ACCELERATED AND OUTDOOR AGEINGS OF LAMINATED VENEER LUMBER AND THEIR CORRELATIONS WITH STRENGTH AND STIFFNESS

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PARIDAH MT, ZAIDON A, CHUO TW, ZAKIAH A & ANWAR UMK. 2012. Accelerated and outdoor ageings of laminated veneer lumber and their correlations with strength and stiffness. This study evaluated the effect of accelerated ageing treatment (AAT) and outdoor ageing on properties of bintangor (*Callophyllum* sp.) laminated veneer lumber (LVL). It established the strength correlations between AAT and outdoor ageing under tropical climate. LVLs of 1220 mm × 2440 mm were fabricated using veneers of 3.1 and 4.1 mm, producing 13- and 17-ply panels respectively. Static bending and bending shear tests were used to determine the strength of LVL after ageing. For AAT, a cyclic boil–dry (CBD) treatment was employed where specimens were submerged in boiling water for 2 hours followed by drying in an oven for 18 hours. The process was carried out for 1, 2, 5 and 10 cycles. Long-term outdoor ageing involved exposure to the tropical weather for 3 and 6 months. At each cycle and duration of exposure to the outdoor, specimens were evaluated for modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending and bending shear. Statistical analysis showed that properties of bintangor LVL were significantly influenced by veneer thickness, number of CBD cycle and duration of outdoor ageing. LVL produced from thinner veneers had higher mechanical properties than that produced from thicker veneers. The former had lower property reduction after exposure to CBD treatment and outdoor ageing. The results also revealed that MOR and MOE after 2, 5 or 10 cycles of CBD treatment had high correlations with properties after 3 and 6 months of outdoor ageing.

Keywords: Cyclic boil–dry, bintangor, LVL, Spearman's correlation, tropics

PARIDAH MT, ZAIDON A, CHUO TW, ZAKIAH A & ANWAR UMK. 2012. Rawatan penuaan pantas dan luar terhadap kayu venir berlamina dan korelasi ujian ini dengan kekuatan dan kekenyalan. Kajian ini menilai kesan penuaan pantas dan penuaan luar di bawah iklim tropika terhadap ciri kayu venir berlamina (LVL) daripada spesies bintangor (*Callophyllum* sp.). Kajian ini juga menyelidiki korelasi antara kekuatan dengan kedua-dua rawatan tersebut. LVL bersaiz 1220 mm × 2440 mm dihasilkan menggunakan venir setebal 3.1 mm dan 4.1 mm bagi menghasilkan panel 13 lapis dan 17 lapis. Ujian lentur statik dan lentur ricih digunakan bagi menentukan kekuatan LVL selepas ujian penuaan. Bagi kaedah penuaan pantas di makmal, spesimen didedahkan kepada rawatan kitaran didih kering (CBD) iaitu spesimen ditenggelamkan dalam air mendidih selama 2 jam diikuti oleh pengeringan di dalam ketuhar selama 18 jam. Proses ini dilakukan sebanyak 1, 2, 5 dan 10 kitaran. Bagi penuaan luar jangka panjang, sampel didedahkan kepada cuaca tropika bagi tempoh 3 bulan dan 6 bulan. Pada setiap kitaran dan tempoh pendedahan luar, spesimen dinilai untuk modulus kepecahan (MOR) dan modulus kekenyalan (MOE) menggunakan ujian lentur statik dan lentur ricih. Analisis statistik menunjukkan yang ciri LVL bintangor dipengaruhi oleh ketebalan venir, bilangan kitaran CBD dan tempoh penuaan luar. LVL yang dihasilkan daripada venir nipis mempunyai ciri mekanik yang lebih baik daripada venir tebal. Berbanding dengan venir tebal, venir nipis mengalami kemerosotan ciri yang lebih rendah selepas pendedahan kepada rawatan CBD dan penuaan luar. Keputusan juga menunjukkan bahawa MOR dan MOE selepas 2, 5 atau 10 kitaran rawatan CBD mempunyai korelasi yang tinggi dengan ciri-ciri LVL selepas 3 bulan dan 6 bulan penuaan luar.

INTRODUCTION

The application of laminated veneer lumber (LVL) for structural use requires the product to be resistant to the weather, at least up to three cycles to be economical. To promote LVL for exterior applications, information on dimensional stability and durability should be

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first established. The durability of a material can be studied in either real outdoor ageing or in an accelerated ageing test (AAT). Since the former is too time consuming, AAT is frequently used. Accelerated ageing test is designed to predict the long-term durability of a material by simulating natural weathering conditions in an accelerated time frame (Alexopoulos 1992). Accelerated ageing test maximises the effects of weathering factors such as heat and moisture on shrinkage and swelling stresses, which influence physical and mechanical changes of the product. Accelerated ageing test is carried out for three major purposes. Firstly, to establish in a conveniently short time the relative ranking of materials with respect to their physical and mechanical durability. Secondly, to estimate the potential long-term serviceability of material systems under expected use condition. Thirdly, processes of deterioration are sped up in the laboratory (Feller 1994). Another purpose which is equally important is to evaluate the glue bond durability especially in laminated products.

There are many laboratory-ageing methods specified in standards for evaluating the physical and mechanical performance of wood-based panels such as cyclic boil–dry (CBD) in ASTM D 1037-93 (ASTM 1999) and automatic boil test in ASTM D 3434-2006 (ASTM 2006). All these methods involve hot water soaking and oven drying. This is due to the effects of hot water and oven drying on physical and mechanical changes of wood panels.

CBD treatment could be correlated with the result of outdoor exposure in terms of modulus of rupture (MOR) and modulus of elasticity (MOE) performance (River 1994). There was a strong correlation of the MOR and MOE of wood panel and solid wood (Pearson's and Spearman's correlation coefficients $r > 0.90$) between CBD treatment and outdoor ageing. Another study by Alexopoulos (1992) showed that the long-term outdoor weathering effects on bending properties of aspen waferboard could be simulated by the CBD. Nevertheless, this procedure is not suitable in tropical condition because of the freezing treatment involved. Therefore, a CBD treatment which was modified by River (1994) to suit the purpose of ageing test in the tropics was used to test LVL made from tropical hardwood, bintangor (*Calophyllum* sp).

This paper discusses the effects of accelerated ageing using CBD treatment and tropical outdoor exposure on the mechanical properties of bintangor (*Callophyllum* sp.) LVL. This study established the correlations of strength and stiffness between these two methods. The data obtained would be helpful in designing a safe and durable LVL structural system for exterior application.

MATERIALS AND METHODS

Fabricating LVL

The bintangor logs were obtained from a sawmill located in Selangor, Malaysia. It is estimated that the mature logs are at least 30 years old. The logs were peeled into 4.1 and 3.1 mm thick veneers to produce 13- and 17-ply LVL respectively. LVLs of 50 mm thick, 1220 mm wide and 2440 mm long were manufactured in a commercial LVL production line with phenol formaldehyde (PF) resin as binder. The veneer surfaces were spread with proportions of glue mix recommended by the manufacturer: 60 parts of PF resin, 50 parts of filler and 2 parts phoxin at 225 g m^{-2} single glue line using an extruder type spreader. The veneers were assembled in a symmetrical construction with the tight side facing the tight side of the adjacent veneers and the loose side facing the loose side. The assembled LVL were cold pressed at 6.0 kgf cm^{-2} specific pressure for 30 min and then hot pressed at specific pressure of 9 kgf cm^{-2} at 125 °C for 30 min. A total of 20 13- and 17-ply LVL panels each were fabricated. The final products were conditioned at ambient condition for 14 days prior to cutting into specimens for treatments.

Cutting of specimens

Static bending specimens (50 mm × 90 mm × 1000 mm) and bending shear (40 mm × 50 mm × 300 mm) test specimens were cut according to AS/NZS (1992). The test specimens were systematically selected to represent each of the panel. Only static bending specimens were subjected to both CBD treatment and outdoor ageing while bending shear specimens were only subjected to CBD treatment. Prior to exposure to these treatments, the dimension and weight of the specimens were measured.

Cyclic boil–dry treatment

The CBD treatment used in this study followed the method of River (1994) except for slight modification in the duration of submersion in boiling water and duration of drying due to the difference in the dimension of the specimens. We found that 10 min submersion of 12.5 mm × 50 mm × 305 mm specimens in boiling water followed by 3¾ hours of drying in forced draft oven at 107 °C could produce a good correlation ($r > 0.90$) with outdoor ageing. Since in the current study larger specimens were used, a preliminary work was conducted to determine the adequate time of submersion in boiling water and duration of drying. This was done by recording the time taken to equilibrate the temperature and moisture content (MC) in the centre of larger specimens during submersion in boiling water and oven drying respectively. A digital protimeter was used to record the temperature and MC at the centre of the sample. The results showed that 2-hour submersion in boiling water and 18-hour drying at 107 °C were needed to equilibrate the temperature and MC at the centre of the larger specimen. The treatments were carried out for 0, 1, 2, 5 and 10 cycles with each cycle utilising 12 replicates. For each cycle, the static bending, bending shear and per cent delamination were evaluated.

Outdoor ageing treatment

Static bending specimens were placed on racks inclined at 45° and exposed fully to tropical weathering (Figure 1). At the end of the third and sixth months, six specimens were removed from the racks, conditioned for 8 weeks in a conditioning room at 25 °C and 65 ± 2% humidity before they were evaluated for their properties.

Static bending test

At each cycle of CBD and duration of outdoor exposure, the specimens were tested for MOR (strength) and MOE (stiffness) in edgewise direction (parallel to the glue line) under three-point loading (Figure 2) using 100 KN load universal testing machine (AS/NZS 1992). The effective span specified by the standard is 18 times the thickness of the specimens. However, due to limitation of the apparatus the maximum length of the specimen was only 1000 mm where the span was only 10 times the thickness. Hence, the calculations for MOR and MOE were corrected using the correction factor specified in AS/NZ (1992). Thus, values for MOR_S and MOE_S for a standard span were calculated using equations below.

$$MOR_o = PL / bd^2 \tag{1}$$

$$MOR_s = (MOR_o) \times (L_o / L_s)^{VR} \tag{2}$$

while

$$MOE_o = P'L^3 / 4.7\, bd^3D \tag{3}$$

$$MOE_s = (MOE_o / 1.04) \times [(1 + 14\,(d / L_o)^2 \tag{4}$$

where

MOR_o = modulus of rupture for a non-standard span, N mm^{-2}

Figure 1 Arrangement of specimens in outdoor ageing

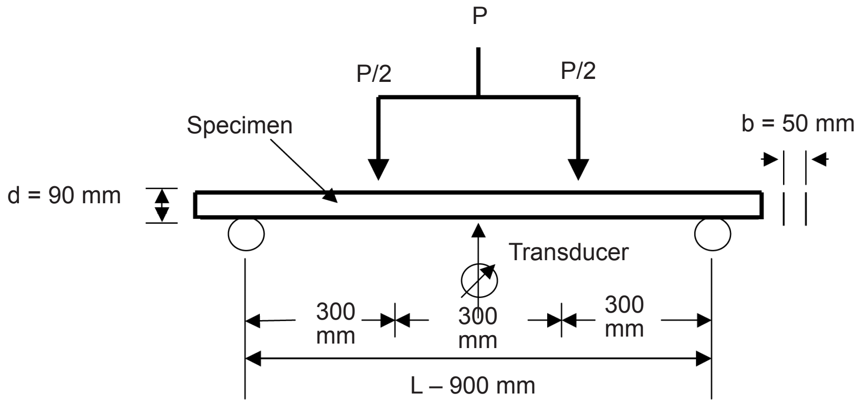

Figure 2 Three-point loading in bending test for LVL specimen

MOR_s = modulus of rupture for a standard span, N mm^{-2}
MOE_o = modulus of elasticity for a non-standard span, N mm^{-2}
MOE_s = modulus of elasticity for a standard span, N mm^{-2}
P = maximum transverse load on specimen, N
P' = load on specimen at proportional limit, N
b = width of specimen, mm
d = depth of specimen, mm
L = span of specimen, mm
l_o = non-standard span, mm
l_s = standard span, mm
D = deflection of specimen, mm, at neutral axis between reaction and centre of specimen at the proportional limit, mm
VR = coefficient of variation (%)

A small section was cut from the remnant of the test specimens for determination of moisture content and density.

Bending shear test

Bending shear test was conducted over 240 mm effective span by centre point loading using 50 kN universal testing machine. Similar to bending test, the loading direction was parallel to the glue lines with a constant loading rate of 0.05 mm s^{-1}. The bending shear was calculated based on AS/NZ (1992).

Delamination test

Delamination was evaluated by probing a feeler gauge into a depth of 2 mm at the glue line zone. The per cent delamination was calculated based on the total length of delamination at four sides over the total length of glue line at four sides of the LVL. The dimensions (thickness and length) and weight of specimens were recorded before and after each cycle of CBD treatment.

Statistical analysis

The analysis of variance (ANOVA) was performed to determine if there was any significant difference in MOR, MOE and bending shear between veneer thickness and ageing test. Spearman's correlation analysis was carried out to establish strength correlations between CBD treatment and outdoor ageing test.

RESULTS AND DISCUSSION

Strength and stiffness of LVL of accelerated and outdoor ageings

The equilibrium moisture content (EMC) of 13-ply LVL specimens after conditioning at 25 °C and 65 ± 2% humidity was not affected by the number of cycles in CBD and duration of outdoor ageing (Table 1). The MC ranged from 11.1 to 11.9% compared with 10.5% for untreated LVL. However, a slight increase of EMC (12.5–12.8%) was recorded in specimens taken from outdoor ageing test. This phenomenon was plausibly due to the crystallinity of the cellulose being altered to amorphous by external factors which in turn created more absorption sites for water. Density of the LVL was found associated with the thickness of the veneer. Laminated veneer lumber produced from thinner veneers (3.1 mm, 17-ply LVL) had relatively higher density (592 kg m^{-3}) than those produced from thicker veneers (4.1 mm, 13-ply LVL), i.e. 570 kg m^{-3}. Density decreased with the number of CBD cycles and duration of outdoor ageing. The difference in density was attributed into the higher amount of PF adhesive incorporated into the 17-ply LVL. In a preliminary calculation, it was found that the contribution of PF to the density of the 17-ply LVL was 15% compared with 11% in the 13-ply LVL. The density reduction after CBD treatment was slightly higher in 17-ply LVL (0.34–2.36%) than 13-ply LVL (0.18–2.63%). Thinner veneer comprised more proportion of wood than thicker veneer. Thus, the former contained higher extractive content. During the CBD treatment, more extractive was dissolved, resulting in higher reduction of density. However, for specimens exposed to outdoor ageing for 3 and 6 months, the reduction was approximately the same.

LVL produced from thinner veneers had superior properties to those from thicker veneers. The MOR was 40.3 vs. 38.6 N mm^{-2} and MOE, 11,000 vs. 10,300 N mm^{-2}. The results are in good agreement with those reported by Tan (2002). Laminated products with high number of ply per unit thickness demonstrated better mechanical strength with improved uniformity due to greater dispersion of defects throughout the whole piece

Table 1 Strength and stiffness of 13- and 17-ply bintangor LVL after cyclic boil–dry treatment (1, 2, 5 and 10 cycles) and outdoor ageing (3 and 6 months)

LVL ply	Treatment	N	MC (%)	Density (kg m^{-3})	MOR (N mm^{-2})	MOE × 1000 (N mm^{-2})
13 ply	Untreated	11	10.5	570	38.6 a ± 1.28	10.3 a ± 0.88
	CBD-1	12	11.1	569	37.8 a ± 3.5 a	9.7 ab ± 0.98
				(-0.18)	(-2.1)	(-5.8)
	CBD-2	12	11.1	559	33 b ± 4.81	9.3 bc ± 0.74
				(-1.93)	(-14.5)	(-9.7)
	CBD-5	12	11.4	555	31.3 bc ± 4.31	9.0 c ± 1.01
				(-2.63)	(-18.9)	(-12.6)
	CBD-10	12	11.9	555	28.5 c ± 4.1	7.9 d ± 0.84
				(-2.63)	(-26.2)	(-23.3)
	OA-3	6	12.5	560	34.4 ab ± 1.9	8.4 cd ± 0.34
				(-1.75)	(-14.7)	(-18.5)
	OA-6	6	12.8	557	27.3 c ± 5.5	8.0 d ± 1.07
				(-2.28)	(-29.3)	(-22.3)
17 ply	Untreated	12	11.6	592	40.3 a ± 4.7	11.0 d ± 0.88
	CBD-1	12	11.8	590	39.4 a ± 5.4	10.7 ab ± 2.90
				(-0.34)	(-2.23)	(-2.72)
	CBD-2	12	11.9	584	34.4 b ± 1.9	10.3 abc ± 1.42
				(-1.35)	(-14.6)	(-6.36)
	CBD-5	12	11.4	579	32.9 b ± 6.9	9.5 bc ± 0.94
				(-2.2)	(-18.4)	(-13.6)
	CBD-10	12	11.4	578	31.8 b ± 6.7	9.5 bc ± 0.94
				(-2.36)	(-21.2)	(-13.6)
	OA-3	6	12.6	581	35 ab ± 3.9	8.9 c ± 0.40
				(-1.86)	(-13.2)	(-19.1)
	OA-6	6	12.8	577	33.1 b ± 3.7	8.8 c ± 1.01
				(-2.53)	(-17.9)	(-20)

LVL = laminated veneer lumber; N = number of specimens; MC = moistute content; MOR = modulus of rupture; MOE = modulus of elasticity; MOR ± SD, MOE ± SD, SD = standard deviation; means followed by the same letter are not significantly different at $p \leq 0.05$ according to least significant difference (LSD); values in parentheses are per cent reduction calculated against control; CBD = cyclic boil–dry; OA = outdoor ageing

(Zakiah et al. 2002). When exposed to the ageing test, thinner veneer experienced lower stiffness and strength reduction than thicker veneer. This implies that the strength and durability of exterior grade LVL can be improved through fabricating using thin veneers. Between the two ageing tests, the MOR and MOE values of LVL that underwent 10 cycles of CBD and 6 months of outdoor ageing did not differ significantly. This was evident for both types of LVL. The properties of both LVLs after 5 cycles of CBD treatment were comparable with those exposed to 3 months of outdoor.

The reduction in strength and stiffness after ageing tests could be due to moisture absorption as a result of degradation of hemicellulose, cellulose and lignin. Moisture absorption increased thickness swelling, resulting in delamination of LVL. Reduction in MOR values for wood-based panels was reported to be very much associated with the degree of thickness swelling and decrease in density (Okkonen & River 1996). The relationships between MOR and MOE of bintangor LVL against delamination can be seen in Figures 3 and 4 respectively. The higher the percentage of delamination in LVL, the lower the MOR and MOE.

A similar trend with regard to veneer thickness was also observed for bending shear (Table 2). Thinner veneer produced 7% higher bending shear compared with thicker veneer. The untreated 17-ply LVL had bending shear of 4.1 N mm^{-2} compared with 3.8 N mm^{-2} in 13-ply LVL. Thinner veneer experienced lower bending shear reduction than thicker veneer after 1, 2 and 5 cycles of CBD treatment. However, after 10 cycles of CBD, both thinner and thicker veneers

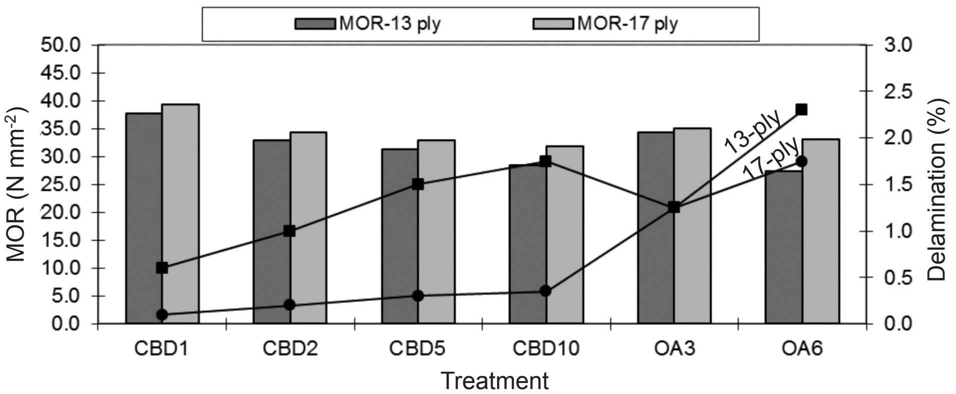

Figure 3 The relationship between delamination and MOR of LVL after cyclic boil–dry (CDB) treatment (1, 2, 5 and 10 cycles) and outdoor ageing (OA) test (3 and 6 months); MOR = modulus of rupture; LVL = laminated veneer lumber

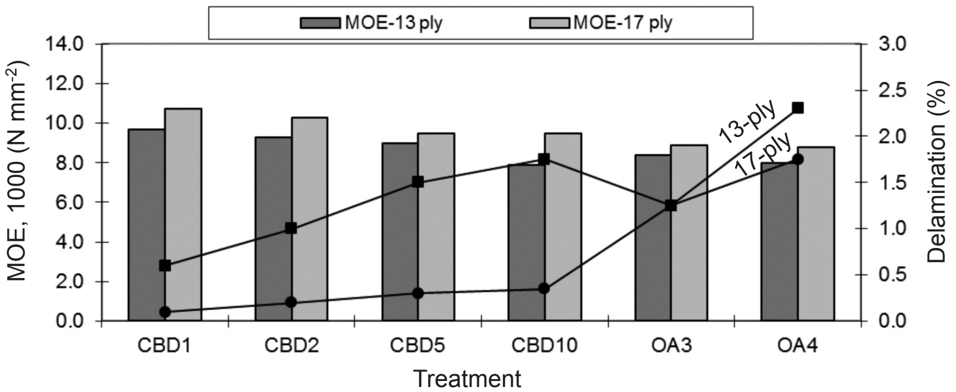

Figure 4 The relationship between delamination and MOE of LVL after cyclic boil–dry (CBD) treatment (1, 2, 5 and 10 cycles) and outdoor aging (OA) test (3 and 6 months); MOE = modulus of elasticity; LVL = laminated veneer lumber

Table 2 Bending shear and delamination of bintangor LVL after cyclic boil–dry treatment (1, 2, 5 and 10 cycles)

Veneer thickness (mm)	Treatment	Bending shear (N mm^{-2})	Delamination (%)
4.1 (13-ply)	Untreated	3.8 a ± 0.39	–
	CBD- 1	3.3 ab ± 0.47 (-13.2)	0.17 ± 0.05
	CBD- 2	2.9 b ± 0.80 (-23.7)	0.19 ± 0.05
	CBD- 5	2.8 b ± 0.54 (-26.3)	0.19 ± 0.04
	CBD- 10	2.8 b ± 0.99 (-26.3)	0.40 ± 0.10
3.1 (17-ply)	Untreated	4.1 a ± 0.37	–
	CBD- 1	4.0 ab ± 0.51 (-2.43)	0.12 ± 0.04
	CBD- 2	3.8 ab ± 0.80 (-7.32)	0.15 ± 0.05
	CBD- 5	3.5 bc ± 0.57 (-14.6)	0.17 ± 0.06
	CBD- 10	3.0 c ± 0.69 (-26.8)	0.24 ± 0.04

n = 12, Number of specimes; bending shear ± SD, SD = standard deviation; means followed by the same letter are not significantly different at $p \leq 0.05$ according to least significant difference (LSD) test; values in parentheses are per cent reduction calculated against control

exhibited approximately similar bending shear reduction, i.e. 26.3 and 26.8% respectively. A close examination of the specimens from each board revealed that the faster rate of decrease in bending shear of the 13-ply LVL was due to the extent of delamination. Bending shear reduction in accelerated ageing test was attributed to the degradation of the glue line and/or wood substance itself (Hayashi et al. 1990). Linear regression analysis showed negative relationship ($y = -4.546x + 3.827$) between delamination and bending shear (Figure 5) for 13-ply LVL. For 17-ply LVL, a curvilinear relationship ($y = -11.86x^2 – 0.894x + 4.322$) was observed (Figure 6). The difference in both trends was probably attributed to the number of glue lines in each panel. The bending shear of 17-ply LVL was more governed by PF due to the presence of more glue lines. The higher ratio of glue lines contributed to lower thickness swelling and delamination in 17-ply LVL. The reduction of bending shear in 17-ply was lower than that of 13-ply LVL.

CBD treatment and outdoor ageing

Selected Spearman's correlations are shown in Table 3. There was good correlation (r = 0.90 to 1.00) for MOR and MOE between CBD treatment and outdoor ageing for 13-ply and 17-ply specimens, except for MOE after 1 CBD cycle in 13-ply specimens (r = 0.32 to 0.41). The results implied that MOR or MOE after either one of the CBD cycle, except cycle 1 would consistently correlate with MOR or MOE after 3 and 6 months of outdoor ageing.

CONCLUSIONS

The study showed that veneer thickness and the number of CBD cycles had significant effects on strength, stiffness and bending shear of bintangor LVL. LVL fabricated from thin veneer had superior mechanical properties to thicker veneer. Both types of LVL showed significant reduction in properties after subjected to either accelerated

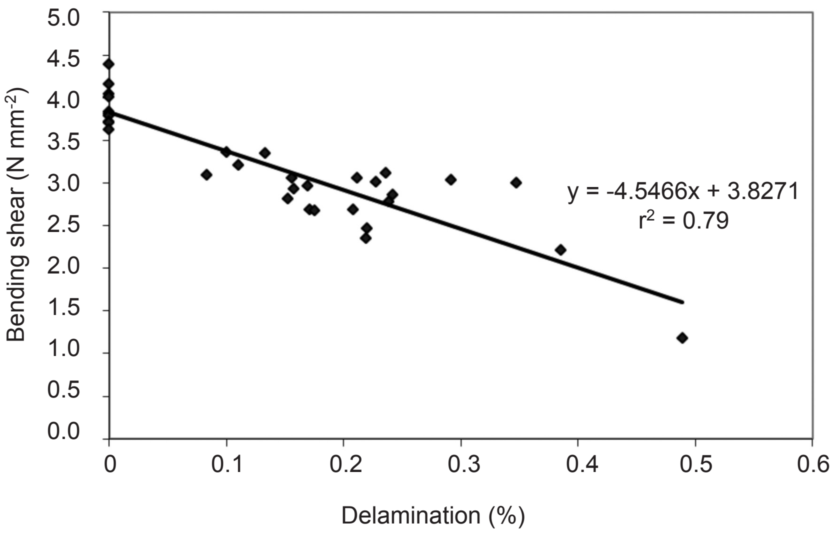

Figure 5 Linear relationship between bending shear and delamination of 13-ply LVL

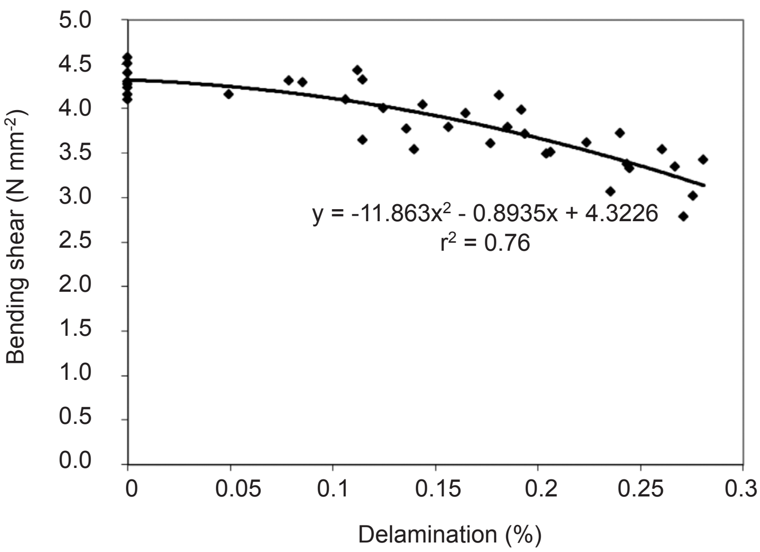

Figure 6 Curvilinear relationship between bending shear and delamination of 17-ply LVL

ageing or outdoor ageing test. The properties decreased as the number of CBD cycle and duration of outdoor ageing increased. Compared with CBD treatments, the outdoor ageing test yielded higher reduction of stiffness, strength and bending shear of the LVL. The reductions of strength and stiffness were associated with the extent of delamination. Regression analyses showed that there was negative relationship between delamination and bending shear where thinner veneer showed curvilinear trend while thicker veneer showed linear relationship. The results also revealed that MOR and MOE after 2, 5 or 10 cycles of CBD treatment had high correlations with MOR and MOE after 3 and 6 months of outdoor ageing.

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Table 3 Selected Spearman's rank correlation coefficients for MOR and MOE in 13-ply and 17-ply LVLs

Ageing treatment	MOR (OA-3)	MOR (OA-6)	MOE (OA-3)	MOE (OA-6)
		13-ply LVL		
MOR (CBD-1)	0.99***	0.97***	0.99***	0.97***
MOR (CBD-2)	1.00***	0.99***	1.00***	0.99***
MOR (CBD-5)	1.00***	0.99***	1.00***	0.99***
MOR (CBD-10)	1.00***	0.99***	1.00***	0.99***
MOE (CBD-1)	0.37 ns	0.41 ns	0.37 ns	0.32 ns
MOE (CBD-2)	0.94***	0.90**	0.94***	0.93***
MOE (CBD-5)	0.99***	0.96***	0.99***	1.00***
MOE (CBD-10)	0.99***	0.96***	0.99***	0.97***
		17-ply LVL		
MOR (CBD-1)	0.99***	0.99***	0.99***	0.98***
MOR (CBD-2)	1.00***	1.00***	1.00***	0.99***
MOR (CBD-5)	1.00***	1.00***	1.00***	0.99***
MOR (CBD-10)	1.00***	1.00***	1.00***	0.99***
MOE (CBD-1)	1.00***	1.00***	1.00***	0.99***
MOE (CBD-2)	1.00***	1.00***	1.00***	0.99***
MOE (CBD-5)	1.00***	1.00***	1.00***	0.99***
MOE (CBD-10)	0.99***	0.99***	0.99***	0.97***

*** = Significant at $p \leq 0.01$, ns = not significant at $p \leq 0.05$; MOR = modulus of rupture, MOE = modulus of elasticity; LVL = laminated veneer lumber; CBD = cyclic boil–dry; OA = outdoor ageing

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