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Bending Properties of Laminated Veneer Lumber Produced from Keruing (*Dipterocarpus* sp.) Reinforced with Low Density Wood Species

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Abstract: Low density wood such as Pulai (*Alstonia* sp.), Sesendok (*Endospermum* sp.) and Kekabu Hutan (*Bombax* sp.) have never been regarded as structural material due to their inferior strengths. Converting these timbers into Laminated Veneer Lumber (LVL) and reinforcing them with stronger timber could turn them into much sought after materials. This study discusses the effects of incorporating Keruing veneers into LVL panels made from low density wood. Laminated Veneer Lumber comprised 11-ply and 15-ply veneers fabricated by arranging Keruing veneers located at the surface and the low density woods were arranged as core. Phenol Formaldehyde (PF) resin was used as the binder. The LVLs were subjected to cyclic boil-dry test according to voluntary product Standard PS1-95: Construction and Industrial Plywood. The bending properties and percent delamination were determined according to the Japanese Agricultural Standard (JAS) for Structural LVL: 1993 before and after the cyclic boil dry treatment. Result showed through incorporating low density wood with Keruing veneers, both 11-ply and 15-ply LVL panels achieved the minimum requirements for various grades stipulated in the JAS for Structural LVL Standard: 1993. At the same panel thickness, 15-ply LVL shows a better performance compares to those of 11-ply LVL. Presence of Keruing veneers as surface layers significantly increased the strength of the LVL panels. All panels passed the delamination test stipulated on the JAS for Structural LVL: 1993. Conclusively, combining Keruing and the low density wood veneers in LVL fabrication gave greater strength and more stable material.

Key words: Laminated veneer lumber, keruing, low density wood, cyclic boil dry

INTRODUCTION

Malaysia's tropical rainforests are unique in their complex forest ecosystems and diverse biodiversity, which arises from abundant amount of different types of vegetation and existence of a wealth of species. Implicit in this very fact, however, are problems in the utilization of such diverse mixture of wood species. Normally, wood species in Malaysia can be divided into two main utilisation groups; high density wood and low density wood. Naturally, preference has developed over the used of high density wood species from the forests. Nonetheless, the list of usable low density wood species has lengthened to some extent because of advances in technology and promotion together with the growing scarcity of the more desired species. However, only a small number of low density wood species are generally utilized with high commercial values compare to the merely 8000 wood species that

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can be found in tropical forest (Anonymous, 2004, 2009; Saw, 1992; Kumari, 1995; Appanah, 1998). There are still a large number of low density wood species (less in commercial values) which might have good wood properties but being used as low grade timbers for non structural used.

Recently, there is an attempt to find balance utilization between those high and low density wood species produced by forests. Value of addition for those low density wood species is possible in the case of Peninsular Malaysia only because of the presence of a well-developed wood-processing industry coupled with a relatively sizeable local and international market. These low density wood species can be converted into superior products such as glulam or Laminated Veneer Lumber (LVL) hence, value added to the raw material. Wang *et al.* (2003) indicated that veneer peeled from low value red maple logs may be used to manufacture high quality LVL products. This could be done with the incorporation of low density wood species as core layer and high density wood species as surface layers, where a superior end product can be produced without compromising the strength and quality of high commercial value wood species.

The main purpose of this study was to evaluate the bending properties of LVL produced from reinforcement of low density wood species with Keruing. Low density wood species of Pulai (*Alstonia* sp.), Sesendok (*Endospermum* sp.) and Kekabu Hutan (*Bombax* sp.) with density ranges 210-500 kg m^{-3} air dry, 305 to 655 kg m^{-3} air dry and 415-545 kg m^{-3} air dry, respectively were used in core layer and Keruing (*Dipterocarpus* sp.) with density ranges from 690-945 kg m^{-3} air dry was used as surface layers (Anonymous, 2001; Gan *et al.*, 1999). The effect of veneer thickness on the bending properties of LVL was also examined. The LVLs were subjected to Cyclic Boil-Dry test where the effects of timber species and veneer thickness on the strength retention were analyzed. Cyclic boil-dry treatment is the most often used for evaluating weather resistant of a product especially for LVL that intended for outdoor application (River *et al.*, 1981; Okkonen and River, 1996). This treatment maximizes the effect of swelling and shrinkage stresses and in conjunction with the internal stresses that developed due to differential rates of expansion of different veneers in mixed species LVL. The cyclic boil dry treatment may be a good indicator to determine the production of LVL from mixed species suitable for long term performance.

MATERIALS AND METHODS

The research was carried out between years of 2002 to 2006 and is an extension of project for development of structural LVL to meet the demand of timbers for construction that initiated by Construction Industry Development Board, Malaysia in 1999. All the LVL were produced in a commercial plywood mill located in Cheras, Selangor, Malaysia. Wood species of Pulai, Sesendok and Kekabu Hutan and Keruing were peeled into 2.6 and 3.6 mm thick veneers to produce LVL with final thickness 38 mm. Two types of LVL were produced; thickness of 2.6 mm was used to make 15-ply LVL and 3.6 mm was used to make 11-ply LVL. The 11-ply LVL comprised 4 and 6 pieces of Keruing veneers (2 and 3 veneers on each surface, respectively) whilst the 15-ply LVL had 2 and 4 veneers on each surface. Table 1 shows the variables of LVL that produced in this research.

The veneers were kiln-dried to approximately 7% moisture content prior to the LVL production. Phenol Formaldehyde (41.5% solids) resin was used a binder. Temperature of 160°C with specific pressure of 12 kg cm^{-2} was applied on the LVL. Panels size of 1200 mm width×2400 mm long×38 mm thick were manufactured in a commercial plywood mill. The LVL panels were cut to test samples according to the Japanese Agricultural Standard for Structural Laminated Veneer Lumber (Anonymous, 1993).

Table 1: Experimental design of LVL produced in this research

Layer of veneer	Design	Description
11	2K+7P+2K	Two Keruing veneers on both surfaces of LVL with seven Pulai veneers as core
11	2K+7S+2K	Two Keruing veneers on both surfaces of LVL with seven Sesendok veneers as core
11	2K+7KH+2K	Two Keruing veneers on both surfaces of LVL with seven Kekabu Hutan veneers as core
11	3K+5P+3K	Three Keruing veneers on both surfaces of LVL with five Pulai veneers as core
11	3K+5S+3K	Three Keruing veneers on both surfaces of LVL with five Sesendok veneers as core
11	3K+5KH+3K	Three Keruing veneers on both surfaces of LVL with five Kekabu Hutan veneers as core
15	2K+11P+2K	Two Keruing veneers on both surfaces of LVL with eleven Pulai veneers as core
15	2K+11S+2K	Two Keruing veneers on both surfaces of LVL with eleven Sesendok veneers as core
15	2K+11KH+2K	Two Keruing veneers on both surfaces of LVL with eleven Kekabu Hutan veneers as core
15	4K+7P+4K	Four Keruing veneers on both surfaces of LVL with seven Pulai veneers as core
15	4K+7S+4K	Four Keruing veneers on both surfaces of LVL with seven Sesendok veneers as core
15	4K+7KH+4K	Four Keruing veneers on both surfaces of LVL with seven Kekabu Hutan veneers as core

Twelve samples with the size of 90 mm width ×38 mm thick ×874 mm length were cut from each LVL panel and conditioned in 65% RH and 25°C prior to testing. The samples were then subjected to bending test in flatwise according to JAS for Structural LVL: 1993 in dry condition and after cyclic boil-dry treatment.

The cyclic boil-dry treatment was carried out on LVL according to the Voluntary Product Standard PS1-95: Construction and Industrial Plywood (Anonymous, 1995). The samples were submerged in boiling water for 4 h and then dried at 145°F for 20 h. This step was repeated five times and after completed the treatment, these samples were conditioned at 65±5% RH and 21±2°C. Delamination percentages on the LVL glueline were measured before subjected to bending test.

The percentage of delamination was calculated by using the equation below:

$$\text{Percentages of delamination (\%)} = \frac{\text{Total length of delamination on 4 sides}}{\text{Total length of glueline on 4 sides}} \times 100$$

The density and moisture content for each of the tested bending specimen were determined. The strength retention was calculated as the ratio of strength after cyclic boil-dry treatment to initial strength under the dried condition before cyclic boil-dry treatment.

The results of this study were analyzed by Analysis of Variance (ANOVA) at 95% confidence level ($p \le 0.05$) to determine the significant effects among the variables studied, i.e., number of keruing veneer and veneer thickness on the bending properties of LVL produced.

RESULTS AND DISCUSSION

The densities for the 12 types of LVL produced in this study were tabulated in Table 2. As shown in the Table 1 all 15-ply LVL had higher density compared to those of 11-ply. This is mainly due to the compaction effect of the veneers during hot pressing, as well as, the presence of gluelines between the plies. Kilic *et al*. (2006) reported that the specific gravity of the LVL produced from 2 mm veneers was higher compared to those from 4 mm veneers. In other words, as the thickness increases, a decrease is observed in the specific gravity and mechanical property values. As predicted, LVL produced from Keruing reinforced with Pulai veneers had the lowest density among the group. This is mainly Pulai exhibit lowest density amongst the three species that reinforced with Keruing.

Bending Properties of LVL Under Dry Condition

The results of Modulus Of Rupture (MOR) and Modulus Of Elasticity (MOE) for all types of LVL tested under dry condition are shown in Table 3. As shown in Table 3, the

Table 2: Density for all types of LVL

LVL 11-ply		LVL 15-ply	
Board type	Density (g cm^{-3})	Board type	Density (g cm^{-3})
2K+7P+2K	0.530	2K+11P+2K	0.565
2K+7S+2K	0.513	2K+11S+2K	0.537
2K+7KH+2K	0.525	2K+11KH+2K	0.587
3K+5P+3K	0.617	4K+7P+4K	0.771
3K+5S+3K	0.520	4K+7S+4K	0.693
3K+5KH+3K	0.579	4K+7KH+4K	0.654

K: Keruing, P: Pulai, S: Sesendok and KH: Kekabu hutan

Table 3: Bending Properties of LVL

Layer of veneer	Design	MOR (kgf cm^{-2})	MOE (kgf cm^{-2})
11	2K+7P+2K	389	115433
11	2K+7S+2K	523	99476
11	2K+7KH+2K	353	98580
11	3K+5P+3K	509	127032
11	3K+5S+3K	600	128111
11	3K+5KH+3K	417	113272
15	2K+11P+2K	538	120056
15	2K+11S+2K	521	107644
15	2K+11KH+2K	525	134987
15	4K+7P+4K	713	150972
15	4K+7S+4K	794	155598
15	4K+7KH+4K	711	151578

number of Keruing veneers used in making LVL influenced the bending properties of those LVL made from reinforcement of Keruing veneers with low density wood. As the number of Keruing veneers used in making 11-ply LVL increased from 2 to 3 layers, the MOR and MOE were increased from the ranges of 5-30% and 10-15%, respectively. The highest increment of MOR and MOE in 11-ply LVL was observed from reinforcement of Keruing with Pulai (30.8% for MOR and 12.0% for MOE). On the other hand, the MOR and MOE for 15-ply LVL show an increment from ranges 32 to 52% and 12 to 44%, respectively. The highest increment for MOR and MOE in 15-ply LVL were observed from reinforcement of Keruing with Sesendok.

ANOVA revealed significant different at 95% confidence level ($p \leq 0.05$) was observed for the MOR and MOE of LVL produced from different number of Keruing veneers and veneer thickness. Lease Significant Difference (LSD) tests was used to further determine the significant level of MOR and MOE values on number of Keruing and veneer thickness for the LVL in this study.

Effect of Keruing Veneers

The ANOVA was performed using Least Significant Different ($p \leq 0.05$) on the effect of Keruing veneers on LVL and the result was presented in Table 4. As the number of Keruing veneers on both LVL surfaces increase from two to three for 11-ply LVL and two to four for 15-ply LVL, the MOR and MOE significantly increased. Bodig and Jayne (1993) reported improved density as in wood composite frequently improved both bending strength and stiffness. Beside that, Keruing wood species had better mechanical properties than those three low density wood species, therefore, more Keruing veneers used in production of LVL, better the strength and stiffness of the LVL.

Kretschmann *et al.* (1993) and Wang *et al.* (2003) reported by incorporating high grade materials into low grade's LVL caused a significant increase in stiffness and strength. Kretschmann *et al.* (1993) stated that an increase in low-grade core content had little effect on the Douglas-fir flatwise material test results until 50% of the low-grade core content was

Table 4: Effect of the numbers of Keruing veneers on LVL mechanical properties

	LVL 11-ply (kgf cm^{-2})		LVL 15-ply (kgf cm^{-2})	
No. of Plies	MOR	MOE	MOR	MOE
4	436^{b}	104497^{b}	528^{b}	120896^{b}
6	509^{a}	117369^{a}		
8			739^{a}	152716^{a}
Pr>F	0.0084	0.0005	0.0001	0.0001
LSD	52	6430	38	6392

Means followed by the same superscripted letter(s) in the same column are not significantly different at $p \leq 0.05$ according to Least Significant Different (LSD)

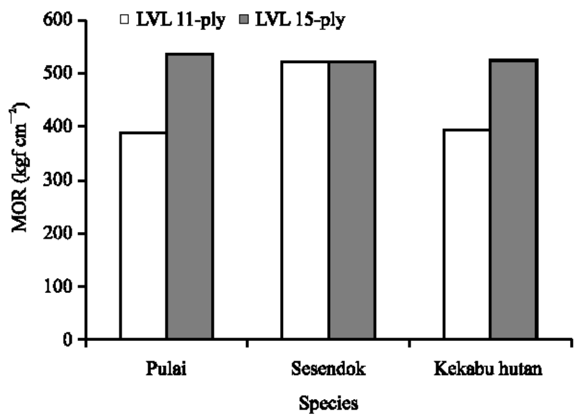

Fig. 1: Effect of veneer thickness on the 38 mm thick LVL MOR

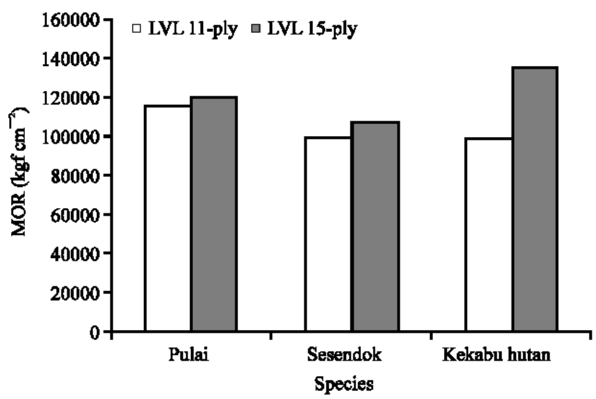

Fig. 2: Effect of veneer thickness on 38 mm thick LVL MOE

exceeded; then the strength and stiffness decreased dramatically. This reduction in strength and stiffness is due to early failure that might occur in low grade materials in LVL.

Effect of Veneer Thickness

As shown in Fig. 1 and 2, the bending properties (MOR and MOE) of the 15-ply LVL were higher than those of 11-ply inspire having the same number of Keruing veneers (2 Keruing veneers on each surface of LVL) and the final board thickness (38 mm).

Generally, the LVL with thinner veneer (15 ply) had the better mechanical performance compare to those thicker veneers (11-ply). Table 5 shows that there were significant different ($p \le 0.05$) for 11-ply and 15-ply LVL produced from Pulai and Kekabu Hutan in terms of MOR and MOE. However, the LVL produced from Sesendok species as core layer shows no significant difference on the MOR values when thinner veneers were used.

The variations in both the MOR and MOE for 11-ply and 15-ply LVL may probably due to the final density of the LVL panels. As mentioned early, the density of LVL is influenced by the number of gluelines in the panel. The thinner the veneer the higher amounts of glue were needed in the manufacturing process resulting in better compaction of the wood during hot pressing. This strongly suggest that by using thinner veneers (higher number of ply), the LVL will exhibit higher strength compare to those thicker veneers in production of LVL. This finding agreed with research published by Kilic *et al.* (2006). He reported that the bending properties of LVL produced with thinner veneers were higher compared to those from thicker veneers.

Bending Properties of LVL after Cyclic Boil Dry Treatment

After undergoing cyclic boil dry treatment, it was observed that all LVL delaminated in the glueline and cracks occurred on the surface and edge of the sample. The delamination percentage ranges from as low as 1 up to 7%. Nonetheless, the delamination that occurred in LVL passed the delamination test (≤10%) according to the requirement of JAS for Structural LVL: 1993. The strength reduction was observed for all types of LVL after cyclic boil dry treatment. Table 6 shows the percentage of delamination for all types of LVL. From the Table 6, the LVL produced from Kekabu Hutan as core layer gave the highest percent delamination for both 11-ply and 15-ply LVL. Obviously, 11-ply LVL exhibit greater delamination than those 15-ply LVL.

Strength reduction was observed on the MOE and MOR for all types of panels after undergoing the cyclic boil dry treatment. The amount of reductions was as low as 0.2 to 10% for MOR and 0.8 to 21.2% for MOE in 11-ply LVL 0.6 to 18.8% for MOR and 22 to 27%

Table 5: Effect of veneer thickness on MOR and MOE for 38 mm thick LVL

	Pulai (kgf cm^{-2})		Sesendok (kgf cm^{-2})		Kekabu Hutan (kgf cm^{-2})	
Number of Plies	MOR	MOE	MOR	MOE	MOR	MOE
11	538^b	120056^b	523^a	107644^b	525^b	134987^b
15	389^a	115433^a	521^a	99478^a	395^a	98580^a

Means followed by the same superscripted letter(s) in the same column are not significantly different at $p \le 0.05$ according to Least Significant Difference (LSD)

Table 6: Percent delamination for all types of LVL after accelerated aging test

Types	Delamination (%)
2K+7P+2K	3.60
2K+7S+2K	5.27
2K+7KH+2K	5.93
3K+5P+3K	4.38
3K+5S+3K	3.83
3K+5KH+3K	6.93
2K+11P+2K	0.94
2K+11S+2K	1.96
2K+11KH+2K	3.00
4K+7P+4K	1.61
4K+7S+4K	1.08
4K+7KH+4K	1.78

K: Keruing, P: Pulai, S: Sesendok and KH: Kekabu hutan

Table 7: Strength reductions of LVL after accelerated test

	Strength reduction (%)	
Types	MOR	MOE
2K+7P+2K	0.2	3.7
2K+7S+2K	2.3	18.8
2K+7KH+2K	1.3	0.6
3K+5P+3K	10.0	6.1
3K+5S+3K	7.5	0.6
3K+5KH+3K	4.6	9.7
2K+11P+2K	5.5	25.4
2K+11S+2K	3.8	26.7
2K+11KH+2K	21.9	25.2
4K+7P+4K	2.2	24.1
4K+7S+4K	0.8	22.3
4K+7KH+4K	19.1	25.6

K: Keruing, P: Pulai, S: Sesendok and KH: Kekabu hutan

for MOE in the 15-ply LVL. As shown in Table 4, the highest MOR reduction was observed for 15-ply LVL comprising of 2k+11kh+2k (21.9%) and for 15-ply LVL comprising 2k+11s+2K (26.7%). Table 7 shows the strength reduction of LVL bending properties after cyclic boil dry treatment.

CONCLUSION

Generally, all types of LVL either 11 and 15-ply met the requirements for various stress and stiffness grades in the JAS for Structural LVL (1993). The number of Keruing veneers and the wood species used in core significantly affect the strength properties on both 11 and 15-ply LVL. The best species combination was shown by Keruing-Sesendok in both of 11-ply and 15-ply LVL panels. The presence of Keruing in the LVL from low density wood provides the strength to the boards. Using thinner veneers in LVL manufacture improved the strength of the resulting panel but they were less stable when exposed to severe moisture and heat conditions.

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