extreme data or outliers were verified for each panel property. A general statistical description (average and coefficient of variation) was then performed for the various panel properties. An analysis of variance (ANOVA) was used to test differences between the LVB and LVL panels. Mean differences between panels were evaluated using Tukey's test ($P < 0.01$)

RESULTS AND DISCUSSION

Physical Properties

The average values of physical properties for LVL and LVB are presented in Table 4. The panel density was between 0.56 and 0.72 g/cm^3, and the water content was between 18 to 19%. In general, there was an increase in density between 0.05 to 0.08 g/cm^3 after becoming a panel. The highest density increase occurred in the case of LVB. The influence of the cross section in the middle of the layer affects the density of the panels (Zhang *et al*. 2018). The position of the fiber cross section between layers 4th, 6th, and 8th is thought to affect the resulting density level. The results of the statistical analysis test showed that the orientation of the veneer fibers was not significantly different from the percentage of moisture content of the panels board. For each treatment, the results were not significantly different from the percentage of artificial board moisture content. This is because the orientation of the veneer fiber direction has a more significant effect on the mechanical and structural properties of the wood panels. Shukla and Kamdem (2008) noted that the physical properties of LVL panels made from two different hardwood species are affected by the physical properties of the solid wood species, but not by the orientation of the fiber direction of the panels made.

Table 4. The Physical Properties of LVL and LVB

Testing		Board Type	Mahoni	Manglid	Gmelina
Delamination		LVL	0%*	0.2%*	0.2%*
			(Passed)	(Passed)	(Passed)
		LVB	0%*	0.3%*	0.2%*
			(Passed)	(Passed)	(Passed)
Formaldehyde Emission		LVL	0.38 mg/L	0.58 mg/L	0.74 mg/L
			(F***)	(F***)	(F***)
		LVB	0.26 mg/L	0.58 mg/L	0.64 mg/L
			(F****)	(F***)	(F***)
MC		LVL	18.60%	19.76%	19.80%
			(Failed)	(Failed)	(Failed)
		LVB	17.83%	17.23%	20.14%
			(Failed)	(Failed)	(Failed)
Density	Before	LVL	0.66 g/cm^3	0.55 g/cm^3	0.51 g/cm^3
	After		0.72 g/cm^3	0.60 g/cm^3	0.56 g/cm^3
	Before	LVB	0.60 g/cm^3	0.53 g/cm^3	0.49 g/cm^3
	After		0.68 g/cm^3	0.60 g/cm^3	0.57 g/cm^3

Note *: wood failure percent.

The adhesive formulation used to produce all types of panels met the requirements for delamination quality and formaldehyde emission tests (four stars). This was achieved while the water content of the panel was still above 14%. This phenomenon can occur due to the production process and very high environmental humidity conditions. This greatly affects the final moisture content of the panels that are made (Sozen *et al*. 2021).

Under conditions of high humidity during storage, wood veneer will absorb water content (moisture) from the surrounding environment. According to Haygreen and Bowyer

(1996), the type of wood can also affect the moisture content of the artificial board. If the type of wood has a higher density, then the water content will be higher.

Mechanical Properties

Considering the average values for mechanical tests on LVL and LVB of the three wood species, LVB panels had higher resistance than LVL at maximum load in terms of hardness, shear strength test, and maximum load of screw withdrawal (Table 5). Panel hardness is highly dependent on density; hardness values correlate positively with density values (Gunduz *et al*. 2009; Scharf *et al*. 2022). The highest value observed was 5005 N at a density of 0.68 g/cm (LVB), and the lowest value was 2314 N at a density of 0.51 (LVL). The highest hardness value was observed in LVB panels for all types of wood. Although there were differences in the density values of the two types of panels, the LVB panel type exhibited higher hardness values than LVL. The higher hardness values of LVB may be caused by the high compaction process in the cross section. The position of the fibers overlaps with each other and has an effect on the hardness due to the crossing position, which requires more power compared to the LVL panel. Parallel panel fiber positions tend to produce lower hardness values than crossed positions (He *et al*. 2019).

Table 5. The Mechanical Properties of LVL and LVB

Test			Board Type	Mahoni	Manglid	Gmelina
Shear Strength	Flat (parallel)		LVL	7.95 N/mm²	7.40 N/mm²	5.87 N/mm²
			LVB	7.88 N/mm²	7.22 N/mm²	5.33 N/mm²
	Edge (perpendicular)		LVL	8.43 N/mm²	6.47 N/mm²	4.93 N/mm²
			LVB	6.82 N/mm²	6.12 N/mm²	4.91 N/mm²
Bending	Flat	*MOR*	LVL	70.71 N/mm²	54.35 N/mm²	39.76 N/mm²
			LVB	64.88 N/mm²	53.32 N/mm²	39.16 N/mm²
		MOE	LVL	11074.28 N/mm²	10940.54 N/mm²	8543.89 N/mm²
			LVB	9256.23 N/mm²	8825.53 N/mm²	7184.04 N/mm²
	Edge	*MOR*	LVL	70.78 N/mm²	57.52 N/mm²	43.83 N/mm²
			LVB	61.37 N/mm²	55.03 N/mm²	43.30 N/mm²
		MOE	LVL	11076.10 N/mm²	10807.46 N/mm²	8855.34 N/mm²
			LVB	9275.17 N/mm²	8837.85 N/mm²	7423.87 N/mm²
Hardness			LVL	4742.97 N	3188.36 N	2314.30 N
			LVB	5004.84 N	4244.77 N	2851.80 N
Screw			LVL	1677.42 N	1341.41 N	986.56 N
			LVB	1748.05 N	1505.24 N	992.03 N

The shear strengths evaluated in the two conditions (flat and edge direction) are shown in Table 5 and Fig. 1. The strength resistance ranged from 5.33 to 8.43 N/mm^2 (flat direction) and 4.91 to 7.88 N/mm^2 (edge direction). LVL panels presented higher shear strength than LVB panels under all conditions. This difference can be attributed to the different orientation of the veneers in the panels. LVB is made from cross-laminated sheets veneer, as opposed to the arrangement in LVL panels, where the sheets are parallel laminated veneers. During the shear test, the force applied to the LVB is perpendicular to the direction of the veneer, while the force applied to the LVL panel is parallel to the direction of the veneer.

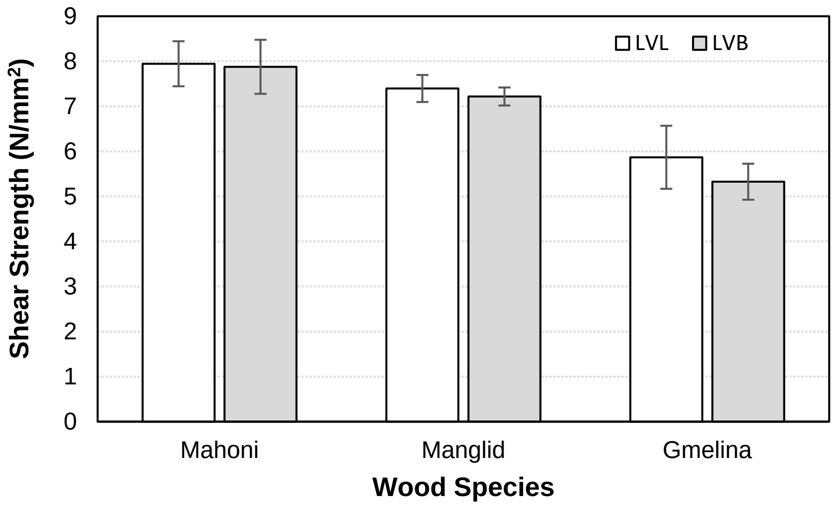

Fig. 1. Shear strength test on flat (parallel) direction

The reduction in shear resistance resulting from veneer being cut from logs by rotary milling machines is characterized by the presence of small checks, called lathe checks, on the veneer side, whereas there is no check on the other side of the sheet. A lathe check is formed when the veneer is bent sharply as it passes between the blade and the nose bridge (Sheldon and Walker 2006). During the gluing process, the unchecked side is glued to the checked side of the veneer; therefore, the irregularities on the surface are filled with adhesive. It appears likely that the surface irregularities increase with the perpendicular joints of the two veneers at LVB. This situation increases the amount of adhesive applied and therefore reduces the resistance of the glue line in the LVB. When veneers are glued in parallel on LVL panels, irregularities are reduced by adjusting checks on the veneer surface. Therefore, the void space on the sheet is reduced, and the resistance of the glue line is increased.

LVB and LVL panels showed higher shear resistance than the minimum values specified by ASTM standards under all test conditions. The shear strength of LVB panels did not reach the average resistance of solid wood, whereas the shear strength of LVL panels had an average value above the minimum under all conditions. LVL panels differed greatly with respect to resistance. Although the shear strength of the LVB panels was higher than the minimum required shear resistance, it was close to the minimum value. Accordingly, LVL and LVB panels can be classified as satisfactory for structural use, but special care must be exercised with LVB panels as they achieve only the minimum shear strength of solid wood.

In contrast, LVB was found to be lower than LVL in terms of shear in plane test, modulus of rupture (MOR), and modulus elasticity (MOE) in parallel bending (Table 5). There was a statistical difference between the LVB and LVL panels determined with respect to the modulus of elasticity (MOE) for both flat and edge conditions (Table 5). The mechanical properties of LVB and LVL panels made of mahoni wood were higher than those of manglid and gmelina (Fig. 2).

The high value of panels from mahoni wood was not only a result of the effect of different densities, but also due to the composition of the veneer layers making up the harvest. The parallel array determines the value obtained. As explained by Kilic *et al*. (2010) and Prakash *et al*. (2019), the parallel arrangement of the veneers will determine its mechanical strength. The LVB value tends to be lower than the LVL in the MOE test in a flat position. This trend is no different for the edge position (Table 5). Where the adhesive strength (bonding power) in the parallel position tends to be higher than that in the cross, even though the density results are inversely proportional (Table 4). From the results of the MOE test there is a positive correlation with shear strength. The high MOE value was offset by the high shear strength test results as well, in addition to the density aspect which also contributed to the test results, and trend MOE values were similar to the values obtained from the MOR test (Table 5).

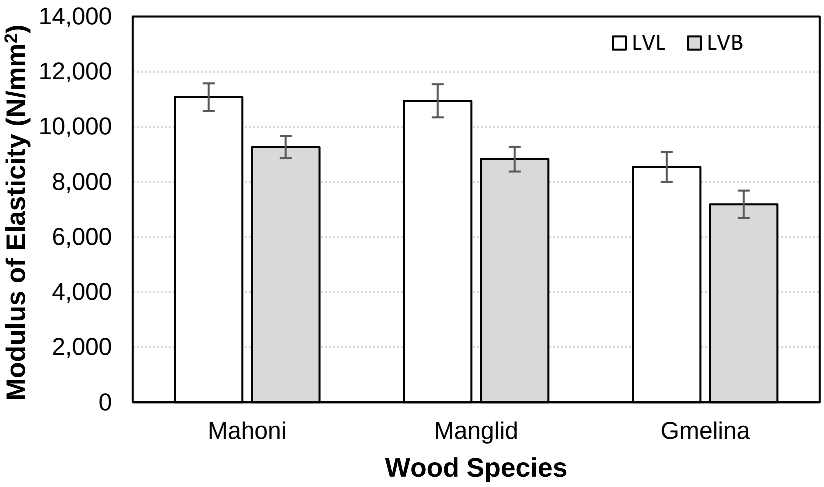

Fig. 2. Modulus of elasticity on flat direction

The high value of mahoni occurred in all tests, both MOE/MOR, shear strength, hardness, and screw tests. The high value obtained was closely related to that naturally higher material density in comparison to the other two woods (Table 2). The difference in wood density in general will affect other properties, especially the mechanical strength, which is the resultant of the density of the material.

In general, the three woods tested were fast growing woods. The values of parallel, perpendicular, compressed-parallel, and MOE in perpendicular-bending were not statistically different between panels. However, other mechanical properties were affected by the orientation of the veneer in the panel, such as hardness, two types of shear tests, MOR of two bending tests, and screw withdrawal.

Another important point to emphasize is that the mechanical properties of the glued veneer products, particularly the removal of screws, are affected by the orientation of the veneer in the panel. For example, LVB panels have better durability when the two parts are joined with screws. However, when the two pieces are screwed parallel to the grain, the LVL panel has better resistance. Abdul *et al.* (2010) observed that some of the mechanical properties of panels depend on panel density, screw diameter, penetration depth of screws, wood species, moisture content, spiral grain, adhesive characteristics, and veneer thickness. Nevertheless, the results obtained in this study confirm that differences in many panel properties (including physical, mechanical, and delamination properties) can be attributed to the orientation of the veneer in the panel.

Based on the results of statistical analysis it is known that the orientation of the veneer fibers in the MOE test was significantly different in the parallel direction of the panel. Based on the graph of the test results (Fig. 2), it is known that the LVL wood panel sample had a higher strength value compared to the LVB wood panel sample in all treatments. This result is in accordance with the statement Tenorio *et al.* (2011) that the parallel arrangement of veneers makes wood panels have a higher bending strength than the perpendicular arrangement of plies within wood panels (Tenorio *et al.* 2011).

CONCLUSIONS

1. The laminated veneer lumber (LVL) and the modified grain orientation of LVL (LVB) panels made of mahoni, manglid, and gmelina veneers from fast-growing plantations have a different specific gravity between 0.5 to 0.7 with MC above 14%. There are differences in terms of absorbing water in the three types of wood studied. Differences in physical properties between panels were caused more by the characteristics of the raw materials, not the shape of the panels.
2. The LVL was mechanically superior to LVB both from the results of the modulus of elasticity/modulus of rupture (MOE/MOR) and shear strength tests except for the hardness and screw tests. The pressing process increased the density of the panel by 9 to 15% of the density of the material. In general, all tests met the requirements for delamination, emission, density, MOE/MOR, shear strength, and screw, except for the water content.

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