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EFFECTS OF CHEMICAL COMPONENTS ON PROPERTIES OF ORIENTED STRAND BOARD FROM *LEUCAENA LEUCOCEPHALA* WOOD

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NAZRI WM, JAMALUDIN K, RUDAINI MN, RAHIM S & NOR YUZIAH MY. 2009. Effects of chemical components on properties of oriented strand board from *Leucaena leucocephala* wood. Chemical components of wood influence the characteristics, properties and opportunities for use of natural composites. The main objective of the study was to determine basic chemical components of *Leucaena leucocephala* from 8- and 16-year-old trees and to correlate the effects of chemical components with properties of its oriented strand board. Besides age, the effects of tree portions, namely, top, middle and bottom were also studied. *Leucaena leucocephala* wood was analysed for holocellulose, lignin, ash and ethanol-toluene, cold water, hot water and 1% natrium hydroxide solubles. Oriented strand boards which were produced from the samples were evaluated for their mechanical and physical properties based on two resin levels (7 and 9%), two target board densities (700 and 800 kg m^{-3}) and two strand sizes, namely, S1 (12.7–19.0 mm) and S2 (6.3–12.7 mm). This study revealed that tree portion significantly affected cold and hot water solubles, the solubilities of alkali and alcohol toluene, and also the ash and holocellulose contents of *L. leucocephala.* Only the solubility of alcohol toluene and lignin and holocellulose contents were affected by age. Although the correlation of some chemical components was significant, the correlation coefficients were relatively small, thus, indicating the loose association between the factors and board properties. It could be deduced that board properties had less association with chemical components but were more dependent on the resin content, board density and strand size used in the study. Generally, 8-year-old wood was found to be a suitable raw material for the manufacture of oriented strand board.

Keywords: Lignin, alcohol toluene, ash, holocellulose, tree portion, bending properties

NAZRI WM, JAMALUDIN K, RUDAINI MN, RAHIM S & NOR YUZIAH MY. 2009. Kesan komponen kimia kayu terhadap sifat papan strand berorentasi dibuat daripada kayu *Leucaena leucocephala*. Kandungan komponen kimia kayu mempengaruhi ciri, sifat dan peluang penggunaan bahan komposit semula jadi. Objektif kajian ini adalah untuk menentukan komponen kimia *Leucaena leucocephala* yang berusia lapan dan 16 tahun dan melihat kaitan kesan komponen kimia terhadap sifat papan strand berorientasi. Selain itu, kesan bahagian pokok iaitu atas, tengah dan bawah turut dikaji. Kayu *L. leucocephala* dianalisis untuk kandungan holoselulosa, lignin, abu serta keterlarutan dalam etanol toluena, air sejuk, air panas dan 1% natrium hidroksida. Papan strand berorentasi daripada sampel ini diuji sifat mekanik dan fizikalnya berdasarkan dua kepekatan perekat (7% dan 9%), dua ketumpatan papan (700 kg m^{-3} dan 800 kg m^{-3}) dan dua saiz emping (S1 yang bersaiz 12.7 mm hingga 19.0 mm dan S2, 6.3 mm hingga 12.7 mm). Kajian menunjukkan bahawa bahagian pokok mempengaruhi secara signifikan nilai keterlarutan dalam air sejuk, air panas, alkali dan etanol toluena. Bahagian pokok turut mempengaruhi kandungan abu serta holoselulosa *L. leucocephala.* Namun usia pokok hanya mempengaruhi keterlarutan dalam alkohol toluena serta kandungan lignin dan holoselulosa kayu ini. Walaupun korelasi sebahagian komponen kimia adalah signifikan, pekali korelasi adalah agak kecil. Ini menunjukkan hubungan yang lemah antara faktor yang diuji dengan sifat papan strand berorientasi. Sifat papan tidak begitu bergantung pada komponen kimia tetapi sebaliknya lebih bergantung pada kandungan perekat, ketumpatan papan dan saiz emping yang digunakan. Pada umumnya, kayu daripada pokok berusia lapan tahun didapati sesuai digunakan sebagai bahan mentah untuk penghasilan papan strand berorientasi.

INTRODUCTION

Oriented strand boards (OSBs) are now mainly made using materials from short rotation forests. This represents an advantage compared with plywood which requires large diameter logs obtained from long rotation forests (Roffael & Schneider 2003). OSB panels can be

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manufactured from a wide range of fast-growing species and from relatively small diameter trees. Knowledge of the impact of small diameter trees or juvenile wood on the physical and mechanical properties of different composite products is quite limited, particularly of OSB (Pugel *et al.* 1990, 2004, Larson *et al.* 2001).

Approximate chemical analysis is often used to determine the general chemical composition of wood. Chemical components of wood strongly influence the characteristics and properties of natural composites and opportunities for their uses. Data on the chemical composition of wood material are required for the many processes and applications in wood industry. Wood is primarily composed of cellulose, lignin, hemicelluloses and minor amounts (5–10%) of extraneous materials (Miller 1999).

Studies of *Leucaena leucocephala* leaves, seeds and roots have been reported (e.g. Ram *et al.* 1994, Gupta & Atreja 1999) but studies of basic properties of its wood are very limited. Basic wood properties will help support suitability and effective use of raw materials in wood composite. The main objective of the study was to determine basic chemical components of *L. leucocephala* (8- and 16-year-old trees, each having three portions) and to correlate effects of its chemical components with oriented strand board properties made from its wood.

MATERIALS AND METHODS

Chemical components

Samples of 8- (juvenile wood) and 16-year-old (mature wood) *L. leucocephala* wood were harvested and received from the Malaysian Agricultural Research Development Institute (MARDI) station in Jeram Pasu, Pasir Putih, Kelantan, Malaysia. Wood samples for chemical analysis were finely ground to pass a 0.4-mm (40-mesh) screen to permit complete reaction of the wood with reagents used in the analysis. Samples used were taken from three wood disks at each portion of the trees, namely, top, middle and bottom (Figure 1). The sampling and preparation of sawdust for this analysis were carried out according to T257 cm-85 (Anonymous 1996). Before storing, sawdust samples were air-dried and homogenized in a single lot to avoid differences in composition among aliquots.

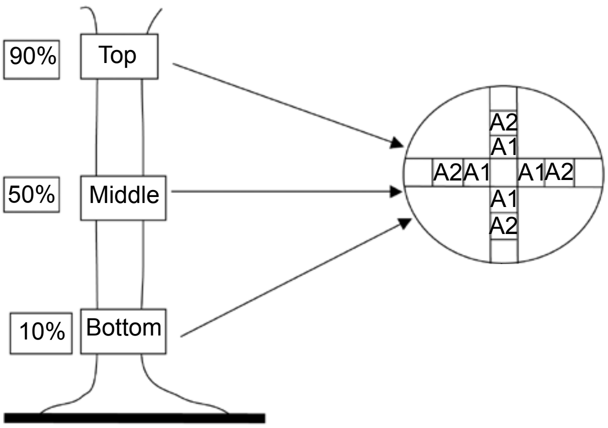

Figure 1 Procurement of wood disc for chemical components. Percentages denote the height above ground. A1 = nearest to the pith.

Using standard methods (Anonymous 1996), *L. leucocephala* wood were analysed for cold and hot water solubles (T207 om-93 1996), 1% natrium hydroxide soluble (T212 om-93 1996), ethanol toluene extractable (T204 om-88 1996), ash (T211 om-93 1996) and lignin (T222 om-88 1996). Method for measuring the holocellulose content was as outlined by Wise *et al.* (1946).

Evaluation of oriented strength board

In this part of the study, phenol formaldehyde (PF) resin was used as binder. The performance of OSB (380 × 380 × 12 mm), which was prepared in the laboratory, was evaluated based on two resin levels (7 and 9%), two target board densities (700 and 800 kg m^{-3}) and two strand sizes (S1, 12.7–19.0 mm and S2, 6.3–12.7 mm). Debarked logs of *L. leucocephala* were first sliced into thin wood strands. The strands were then dried, blended with resin and formed into thick, loosely consolidated mats before being heat-pressed and pressurized into boards.

Prior to evaluation of the physical and mechanical properties, OSBs were conditioned at 20 °C and 65% relative humidity (RH) for three weeks. Test specimen preparation and evaluation of board quality were carried out according to European norms (EN).

Mechanical test

OSB samples were destructively tested for bending and tensile strength properties. Bending test was carried out for directions parallel (major axis) and perpendicular (minor axis) to the grain. The modulus of elasticity (MOE) and modulus of rupture (MOR) were obtained based on deformation and load measurement (Anonymous

1993a). Internal bond (IB) values were measured by the tensile strength perpendicular to the plane of the OSB sample (Anonymous 1993c).

Physical test

Sampling and cutting of test samples was carried out according to Anonymous (1993b). Test samples were cut into squares of 50 ± 1 mm length. Then the thickness of each sample was measured to an accuracy of ± 0.01 mm at its intersection diagonal.

Statistical analysis

Results of chemical components were statistically analysed using analysis of variance (ANOVA) (SPSS version 12, 2003). ANOVA from a general linear model (GLM) procedure was used to evaluate the significant effects of age and tree portion on chemical components. The data was further tested using Duncan multiple range test (DMRT) and independent sample *t*-test. Correlation analysis was also carried out in order to study the relationship of chemical components with age, tree portion and board properties.

RESULTS AND DISCUSSION

Chemical components

Table 1 shows the chemical components of *L. leucocephala* according to age and tree portion.

Cold and hot water solubles

Generally, the cold and hot water solubles of *L. leucocephala* increased from bottom to top portion of the tree. The highest value for cold water soluble was observed in the top portion (5.97%) of the 8-year-old tree and the lowest, in the bottom portion (4.25%) of the 16-year-old. The greatest hot water soluble was observed in the top portion (7.91%) of the 8-year-old tree and the lowest, the middle portion (5.28%) of the 16-year-old tree. Values of hot water soluble were higher than those of cold water. The difference in solubility is due to hydrolysis and corresponding increase in solubility of wood substance during the boiling with water.

Results of this study indicated that cold and hot water solubles of *L. leucocephala* were affected only by tree portion and not by age (Tables 2 and 3). This is because hot-water extraction eliminates greater quantities of materials, removes a portion of the cell structure and extracts some inorganic extractives (Shebani *et al.* 2008). The removal of water-soluble extractives contributes to the increase in the hydrophilic nature of the wood surface (Maldas & Kamdem 1999). Our study also showed that cold and hot water solubles had insignificant negative correlations with age ($r = -0.28$ and -0.40 respectively, $p > 0.05$) but positive correlations with tree portion ($r = 0.78$ and 0.77 respectively, $p < 0.01$). Generally, the portion with higher cold and hot water solubles contained more active cells and portions with lower values contained higher lignin content.

Table 1 Chemical components of *Leucaena leucocephala* according to age and tree portion

Age (years)	Portion	CW (%)	HW (%)	NaOH (%)	AT (%)	Ash (%)	Lignin (%)	Holo (%)
8	Top	5.97	7.91	17.73	2.11	0.63	21.03	76.25
	Middle	5.01	6.68	15.59	1.76	0.70	23.33	75.16
	Bottom	4.44	5.48	15.54	1.73	0.87	24.67	73.38
	Average	5.14	6.69	16.29	1.87	0.73	23.01	74.93
16	Top	5.44	6.84	17.29	2.61	0.73	25.19	72.36
	Middle	4.52	5.28	16.06	2.06	0.76	26.28	71.77
	Bottom	4.25	5.56	16.33	1.99	1.12	27.07	69.56
	Average	4.74	5.89	16.56	2.22	0.87	26.18	71.23

Values are averages of three determinations; CW = cold water solubles; HW = hot water solubles; NaOH = alkali solubles; AT = alcohol toluene solubles; Holo = holocellulose

The upper reaches of crown contain higher early wood compared with the base of the tree (Panshin & de Zeeuw 1980).

Alkali solubles

Alkali solubles can be related to the processes of wood decay and to the damage caused by animals and pests of plants (Hill 2006). Alkali solubles of *L. leucocephala* ranged from 15.54 to 17.73%, both values in the 8-year-old tree (Table 1). In both age groups, alkali solubles were higher in the top portion of the tree compared with the middle and bottom portions.

As with cold and hot water solubles, age ($r = 0.16$, $p > 0.05$) did not affect alkali solubility but tree portion ($r = 0.75$, $p < 0.01$) did (Tables 2 and 3). This could explained by the fact that most of the extractives that can be dissolved by alkali are located in the active cells at top portion of the tree (Ucar & Yillgor 1995). Sapwood in the top portion of a tree contains compounds such as starch, sugar, protoplasm and gums and these provide food for fungus and encourage its growth. Alkali solubles are high in juvenile wood and alkali solubility is correlated with the degree of fungus attack (Ucar & Yillgor 1995).

Alcohol toluene solubles

Leucaena leucocephala had a higher percentage of alcohol toluene solubles in the older tree and in the top portion compared with the younger tree and the middle and bottom portions (Table 1). Alcohol toluene soluble was significantly affected by age ($r = 0.58$, $p < 0.05$) and tree portions ($r = -0.68$, $p < 0.01$) (Tables 2 and 3). Higher percentage of extractive in the 16-year-old wood made it stiffer and more resistant. Extractives help to reinforce wood structure (Luxford 1931) and, in the heartwood, they are recognized as the most important factor in fungal resistance (Taylor *et al.* 2002). Natural durability of timber depends not on the amount of extractable substances present but rather on components in the extractives. However, too high extractive compounds can interfere with bonding between wood and adhesive (Vick & Okkonen 1998). Extractives have been shown to interfere with

Table 2 Effects of age and tree portion on chemical components

Age (years)	CW	HW	NaOH	AT	Ash	Lignin	Holo
8	5.14 a	6.69 a	16.29 a	1.86 b	0.73 a	22.34 b	74.93 a
16	4.74 a	5.89 a	16.56 a	2.22 a	0.87 a	26.01 a	71.23 b
Tree portion							
Bottom	4.35 b	5.52 c	15.82 b	1.85 b	0.99 a	25.37 a	71.47 b
Middle	4.77 b	5.98 b	15.93 b	1.91 b	0.73 b	24.05 b	73.47 a
Top	5.70 a	7.37 a	17.51 a	2.36 a	0.68 b	23.11 c	74.31 a

Different letters down the column indicate significant differences at $p < 0.05$; CW = cold water solubles; HW = hot water solubles; NaOH = alkali solubles; AT = alcohol toluene solubles; Holo = holocellulose

Table 3 Correlation coefficients of chemical components with age and tree portion

Properties	Age	Tree portion
Cold water solubles	-0.28 ns	0.78**
Hot water solubles	-0.40 ns	0.77**
Alkali solubles	0.16 ns	0.75**
Alcohol-toluene solubles	0.58*	-0.68**
Ash content	0.41 ns	-0.78**
Lignin content	0.87**	-0.44 ns
Holocellulose content	-0.80**	0.50*

ns = not significant at $p > 0.05$, * significant at $p < 0.05$, **highly significant at $p < 0.01$

the cure of phenolic resin systems used in wood composite manufacture (Tohmura 1998).

Ash content

Ash contents of *L. leucocephala* ranged from 0.63 to 1.12% (Table 1) with the highest value in the bottom portion of the 16-year-old tree while the lowest, in the middle portion of the 8-year-old. The ash content was not affected by age ($r = 0.41$, $p > 0.05$) but there was a significant difference between the bottom and middle and top portions ($r = -0.78$, $p < 0.01$) (Tables 2 and 3). The result showed that wood with higher density contributed to the increase in the percentage of ash content. An older tree has more heartwood and higher density and, thus, higher ash content compared with a younger tree (Jenkins *et al.* 1995).

Lignin content

Lignin occurs in wood throughout the cell wall, but it is concentrated towards the outside and between cells. Lignin content exhibited a definite trend with age and tree portion (Tables 1 and 2). Lignin contents in the 8-year-old samples were lower (average 23.01%) than the 16-year-old (26.18%) and the values decreased from bottom to top portions of the tree. The correlation analysis further revealed that the lignin content showed a positive correlation with increase in age ($r = 0.87$, $p < 0.01$) and was insignificantly correlated with tree portion ($r = -0.44$, $p > 0.05$) (Table 3). Generally, it has been reported that lignin content shows a general decrease from pith to bark but does not show any significant increase from top to bottom of the tree (Panshin & de Zeeuw 1980). The functional significance of lignin has long been associated with the mechanical support for plant organs that enables increased growth in height (Boudet 2000).

Holocelullose content

The highest (76.25%) holocellulose content in *L. leucocephala* was observed in the top portion of the 8-year-old tree while the lowest value (69.56%) in the bottom portion of the 16-year-old tree (Table 1). Diaz *et al.* (2007) reported that the holocellulose contents of *Leucaena* varieties under their investigation were higher than 68%, similar to the values obtained in this study.

This study showed that the 8-year-old tree had higher holocellulose content compared with the 16-year-old. There was a clear decreasing trend on the effect of age ($r = -0.80$, $p < 0.01$) and an increasing trend in tree portion ($r = 0.50$, $p < 0.05$) on holocellulose content (Table 3). Juvenile wood is characterized by faster growth rate, lower density and higher cellulose content (Bendsten 1978). Lower wood density yields higher holocellulose and alpha cellulose contents in wood (Shupe *et al.* 1996).

Board properties

Overall, board density of 800 kg m^{-3} performed better than that of 700 kg m^{-3} and higher resin content also contributed to better performance of *L. leucocephala* wood (Table 4). MOR, MOE and internal bond increased as board density and resin content increased. Boards produced from strand size S1 and with a density of 800 kg m^{-3} and 9% resin content gave the highest mechanical properties. Values for thickness swelling (6.00–12.63%) for all boards were lower than 25%, i.e. the maximum requirement stipulated in the EN 317 (Anonymous 1993b).

Based on EN 300 (Anonymous 1997), OSB from the 8-year-old wood with a density of 700 kg m^{-3} and 9% resin content can already be categorized as heavy duty load bearing boards for use in humid conditions. However, boards produced using 16-year-old wood can only attain this classification if its density is 800 kg m^{-3} and resin content, 9%.

Effects of chemical components on board properties

Table 5 shows the relationship between chemical components of *L. leucocephala* wood and board properties. Results indicated that cold water soluble significantly affected the internal bond strength ($r = -0.49$, $p < 0.05$) but had negative correlation with board properties. This was due to the higher percentage of heartwood with higher extractive contents giving a negative impact on mechanical properties of OSB. Higher extractive content in wood affects the internal bonding between wood elements and adhesive which disturbs the curing process.

Hot water solubles showed insignificant correlation with board properties except for

Table 4 Properties of OSB from 8- and 16-year-old *Leucaena leucocephala* using S1 (12.7–19.0 mm) and S2 (6.3 –12.7 mm) strand sizes

Age (year)	Strand size	Resin (%)	OSB types[a]	Actual density (kg m^{-3})	Major axis		Minor axis		IB (MPa)	TS (%)
					MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)		
8	S1	9	1,2,3,4	720	47.07	7747	20.84	1933	1.06	8.76
8	S1	7	1,2,3,4	797	49.82	8227	27.75	2367	1.17	10.81
8	S1	9	1,2,3,4	802	52.96	8243	30.04	2417	1.40	6.44
8	S2	7	1,2,3	713	33.30	6532	18.58	1686	0.97	11.53
8	S2	9	1,2,3,4	712	38.63	6611	20.92	2026	1.01	7.75
8	S2	7	1,2,3,4	799	42.30	7246	23.97	2068	1.31	11.50
8	S2	9	1,2,3,4	801	52.44	7629	24.76	2208	1.49	6.33
16	S1	7	1,2,3	695	22.94	5596	14.52	1497	0.55	8.15
16	S1	9	1,2,3	704	29.09	6349	13.39	1450	0.58	7.40
16	S1	7	1,2,3	807	41.30	7470	24.00	2053	1.05	12.26
16	S1	9	1,2,3,4	806	49.68	7541	28.16	2370	1.18	7.67
16	S2	7	1,2,3	698	22.42	5316	14.03	1517	0.76	10.17
16	S2	9	1,2,3	706	26.97	5578	16.15	1535	0.88	9.17
16	S2	7	1,2,3	801	32.30	6248	19.76	1783	1.16	12.63
16	S2	9	1,2,3,4	798	39.43	6722	20.53	2014	1.50	9.23

[a]1 = General purpose boards and boards for interior fitments for use in dry conditions; 2 = load bearing boards for use in dry conditions; 3 = load bearing boards for use in humid conditions; 4 = heavy duty load bearing boards for use in humid conditions; MOR = modulus of rupture; MOE = modulus of elasticity, IB = internal bond, TS = thickness swelling

Table 5 Intercorrelation coefficients of chemical components on board properties

Variables	Major axis		Minor axis		IB (MPa)	TS (%)
	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)		
Cold water	-0.30 ns	-0.26 ns	0.08 ns	-0.29 ns	-0.49*	-0.08 ns
Hot water	-0.24 ns	-0.10 ns	0.17 ns	-0.26 ns	-0.55*	-0.41 ns
1% NaOH	-0.72**	-0.62*	-0.19 ns	-0.53*	-0.07 ns	0.19 ns
Alcohol toluene	-0.67**	-0.80**	-0.05 ns	-0.46 ns	0.30 ns	0.36 ns
Ash	-0.13 ns	-0.02 ns	-0.17 ns	0.31 ns	0.50*	0.26 ns
Lignin	-0.38 ns	-0.46 ns	-0.20 ns	0.13 ns	0.78**	0.46 ns
Holocellulose	0.34 ns	0.39 ns	0.01 ns	-0.40 ns	-0.76**	-0.35 ns

ns = not significant at $p > 0.05$, * significant at $p < 0.05$, **highly significant at $p < 0.01$

internal bond strength ($r = -0.55$, $p < 0.05$). The decrease in the internal bond strength with increasing amount of cold and hot water solubles indicated that higher concentrations of extractives may interfere with the cure of adhesives which are common in high density wood. Generally extractive contents in wood vary between 2 and 5% but can be as high as 15% (Zhang *et al.* 2007). Although extractives contribute merely a few per cent to the entire wood composition, they have a significant influence on its properties, such as mechanical strength or colour (Pandey 2005) and the quality of wood can be affected by the amount and type of these extractives (Hillis 1972).

The effects of 1% NaOH solubles showed significant correlation with MOR (r = -0.72, p < 0.01) and MOE (-0.62, p < 0.05) in major axis and MOE (r = -0.53, p < 0.05) in minor axis. Other properties showed insignificant correlation with alkali solubles. This implies that *L. leucocephala* wood was less resistant to alkaline environment. High alkali solubles are associated with high degradation of cellulose and polyphenol (Tadena & Villaneuva 1971). Alcohol toluene solubles also showed insignificant correlation with board properties except for MOR and MOE (r = -0.67, p < 0.01 and -0.80, p < 0.01 respectively) in the major axis. This indicated that high alcohol toluene extraction of wood affects bending properties of OSB.

Ash content showed insignificant effect on mechanical properties except for internal bond strength. This is consistent with the fact that increase in ash content is usually accompanied by a decrease in bending properties. The significant correlation (r = 0.50, p < 0.05) obtained by internal bond strength was due to a higher percentage of heartwood in the wood. Ash, comprising primarily silica, causes non-uniform resin distribution and, thus, influences proper cure of the resin during pressing (Jenkins *et al.* 1995). All board properties studied were insignificantly correlated with lignin content except for internal bonding (r = 0.78, p < 0.01). Lignin has excellent compatibility with thermosetting resins commonly used in product manufacture and contributes itself as an adhesive material (Donaldson *et al.* 2001). Higher lignin content in wood contributed to harder and denser wood. In this study, we obtained relatively high amounts of extractives especially in lignin content (26.18%, Table 1) in older *L. leucocephala* wood. Older tree and peeler core woods of *Pinus caribaea* have been reported to contain higher total extractives and lignin contents compared with younger tree and sapwood (da Silva *et al.* 2004).

The holocellulose content showed insignificant correlation with board properties except for internal bond strength (r = -0.76, p < 0.01). Higher holocellulose content indicated a lower internal bonding between wood strands and resin. High holocellulose content would lead to a highly crystalline nature of cellulose and reduce bonding performance (Jamaludin 1999).

CONCLUSIONS

The chemical nature of *L. leucocephala* wood was analysed for cold and hot water solubles, alkali solubles, alcohol toluene solubles, ash content, lignin content and holocellulose content. Generally, age and tree portion were found to significantly affect chemical components. The 8-year-old wood was found to be a suitable raw material to manufacture OSB. Although the correlation of some chemical components was significant, the correlation coefficients were relatively small. This indicated the loose association between factors and board properties. It could be deduced that board properties had less association with chemical components but were more dependent on resin content, board density and strand size used in the study.

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