Original

Properties of Rubberwood LVL reinforced with Acacia Veneers*[1]

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Abstract——The properties of laminated veneer lumber (LVL) [15-ply, 3.6 mm veneer thickness] produced from *Acacia mangium* (Mangium) thinnings, *Hevea brasiliensis* (Rubberwood) and their combinations were investigated. Melamine urea formaldehyde (MUF) was used as the binder. In the species combination, Mangium veneers were incorporated in the tension and compression zones (i.e., top and bottom layers) of the LVL, with Rubberwood veneers in the core. The effects of two Rubberwood : Mangium combination ratios were studied, i.e., 3 : 2 and 1 : 2. Rubberwood LVL reinforced with Mangium exhibited a lower degree of bow compared to pure Rubberwood LVL. The LVLs were evaluated in accordance with the Japanese Agricultural Standard for Structural LVL (1993). All of the LVLs passed the cold water soak and boiling water delamination tests. Similar dry shear strength was registered by all of the LVLs, with shear retention of 58 to 63% after cyclic boiling. LVL with higher proportion of Mangium recorded higher shear strength retention. Modulus of elasticity (MOE) was found to increase with increasing Mangium plies in the faces. This is reflected by 2 and 12% MOE increment in LVL reinforced with 3 and 5 plies of Mangium, respectively. Reinforcement using 3 Mangium plies did not seem to improve the modulus of rupture (MOR), but 13% MOR increment was recorded by incorporating 5 plies of Mangium. Rubberwood and 3-ply Mangium reinforced LVL met the minimum requirements stipulated for 80E Special Grade, while the 5-ply Mangium reinforced LVL made the 100E Special Grade. Mangium LVL passed the 120E Special Grade.

Key words : Laminated veneer lumber, reinforced, *Hevea brasiliensis, Acacia mangium,* melamine urea formaldehyde.

1. Introduction

The previous study has shown the technical feasibility to produce structural grade laminated veneer lumber (LVL) from Rubberwood (*Hevea brasiliensis*) and Mangium (*Acacia mangium*) using phenol formaldehyde (PF), melamine urea formaldehyde (MUF) and urea formaldehyde (UF) as the binders[1)]. Except where UF was used as the binder, Mangium LVL generally had higher shear strength compared to Rubberwood LVL. In term of static bending, Mangium LVL registered higher modulus of elastic (MOE) and modulus of rupture (MOR) than Rubberwood LVL, irrespective of resin type. The uniformity of both

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physical and mechanical properties of solid wood has been improved through processing into LVL.

It has been demonstrated that combination of different wood species in various proportions would provide wood composites with properties differing from those based on mono-species[2]. Product engineering in composite manufacture enables optimal utilization of the existing resource, as wood elements of varying grades, qualities or types could be placed in various zones to produce composites with "tailored" properties. In LVL, this engineered profile may take the form of placement of high quality veneers at the surfaces, and low grade veneers in the inner plies. Since the Mangium LVL were found to have superior strength properties compared to Rubberwood LVL in the earlier work, it is therefore the object of this study to investigate the properties of 15-ply LVL fabricated using mixtures of Rubberwood and Mangium.

2. Experimental Procedure

2.1 Raw materials

Two plantation species, i.e., Mangium and Rubberwood were used. The ten-year old Mangium thinnings were obtained from Batu Arang Forest Plantation, Selangor, whereas the matured 25-year old Rubberwood were supplied by rubber estate holders to a plywood mill in Cheras, Kuala Lumpur.

The logs were bucked to about 132 cm length. The tough bark of Mangium was removed manually, while debarking was not done for Rubberwood logs. Both species were peeled to 3.6 mm thick veneer on a 4-foot Meinan lathe using varying peeling speed.

2.2 Fabrication of LVLs

The LVLs were manufactured on a newly installed LVL line which has yet to start commercial production. Low quality Rubberwood veneers (virtually all were round-up veneers marred by tapping wounds, pin holes and sap stain) were used. The Mangium veneers used were fairly tight and smooth with rather high incidence of loose knots (less than 2 cm in diameter).

In order to avoid excessive veneer waviness, Rubberwood veneers were dried to about 15% moisture content (MC), while Mangium veneers were dried to less than 6% MC, at a temperature of 150–170°C. The 1,219 mm long veneers were end-jointed using scarf joints of 1 : 3 slope to a length of 2,438 mm. These joints were randomly staggered throughout the LVL to reduce the weakening effect. Melamine urea formaldehyde (MUF) was applied to the 1,219×2,438 mm veneer using roller coater. The veneers were assembled with tight-side facing tight-side and loose-side facing loose-side. Fifteen-ply mono-species and mixed species LVL were produced. In LVL with species combination, the effects of two Rubberwood : Mangium combination ratios were studied, i.e., 3 : 2 and 1 : 2, where equal number of Mangium veneers (3 and 5 plies) were placed in the tension-compression zone, i.e., top and bottom layers, with 9 and 5 plies of Rubberwood in the core. The assembly time was limited to less than 30 min. Cold pressing at 10 kgf/cm^2 specific pressure was applied for 20 min, followed by hot pressing at 125°C under specific pressure of 12 kgf/cm^2 for about 50 min.

2.3 Evaluation of LVLs

Evaluation of the LVLs produced were based on JAS (1993) for Structural Laminated Veneer Lumber. All the test specimens were conditioned under controlled relative humidity and temperature of 65±5% and 21±2°C, prior to testing.

Six test specimens of 75×75 mm were prepared from each sample for water soak test (24 h water soak followed by 24 h oven dry at 60±3°C) ; and boiling water delamination test (5 h boiling water immersion followed by 1 h cold water soak, and 24 h oven dry at 60± 3°C), respectively. The thickness swelling and water absorption were measured after 24 h water soak.

The shear specimens were cut to 40 mm width with length of six times the thickness. The load was applied perpendicular and parallel to the veneer faces for flatwise and edgewise bending, respectively, at a constant rate of about 150 kgf/cm^2/min. In wet shear test, the specimens were tested after cyclic boiling, i.e., 4 h boil followed by 20 h oven dry at 60±3°C, with another 4 h boil and 1 h cold water soak, and shear tested when the specimens were still wet.

Two specimens of width 90 mm and length 23 times the thickness were prepared for flatwise and edgewise 4-point bending tests, respectively.

3. Results and Discussion

3.1 Physical properties of LVLs

3.1.1 Dimensional property

Upon removal from the hot press, no obvious warping was observed in the LVLs. However, some degree of bow was noticed in the 50×90×2,438 mm LVL beams, after conditioning to about 10% MC. Mono-species Rubberwood LVL registered 8 to 22 mm deviation from the neutral axis, while incorporation of Mangium veneers in the faces significantly reduced the deviation to 0–4 mm.

3.1.2 Density and moisture content

Based on the respective veneer density of 0.64 and 0.56 g/cm^3, Rubberwood and Mangium LVLs with densities of 0.65 and 0.61 g/cm^3 recorded a densification of 2 and 8%, respectively. As reflected by the thicknesses of veneer and LVL, thickness reduction in both Mangium (6–8%) and Rubberwood (1–2%) correlates well to the respective degree of densification. The low density juvenile Mangium veneer was obviously more compressible compared to the high density matured Rubberwood. Incorporation of lower density Mangium veneer at Rubberwood : Mangium ratios of 3 : 2 and 1 : 2 reduced the LVL density from 0.65 g/cm^3 in Rubberwood LVL to 0.63 and 0.62 g/cm^3, respectively (Table 1). The MC of the LVL produced ranged from 8 to 10%.

3.1.3 Thickness swelling and water absorption

Rubberwood is more hygroscopic than Mangium. Reinforcement of Rubberwood LVL using Mangium could reduce water absorption by 40–58%, and the resultant thickness swelling was significantly lower (Table 1).

3.1.4 Delamination test

Cold water soak delamination test (24 h cold water soak followed by 24 h drying at 60 ± 3°C) did not result in any delamination in all the LVL. While soaking in boiling water for 5 h followed by 1 h cold water soak and drying at 60 ± 3°C for 24 h gave rise to less than 4% delamination in the LVL samples.

3.2 Mechanical properties of LVLs

3.2.1 Shear strength

Melamine urea formaldehyde (MUF) was found to bond well with both Mangium and Rubberwood[1]. The mean dry shear value of the reinforced Rubberwood LVL declined slightly with increasing proportion of Mangium (Table 2). Since most (70%) of the flatwise shear samples failed in Rubberwood core during shear bending, the dry shear strength of the reinforced Rubberwood LVL was similar to that of Rubberwood LVL. In the edgewise shear bending, 54% of the samples experienced failure across laminae, while

Table 1. Density and moisture content of veneer and LVL

Species	Density (g/cm^3)	Moisture content (%)	Water absorption* (%)	Mean water absorption reduction** (%)	Thickness swelling* (%)
Veneer[a]					
Mangium	0.56	9.1	—		—
Rubberwood	0.64	10.5	—		—
LVL[b]					
15-ply Rubberwood	0.65	8.5	48		2.40
3-ply Mangium + 9-ply Rubberwood + 3-ply Mangium	0.63	9.7	29	40	1.95
5-ply Mangium + 5-ply Rubberwood + 5-ply Mangium	0.62	9.1	20	58	1.57
15-ply Mangium	0.61	9.9	12		1.08

Note: * 75×75 mm sample size, after 24 h water soak, ** Based on 15-ply Rubberwood LVL, [a] and [b] are means of 10 and 4 specimens, respectively.

Table 2. Dry and wet shear strengths of LVL.

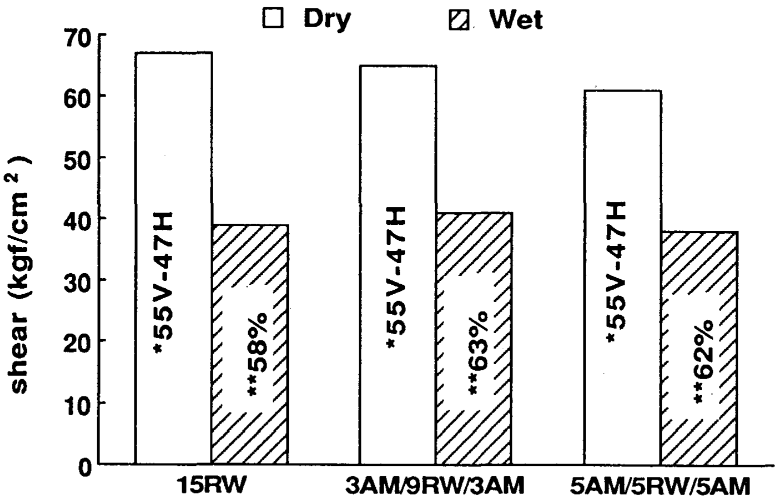
		Shear strength (kgf/cm^2)			
		Flatwise*	Edgewise*	Mean**	
Dry					**JAS Grade**
15-ply Rubberwood	μ	69	64	67	55V-47H
	σ	5	5	4	
	cv	7	8	6	
3-ply Mangium	μ	64	65	65	55V-47H
+ 9-ply Rubberwood	σ	5	6	4	
+ 3-ply Mangium	cv	8	9	6	
5-ply Mangium	μ	63	59	61	55V-47H
+ 5-ply Rubberwood	σ	2	6	4	
+ 5-ply Mangium	cv	3	10	7	
Wet					**mean shear reduction (%)**
15-ply Rubberwood	μ	36	41	39	42
	σ	3	2	3	4
	cv	8	5	8	10
3-ply Mangium	μ	41	41	41	37
+ 9-ply Rubberwood	σ	8	1	4	6
+ 3-ply Mangium	cv	20	2	10	16
5-ply Mangium	μ	37	38	38	38
+ 5-ply Rubberwood	σ	6	6	3	6
+ 5-ply Mangium	cv	16	16	8	16

Note: Wet-cyclic boiling, i.e., 4 h boil followed by 20 h oven dry at 60±3°C, with another 4 h boil and 1 h cold water soak, * Means of 8 specimens, ** Mean values of flatwise and edgewise strengths, LVL evaluation based on JAS for Structural LVL (1993). Legend: μ: mean, σ: standard deviation, CV: coefficient of variation (%).

the remaining underwent tensile/compression failure. Generally, the shear retention after cyclic boiling was higher in the reinforced Rubberwood LVL. After cyclic boiling, reinforced LVL with 3 and 5 plies of Mangium recorded 62 and 63% shear retention, respectively, compared to 58% in Rubberwood LVL (Fig. 1). The occurrence of shear failure in indefinite layers indicates that there was no particular weak zone in the LVL, hence eliminating the possibility of bonding inefficiency at the interface of Mangium and Rubberwood.

3.2.2 Static bending

Incorporation of Mangium in the faces of Rubberwood LVL improved the flatwise MOE by up to 30%, but no definite trend was observed in the edgewise MOE (Table 3, Fig. 2). The MOE of Rubberwood LVL and 3-ply Mangium reinforced LVL met the 80E



Note: RW - Rubberwood, AM - Mangium, *Shear grade based on JAS for Structural LVL (1993) V = edgewise, H = flatwise, ** Shear strength retention after cyclic boiling (Refer Table 2 for cyclic boiling condition).

Fig. 1. Dry and wet shear strengths of reinforced Rubberwood LVL.

Table 3. Modulus of elasticity (MOE) of LVL

		MOE (10^3 kgf/cm^2)			
		Flatwise*	Edgewise*	Mean**	JAS Grade
15-ply Rubberwood	μ	96	103	100	80E
	σ	3	5	2	
	cv	3	5	2	
	X_5	91	95	97	
3-ply Mangium	μ	121	83	102	80E
+ 9-ply Rubberwood	σ	8	7	5	
+ 3-ply Mangium	cv	7	8	5	
	X_5	108	71	94	
5-ply Mangium	μ	125	97	111	100E
+ 5-ply Rubberwood	σ	10	9	9	
+ 5-ply Mangium	cv	8	9	8	
	X_5	109	82	96	
15-ply Mangium	μ	160	112	136	120E
	σ	16	4	8	
	cv	10	4	6	
	X_5	134	105	122	

Note: * Means of 4 specimens, ** Mean values of flatwise and edgewise strengths, see Table 2 for legend, $X_5=\mu\text{-}1.645\cdot\sigma$.

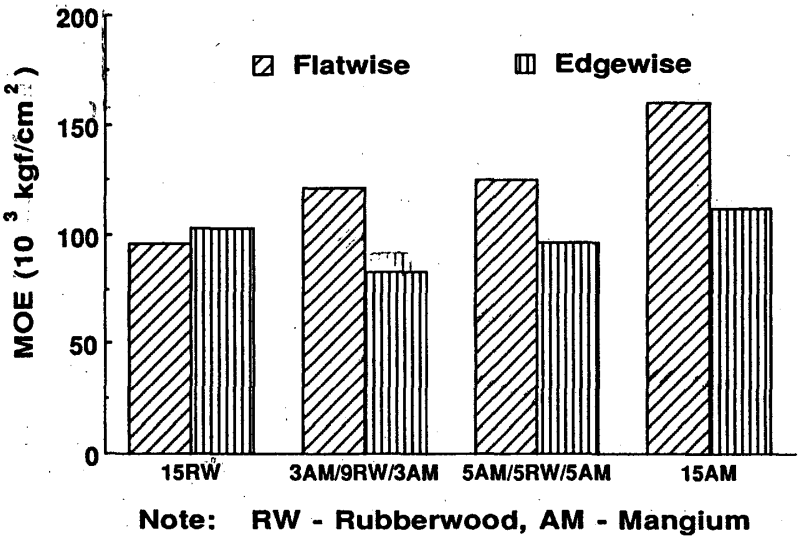


Fig. 2. Flatwise and edgewise MOE of reinforced Rubberwood LVL.

grade requirement, while 5-ply Mangium reinforcement upgraded the LVL to 100E. Mangium LVL met the 120E grade.

Almost all of the static bending specimens exhibited simple tension failure, with no conspicuous shear failure. Therefore, MUF was satisfactorily efficient in bonding Mangium and Rubberwood, even at their interface. To simulate the "worst case" situation during application, veneer end-joints in the surface layers were positioned at the bottom, so as to subject them to the maximum tensile load during bending. Bending failure was observed to initiate at these joints in most cases. In LVL with well distributed veneer end-joints, shear failure would then occur along the adjacent glueline, and the remaining plies of the member would continue to take the load imposed, until tensile failure occurred at the maximum load. Where the veneer end-joints were situated in close proximity, bending failure extended from one joint to another through shear failure propagated along the gluelines in between. In order to achieve high bending strengths, scarf joints in LVL should be well made and properly dispersed. As far as possible, joints of steep slope should not be placed in the outer-most layers.

In the flatwise bending, the respective MOE of 3- and 5-ply Mangium reinforced LVL were 26.5 and 30.7% higher than Rubberwood LVL. However, the MOE of 5-ply Mangium reinforced LVL was substantially lower than that of Mangium LVL. Reinforcement of Rubberwood LVL using 3 plies of Mangium did not result in significant MOR improvement (Table 4). However, incorporation of 5 Mangium plies gave rise to 13.3% higher MOR compared to the unreinforced Rubberwood LVL. The improvement in mean MOR was mainly due to the improvement in edgewise loading, where incorporation

Table 4. Modulus of rupture (MOR) of LVL

		MOR (kgf/cm^2)			
		Flatwise*	Edgewise*	Mean**	JAS Grade
15-ply Rubberwood	μ	580	554	567	80E
	σ	80	25	48	Special
	cv	14	5	8	Grade
	X_5	448	513	488	
3-ply Mangium	μ	580	565	572	80E
+ 9-ply Rubberwood	σ	150	54	95	Special
+ 3-ply Mangium	cv	26	10	17	Grade
	X_5	333	476	417	
5-ply Mangium	μ	639	646	642	100E
+ 5-ply Rubberwood	σ	125	23	59	Special
+ 5-ply Mangium	cv	20	4	9	Grade
	X_5	433	608	546	
15-ply Mangium	μ	762	659	711	120E
	σ	133	68	65	Special
	cv	17	10	9	Grade
	X_5	543	547	604	

Note: * Means of 4 specimens, ** Mean values of flatwise and edgewise strengths, see Table 2 for legend, $X_5 = \mu - 1.645 \cdot \sigma$.

of 3 and 5 Mangium plies increased the edgewise MOR by 2 and 16.6%, with negligible and 10% flatwise MOR improvements, respectively.

4. Conclusions

Low grade raw materials from fast growing trees such as Mangium and Rubberwood could be upgraded into high quality composite product, either through processing into mono- or mixed-species structural LVL. It is possible to improve the physical and mechanical properties of Rubberwood LVL by incorporating Mangium veneers at the surface layers. The extent of improvement would depend on the number of reinforcement layers.

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