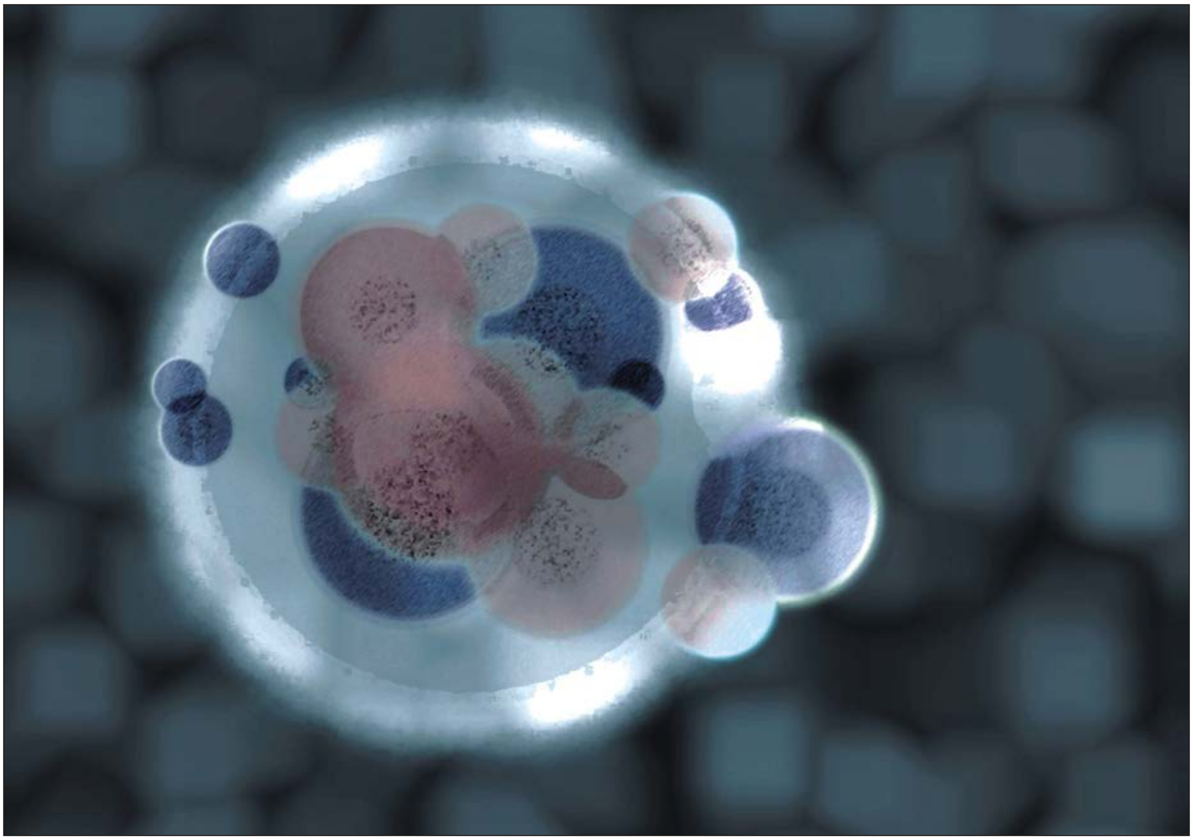

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Performance of Glued-Laminated Beams Made from Small Diameter Fast-Growing Tree Species

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Abstract: This study presents properties test results of glued-laminated (glulam) beams made from two fast growing tree species, namely African wood (*Maesopsis eminii*) and mangium (*Acacia mangium*) using water based polymer isocyanate (WBPI) as a binder. Laminations were used consist of 2, 4, 6, 8 and 12 cm in widthnesses, 2 cm in thickness and 260 cm in length. Each lamination was graded using Machine Stress Grading (namely by Panter or plank sorter) to determine its Modulus of Elasticity (MOE). Cross-section of five types of glulam beams was 6×12 cm, arranged of various widths and based on MOE of laminations. The study results describe that glulam beams made from mangium showed better performance compared to those of African wood based on values of MOE and Modulus of Rupture (MOR). In general, results showed that almost all of glulam beams types of both wood species fulfill the JAS 234:2003 standard in moisture content, MOE, MOR, shear strength and immersion delamination test. However, performance of glulam beams was unsatisfactory in wood failure ratio and boiling water soak delamination test.

Key words: Glulam beam, MOE, MOR, shear strength, delamination

INTRODUCTION

The utilization of fast-growing timber of plantation forest is expected to be able to substitute the role of slow-growing timber of natural forest due to the shortage in wood supply from natural forest. The fast-growing tree species commonly found in Industrial plantation and community forests in Indonesia. Based on Indonesian Forestry Statistics in 2005, log production from plantation forest was about 13.58 million m^3, higher compared to those of natural forest about 9.33 million m^3 (Ministry of Forestry Republic of Indonesia, 2006).

Initially most of these fast growing tree species were focused to provide the raw material for pulp and paper production, but nowadays some of them, especially mangium (*Acacia mangium*) is investigated for the use of structural material to substitute timber from natural forest. Mangium was widely planted about a decade ago for supplying the raw materials in pulp and paper and in MDF industries (Alamsyah *et al*., 2005; Firmanti and Kawai, 2005; Hardiyanto and Supriyadi, 2005). One of the structural uses of wood products is glued-laminated (glulam) beams (Bowyer *et al*., 2003).

Glulam beams is defined as a material that is made from suitably selected and prepared pieces of wood either in a straight or curved form, with the grain of all pieces essentially parallel to the longitudinal axis of the member (Moody and Liu, 1999). Glulam beams offer a good opportunity for small diameter and underutilized material. High quality lumber is required only for the outer laminations and lower quality lumber can be used in the core laminations (Levan-green and Livingston, 2001). Glulam beams made from fast growing tree species can be utilized as building structural components for housing construction or light structural member in building (Alamsyah *et al*., 2005).

The orientation of the plane of the lamination in relation to the applied moment leads to two classes of glulam beams described as horizontal and vertical (Bodig and Jayne, 1993). To optimize the bending stiffness of horizontal type of glulam member, equal amounts of high quality laminations on the outside faces should be included to produce a balanced combination. While to optimize bending strength, the combination can be unbalanced with more high quality laminations placed on the tension side of the member compared with the quality used on the compression side (Moody and Liu, 1999; American Plywood Association, 2003).

In order to increase utilization of fast-growing tree species for structural materials, wood species used in this

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research were African wood (*Maesopsis eminii*) and mangium (*Acacia mangium*). African wood is one of the fast-growing tree species which widely planted in community forest in West Java while mangium widely planted in Industrial Plantation Forest (HTI) in Indonesia. Various lamination widths were used for manufacturing glulam beams to maximize the use of whole log. Designs of lamination arrangements consist of horizontal, vertical and combinations of horizontal and vertical using different stiffness in compression and tension side. For the purpose of obtaining optimal of bending strength and using efficient of wood resources (Moody and Hernandez, 1997; American Plywood Association, 2003).

The objective of this research was to evaluate the performance of glulam beams made from two fast-growing tree species, African wood and mangium using various types of lamination arrangement.

MATERIALS AND METHODS

Materials: Two fast-growing tree species, African wood and mangium (diameters range from 20 to 35 cm) were selected from the community forest in Bogor, West Java, Indonesia. The adhesive used was Water Based Polymer Isocyanate (WBPI) PI 3100 produced by PT. Polychemi Asia Pasifik, Indonesia. The study was conducted from January to August, 2007 at the laboratory of Department of Forest Products, Faculty of Forestry, Bogor Agricultural University, Bogor, Indonesia.

Methods: Logs of African wood and mangium measuring approximately 280 cm in length were converted into sawn timbers to a thickness of 2.6 cm. The sawn timbers were then kiln dried to approximately 12% moisture content. After drying and conditioning about a week, the sawn timbers were cut to 260 cm in length, sawed to various widths (2, 4, 6, 8 and 12 cm with number of each width dimension was 20, 30, 60, 25 and 15, respectively) and then planed to 2 cm in thickness.

Each lamination was then graded using Machine Stress Grading (namely by Panter or plank sorter) to determine the Modulus of Elasticity (MOE) value. The MOE values obtained then classified into three groups, namely E1, E2 and E3 (E1>E2>E3). The glulam beams was 6×12 cm in five types of cross-section which arranged by various widths and those MOE of laminations. Five types of cross-section consist of horizontally (type A), vertically (type B) and combinations of horizontally-vertically laminated orientations (type C, D and E) as shown in Fig. 1A-E. These five types of glulam beams consist of balanced and unbalanced combinations (refer to placement of E1, E2 and E3).

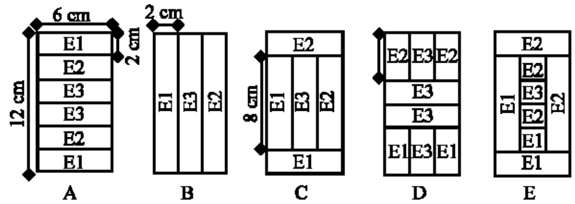

Fig. 1: (A-E) Cross-section layups for five types of glulam beams

The laminations were then bonded by WBPI adhesive using 280 g cm^{-2} double glue spread, clamped and cured approximately 2 h to produce glued-laminated beam. These glulam beams were then conditioned for at least a week before testing. All specimens were loaded to failure under three point loading using universal testing machine Baldwin with capacity of 30 ton. Test samples were cut from the glulam beams for determination of moisture content, MOE, Modulus of Rupture (MOR), shear strength and delamination in accordance with JAS 234:2003 (Japan Plywood Inspection Corporation, 2003).

RESULTS AND DISCUSSION

Laminations grading: The results of laminations grading using Panter machine shown in Table 1. MOE values of laminations used for manufacturing glulam beams from both species showed wide variation. MOE values of African wood laminations ranged from 4.33×10^4 to 13.73×10^4 kg cm^{-2} and that of mangium from 4.98×10^4 to 15.11×10^4 kg cm^{-2}. Also shown by coefficients of variation values for each lamination widths (2, 4, 6, 8 and 12 cm) were 30.8, 19.9, 18.8, 17.4 and 8.4%, respectively for African wood and 18.8, 18.8, 24.6, 30.5 and 22.0%, respectively for mangium. Wide variation of MOE values understandable because grading was only used to classified MOE values into three groups (high/E1, medium/E2 and low/E3) in order to use all laminations.

Modulus of elasticity values showed there were no correlation between lamination width and its MOE value. Modulus of elasticity was affected by defects in each lamination such as knots and cross grain. Knots and cross grain are among the natural characteristics affecting mechanical properties and important defects that reduce the strength of wood (Green *et al*., 1999; Tsoumis, 1991). These types of defect were the most common defect found in African wood and mangium.

In general, MOE values of mangium are higher than that of African wood. It is because density of mangium (610 kg m^{-3}) used in this research was higher than that of African wood (440 kg m^{-3}) and also African wood had more knots than mangium. A study by Ani and Aminah

Table 1: The results of laminations grading at various widths

Wood species	Lamination widths (cm)	MOE (×104 kg cm^{-2}) and number of each group (Σ)					
		E1	Σ	E2	Σ	E3	Σ
African wood	2	9.40-13.73	5	6.05-9.39	10	4.33-6.04	5
	4	8.45-10.36	10	6.30-8.44	10	5.34-6.29	10
	6	7.81-10.75	20	6.50-7.80	20	5.17-6.49	20
	8	8.40-10.78	10	6.90-8.39	10	6.15-6.89	5
	12	7.10-7.45	5	6.60-7.09	5	5.34-6.59	5
			50		55		45
Mangium	2	8.81-11.21	5	6.71-8.80	10	6.38-6.70	5
	4	8.41-11.43	10	7.25-8.40	10	5.52-7.24	10
	6	9.06-14.10	20	7.16-9.05	20	5.28-7.15	20
	8	8.31-15.11	10	6.80-8.30	10	4.99-6.79	5
	12	8.81-10.71	5	7.20-8.80	5	4.98-7.19	5
			50		55		45

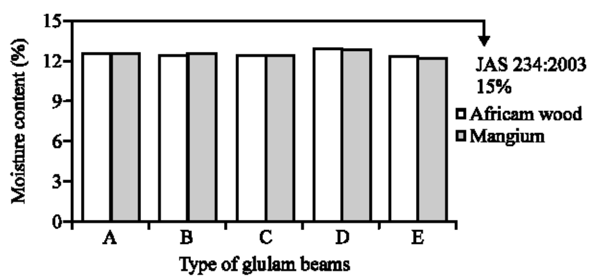

Fig. 2: Moisture content of five types of glulam beams

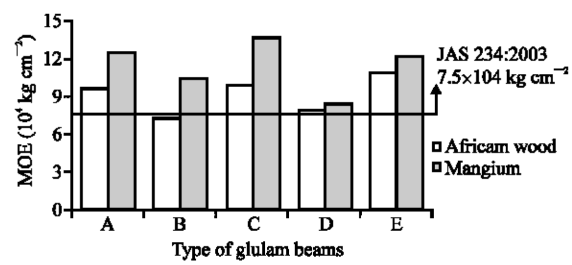

Fig. 3: MOE of five types of glulam beams

(2006) reported that density of African wood at 15% moisture content of the 6-year-old tree ranged from 575 to 644 kg m^{-3} and averaged 605 kg m^{-3}. Difference in wood density may be caused by difference in growth rate.

Moisture content: Moisture content of five types of African wood and mangium glulam beams ranged from 12.4 to 12.9% and 12.2 to 12.8%, respectively as shown in Fig. 2. All of the glulam beams moisture content fulfills the JAS 234:2003 which set forth maximum of 15%. It was relatively uniform so it was expected no moisture content different effect to the strength of glulam beams. Moisture is one of the factors affect mechanical properties. When moisture is reduced, strength increases. Due to the effect of moisture and in order to have comparable results, mechanical properties are determined at constant moisture content, that is, in green condition (above the fiber saturation point) or in air dry conditions (usually 12% and sometimes 15%) (Tsoumis, 1991). According to Moody and Liu (1999), maximum range in moisture content is 5% among laminations to minimize differential changes in dimension following manufacture. Many plants use lumber at or slightly below 12% moisture content because the material is more easily end jointed at level and that is an average equilibrium moisture content for many interior applications.

Modulus of Elasticity (MOE): The results for the MOE values of African wood and mangium glulam beams ranged from 7.30×10^4 to 10.89×10^4 kg cm^{-2} and 8.41×10^4 to 13.67×10^4 kg cm^{-2}, respectively as shown in Fig. 3. Almost all of the glulam beams MOE exceed the minimum requirement of 7.5×10^4 kg cm^{-2} set forth by JAS 234:2003 except MOE of type B of African wood glulam beams. This is because all of MOE values of laminations (12 cm wide) arranged the glulam beams were below the minimum requirement value. The MOE of glulam beam is directly related to the MOE of its individual laminations (Moody and Hernandez, 1997). But, using vertically orientations of laminations, the MOE values of glulam beams were higher than most of MOE values of laminations.

MOE value of mangium glulam beams are higher than that of African wood, as stated before, it is because of the difference between density and character of wood. In general, MOE values of glulam beams were near below the maximum MOE values of their laminations. Besides effect of MOE values of laminations, MOE values of glulam beams also affected by design of laminations arrangement. Combinations horizontal and vertical laminations of type C result in highest MOE value compared to those of others for mangium glulam beams. Combinations of horizontal and vertical laminations of type E result in highest MOE value compared to those of others, followed by type C for African wood glulam beams. Meanwhile glulam beams of type A also showed high MOE value. This result agreed with the previous result of glulam beams made from kaya dan bipa wood

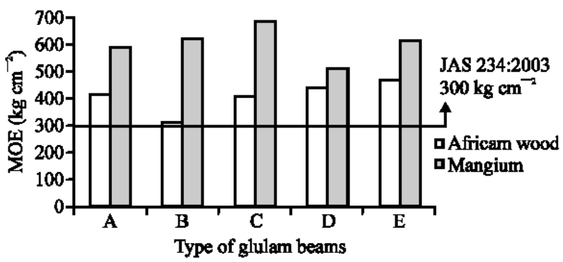

Fig. 4: MOR of five types of glulam beams

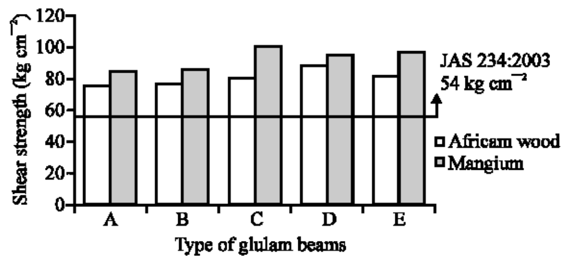

Fig. 5: Shear strength of five types of glulam beams

reported by Abdurachman and Hadjib (2005), MOE of the 5-plies glulam beams were higher than those of the 3-plies glulam beams. According to Moody and Hernandez (1997), equal amounts of high quality laminations may be included on both of the outside faces to produce a balanced combination to optimize the bending stiffness of glulam beam. With respect to type D, lower MOE values caused by lower MOE values of laminations placed in the outside faces.

Based on the MOE values obtained then any type of glulam beam can be produced depending on the availability of the lamination size with consideration of the use of adhesives and the MOE values of glulam beam are needed. As in the case of glulam beam of types C and E, the centre of the glulam beam type E can be constructed from the lamination small width (2 cm) to replace a wider lamina (8 cm). This can increase the efficiency of the use of materials but with the consequence that it needs more adhesive.

Modulus of Rupture (MOR): The results for the MOR values of African wood and mangium glulam beams ranged from 311 to 468 kg cm^{-2} and 516 to 687 kg cm^{-2}, respectively as shown in Fig. 4. All of the glulam beams MOR exceed the minimum requirement of 300 kg cm^{-2} set forth by JAS 234:2003. MOR value of mangium glulam beams are higher than that of African wood, as stated before it is because of difference between density and character of wood. Knot is one of important defects that reduce the strength of wood (Tsoumis, 1991). A study by Karlinasari (2007), shown that African wood had so many knots and its strength ratio was about 72.8%. MOR values of glulam beams also affected by design of laminations arrangement like MOE values. Combinations horizontal and vertical laminations of type C result in highest MOE value compared to those of others for mangium glulam beams.

Type B had lowest MOR value like its MOE value for African wood glulam beams. Meanwhile combinations of horizontal and vertical laminations of type E also result in highest MOE value compared to those of others.

Although, type D had lower MOE value, but its MOR value was high. Bending strength can be optimized using the unbalanced combination with additional high quality laminations placed on the tension side of the member (Moody and Hernandez, 1997). A study by Sulistyawati *et al.* (2008) reported that MOR of vertical glued-laminated beam was around 27% higher than that of horizontal glued-laminated beam.

Similar to MOE values, based on the MOR values obtained then any type of glulam beam can be produced depending on the availability of the lamination size with consideration of the use of adhesives and the MOR values of glulam beam are needed. MOR values of glulam beams produced in this study can be improved by reducing defects mainly knots and then jointed laminations with fingerjoint, as commonly used in the manufacture of glulam beams commercially (Moody and Hernandez, 1997).

Shear strength and wood failure ratio: The purpose of testing performance is to ensure that adhesive bonds will not deteriorate before they can meet these expectations. The common measures used to estimate potential performance of bonded wood joints are strength, wood failure and delamination (Vick, 1999).

Figure 5 shows the shear strength of African wood and mangium glulam beams. All of gulam beams shear strength fulfills the JAS 234:2003 which set forth minimum of 54 kg cm^{-2}. Wood failure ratio of African wood glulam beams are 100, 100, 93, 100 and 100% for type A, B, C, D and E, respectively and that of mangium are 46, 26, 20, 42 and 32 for type A, B, C, D and E, respectively. The minimum requirement of wood failure ratio according to JAS 234:2003 is 70%. This means that only African wood glulam beams meet the minimum requirement. High shear strength with high wood failure is difficult to achieve by mangium laminations due to its wood density is higher compared to that of African wood and most likely related to the extractive content. Density and extractive on wood surfaces are two among factors affecting the bondability of wood (Vick, 1999). Alamsyah *et al.* (2005)

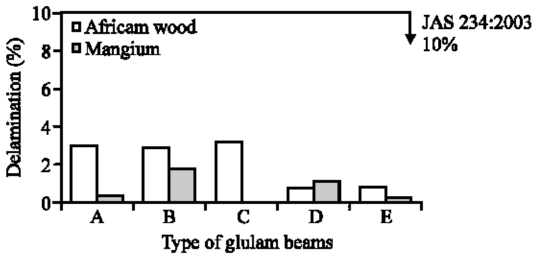

Fig. 6: Delamination after immersion delamination test of five types of glulam beams

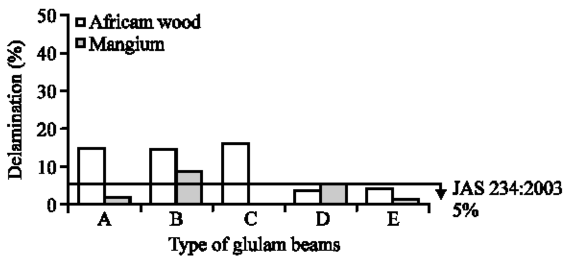

Fig. 7: Delamination after boiling water soak delamination test of five types of glulam beams

reported that the wood failure ratio of laminated mangium was about 49% using isocyanate adhesive.

The bondability of wood is also affected by wettability. Wetting of a surface occurs when the contact angle (the angle between the edge of a drop of adhesive and the surface of wood) approaches zero. A study by Herawati (2007) reported that the contact angle was about 43° on the surface of mangium and about 34° on of African wood using WBPI adhesive.

Delamination: Figure 6 shows the delamination values after immersion delamination test. All of glulam beams delamination fulfills the JAS 234:2003 which set forth maximum of 10%. Norwegian Institute of Wood Technology (2005) reported that delamination testing on spruce and pine had the same indicates using emulsion polymer isocyanate. Figure 7 shows the delamination values after boiling water soak delamination test. All of glulam beams delamination failed to fulfill the JAS 234:2003 which set forth maximum of 5%. Delamination is an indicator of how well the bonded joint withstands severe swelling and shrinking stresses in the presence of high moisture and heat (Vick, 1999). This means that adhesion using WBPI in this research is not good enough to high moisture and heat.

CONCLUSIONS

MOE values of laminations used for manufacturing glulam beams from both species showed wide variation but could be used to produce glulam beams that had high enough MOE and MOR values. The performance of glulam beams made from mangium were better than those of African wood based on MOE and MOR values. MOE and MOR values of glulam beams were affected by the arrangement of laminations and MOE values of laminations. In general, almost all of glulam beam types of both wood species fulfill the JAS 234:2003 standard in moisture content, MOE, MOR, shear strength and immersion delamination test. However, performance of glulam was unsatisfactory in wood failure ratio and boiling water soak delamination test.

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