Research Journal of Forestry

ISSN 1819-3439

Academic Journals Inc.

www.academicjournals.com

Research Journal of Forestry 6 (3): 55-65, 2012
ISSN 1819-3439 / DOI: 10.3923/rjf.2012.55.65

Anatomical Properties of *Leucaena leucocephala* Wood: Effects on Oriented Strand Board

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ABSTRACT

The data on the anatomical properties of wood material is generally preferred and required for the many processes and applications in the wood industry. The main objective of the study was to determine anatomical properties of *L. leucocephala* wood and to correlate the effects of anatomical properties with oriented strand board properties. The statistical analysis show significant differences in anatomical properties between the age variable. This study revealed that number of vessels per square millimeter in sixteen-year-old wood is higher than eight-year-old wood. Vessels per square millimeter are inversely correlated with vessel width, where with smaller vessel width more vessels per square millimeter are found. Ray width and ray cell were also found to be significantly affected by age. There is no significant difference between number of vessel and tree portion. For vessel width there was no significant different between top and middle portions but shows significant difference with bottom portion. Tree portion was found to affect ray width significantly. Overall, the bottom portion had the bigger ray width. Number of ray cell showed similar trends to effect of vessel width on tree portion. The results of intercorrelation indicated that the effects of the anatomical properties of *Leucaena leucocephala* on board properties were insignificant except for MOR and MOE in major axis. Generally, the board properties depend on the variation of anatomical properties only for bending properties in major axis.

Key words: Vessel, ray width, age, tree portion, oriented strand board

INTRODUCTION

In wood industry, the use of fast-growing species may be an alternative way to not only extend the wood supply, but also to preserve natural resources from over-exploitation. Many Oriented Strand Board (OSB) plants around the world are using material from short rotation forests. This represents an advantage compared to plywood which requires large diameter logs obtained from long rotation forests (Roffael and Schneider, 2003). OSB panels can be 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 on OSB (Geimer and Crist, 1980; Dimitri *et al.*, 1981; Stefaniak, 1981; Pugel *et al.*, 1990, 2004; Larson *et al.*, 2001).

Leucaena is a fast-growing species from leguminous shrub. In Malaysia it is locally known as "petai belalang". *Leucaena* is widely used as livestock forage, fuelwood, reforestation material and green manure consumption. Its uses have also been expanded to gum production, furniture and construction timber, pole wood, pulpwood, shade and support plants in agroforestry systems (Wan-Mohd-Nazri *et al*., 2011). In Southeast Asia, large growing trees are used to shade coffee and cocoa plantations (NAS, 1979; Brewbaker, 1987; Diaz *et al*., 2007). *Leucaena leucocephala* is pantropical tree and the distribution was done by Spanish galleons from Mexico to Southeast Asia in the early 16th century. *Leucaena* species were served as fodder and bedding for the animals which the Spaniards shipped. Unfortunately, only the shrubby strain of *Leucaena leucocephala* was involved. This "common" form seeded abundantly and aggressively colonized much of the tropics, notably on sub-humid alkaline soils, especially coralline islands. By the late 19th century, its value as a shade crop for the new coffee and cacao plantations of Asia promoted further international distribution and planting (Brewbaker, 1987).

Wood density of *Leucaena leucocephala* is medium to heavy hardwood (about 800 kg m^{-3}), with a pale yellow sapwood and light reddish-brown heartwood. The wood is known to be of medium density and dry without splitting or checking. It is strong, medium textured, close grained and easily workable for a wide variety of carpentry purposes. Sawn timber, mine props, furniture and parquet flooring are among the increasingly popular uses. However, the use of *Leucaena leucocephala* for sawn timber is greatly limited by its generally small dimensions (usually not greater than 30 cm diameter), its branches, limits lengths of clear bole available and the wood is often knotty and its high proportion of juvenile wood. Nevertheless, there is growing use of small-dimension sawn wood in a number of industries such as flooring which might include *Leucaena leucocephala* in the future. Poles are used to prop bananas and as a support for yams, pepper and other vines. Use of short-rotation *Leucaena leucocephala* for poles is limited by their lack of durability and susceptibility to attack by termites and woodborers Hughes (1998).

Research on mechanical properties, including static bending, compression strength and toughness indicated that *Leucaena leucocephala* has fair qualities which would not limit its uses as solid products (Tang, 1981). Van den Beldth and Brewbaker (1985) reported that *Leucaena leucocephala* produced wood of medium density with moderate strength properties. Its specific gravity ranges from 0.45 to 0.55 at the age of two years, a value that is fairly comparable to other commonly grown fuelwood species such as *Gliricidia sepium* (McDicken and Brewbaker, 1982). The wood of *Leucaena leucocephala* has excellent pulping qualities and makes excellent pulping and writing paper (Brewbaker, 1987). It has higher cellulose and lower lignin contents than other native hardwood of Taiwan (Tang and Ma, 1982). Diaz *et al*. (2007) reported that chemical characteristics of *Leucaena* varieties are suitable to be use as alternative source of cellulose pulp. The main objective of the study was to determine anatomical properties of *Leucaena leucocephala* wood and to correlate the effects of anatomical properties with oriented strand board properties.

MATERIALS AND METHODS

Sampling for anatomical, physical and chemical properties: The characteristic of wood was investigated at three levels of portions along the height of the tree. The wood disks were cut and separated into Top (T), Middle (M) and Bottom (B) portions for the determination of anatomical, physical and chemical properties (Fig. 1).

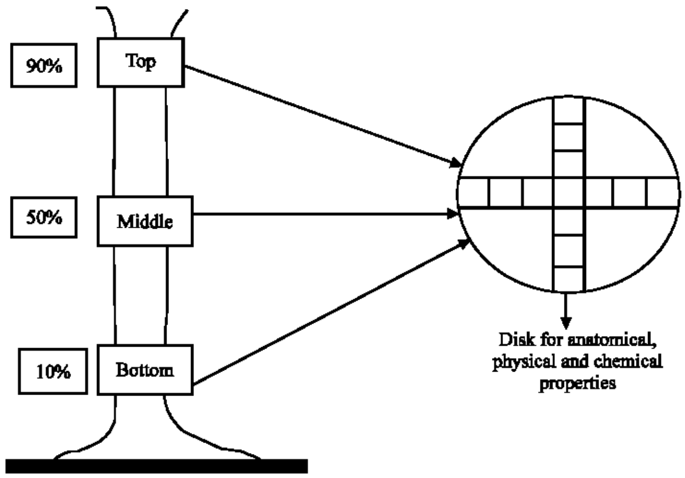

Fig. 1: Tree portions used for different analyses

Fig. 2(a-b): Wood disk (a) Eight years old and (b) Sixteen years old used for anatomical studies, T: Top, B: Bottom

Anatomical properties: A block of wood approximately 1 cm^3 in size was cut from each wood disk (Fig. 2) and the best part of the block was cut to right angle as possible using a saw and chisel. Wood samples were softened by boiling to remove excess air followed by immersion in distilled water. The boiled wood blocks were clamped onto the LEICA SM200R sliding microtome. Cross, radial and tangential sections, between 20-30 μm thick were sliced using the microtome knife. Then, the thin wood slice was placed onto a slide and stained with safranin red. The thin wood slices were then washed in successive ethanol baths (50, 95 and 100%) until all traces of excess stain (and water) was gone. The thin wood slices then were cleared in histo-clear to improve the clarity. After bleaching, staining and dehydrating, thin wood slices were mounted on Canada balsam glue for optical microscopic examination. Motic Images 2000 Software was used to measure and capture the image of the wood anatomical properties.

In this study, three main characters of vessels and ray were determined using the terminology and methodology of the International Association of Wood Anatomists (IAWA, 1957, 1989). The IAWA list is an important standardized hist of characters and terminology to be used in descriptive wood anatomical studies and identification. The IAWA hist is the most obvious resource for plant

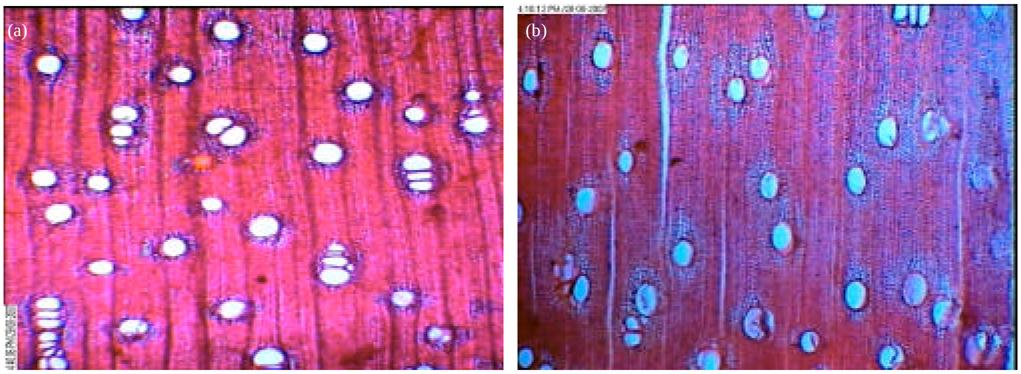

Fig. 3(a-b): Number of vessels in middle portion (4x magnification) of (a) Eight-year-old tree; vessels are solitary and multiple and (b) Sixteen-year-old tree; vessels are solitary

Table 1: Classifications for number of vessels

Category	Vessels No. (mm^{-2})
Very few	less than 5
Few	Between 5 and 20
Moderately few	Between 20 and 40
Numerous	Between 40 and 100
Very numerous	More 100

systematists (wood anatomists and others) to use in applying cladistic techniques to wood anatomical data. For vessel, two measurements were made and analyze; vessel diameters and number of vessel per square millimeter. For ray width, the most predominant width was recorded not to bias the selection. Number of ray cell was conducted by counting the widest part of rays. At least 25 measurements were made and averages of all specimens were recorded.

Number of vessels: Frequency of vessel per square mm was determined by counting all vessels individually (10 counts per sample). Vessel distribution patterns were determined from the cross section at a low magnification (4x) and were recorded only where there is a distinct pattern (Fig. 3). Table 1 shows 5 classifications for number of vessels (IAWA, 1989). Frequency of vessels was determined from the average of 10 counts per square millimeter area.

Vessel width: Vessel width was measured in cross section. Vessels were selected randomly for measurement with the selection towards the larger or smaller vessels. The vessel width is measured at the widest part of the opening. Information about cross section diameters of vessels would be useful in a description of size classes. Table 2 shows 4 classifications of vessels width (IAWA, 1989). The average tangential diameter of the vessels was determined from 25 measurements from cross-section.

Ray width and number of ray cell: Ray composition was assessed by collecting data from a tangential section observed with a light microscope. Table 3 shows 7 classifications of ray width (IAWA, 1957). For ray width, the most predominant width was recorded. The features for ray width do not apply to rays containing radial canals or to the rays composing an aggregate ray. The ray

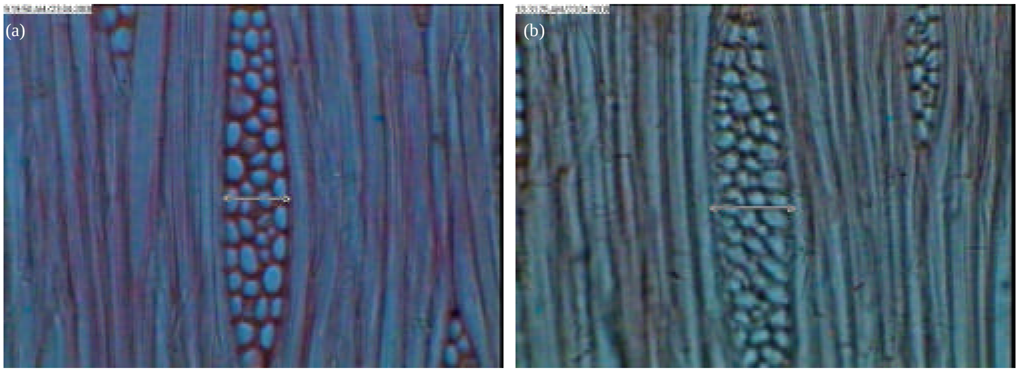

Fig. 4(a-b): Ray width and number of ray cells in middle portion of tree (10x magnification) of (a) Eight years old and (b) Sixteen years old tree, Vessels are large and multiseriate

Table 2: Classifications for vessel width

Category	Vessel width (μm)
Small	Less than 50
Moderately small	Between 50 and 100
Medium	Between 100 and 200
Large	More than 200

Table 3: Classifications for ray width

Category	Ray width (μm)
Very small	Less than 15
Small	Between 15 and 25
Moderately small	Between 25 and 50
Medium	Between 50 and 100
Moderately Large	Between 100 and 200
Large	Between 200 and 400
Very Large	More than 400

Table 4: Classifications for number of ray cell

Category	No. of ray cell
Few or uniseriate	Less than 1
Medium or multiseriate	Between 1 and 3
Large or multiseriate	Between 4 and 10
Larger or multiseriate	More than 10

width was determined on the cross section by measuring the widest part of the rays, perpendicular to the ray axis. When rays are of two distinct size classes, width of the larger size class was recorded in the database with magnification of 10x (Fig. 4). Ten measurements were carried out and the mean, range and standard deviation were recorded.

Table 4 shows 4 classifications number of ray cell (IAWA, 1989). Determination was conducted by counting the number of cells in the widest part of rays, perpendicular to the ray axis.

RESULTS AND DISCUSSION

Anatomical properties: The anatomical properties of *Leucaena leucocephala* was carried out by microstructure study on the wood samples. Results of the study on anatomical properties were compared to the classification of IAWA Committee (IAWA, 1957, 1989). The IAWA list of microscopic features for hardwood identification and wood anatomy for tropical woods are important standardized list of characters and terminology used in descriptive wood anatomical studies and identification.

Table 5 shows the average number of vessel per mm^2 for sixteen-year-old wood was higher than eight-year-old wood. Vessels were mostly solitary in sixteen-year-old wood, although it was possible to find them in groups of two or three vessels in wall-to-wall contact with each other (Fig. 3). Meanwhile, aggregations of two to three vessels were more common in eight-year-old wood.

According to microscopic features for hardwood identification as interpreted by IAWA (1989), results of the study on number of vessel per mm^2 show *Leucaena leucocephala* wood was classified as moderately few and moderately numerous in size classes (Table 6). Eight-year-old wood in top and middle tree portion performed in moderately few class and all portions of sixteen-year-old wood in numerous class.

The result also revealed the vessel width increased with along the height of the tree in both eight-year-old wood (from 153.56 to 187.60 μm) and sixteen-year-old wood (from 149.63 to 161.74 μm) (Table 5). Basically, the vessel width in sixteen-year-old is smaller than vessel width in eight-year-old. As reported in IAWA (1989), vessel width of *Leucaena leucocephala* wood was classified into medium size classes (Table 7).

Table 5: Anatomical properties of *Leucaena leucocephala*

				Ray**	
Age (year)	Tree portion	No. of vessel (mm^{-2})*	Vessel width (μm)*	Width (μm)	No. of cells
8	Top (8T)	35	187.60	43.53	4
	Middle (8M)	38	163.35	49.73	4
	Bottom (8B)	41	153.56	52.05	4
	Average	38	168.17	48.44	4
16	Top (16T)	42	161.74	50.50	4
	Middle (16M)	49	152.68	55.63	4
	Bottom (16B)	53	149.63	70.20	5
	Average	48	154.68	58.77	4

*,**Values are averages of 25 and 10 observations, respectively, T: Top, M: Middle, B: Bottom, 8: Eight years old, 16: Sixteen years old

Table 6: Vessels No. classification with respect to its size category, age and tree portion

Category	Vessels (mm^{-2})	Age and tree portion
Few	Between 5 and 20	
Moderately few	Between 20 and 40	8T and 8M
Numerous	Between 40 and 100	8B, 16T, 16M and 16B
Very numerous	More than 100	

T: Top, M: Middle, B: Bottom, 8: Eight years old, 16: Sixteen years old

Table 7: Vessel width classification with respect to its size category, age and tree portion

Category	Width (μm)	Age and tree portion
Moderately small	Between 50 and 100	
Medium	Between 100 and 200	8T, 8M , 8B, 16T, 16M and 16B
Large	More than 200	

T: Top, M: Middle, B: Bottom, 8: Eight years old, 16: Sixteen years old

According to definitions of IAWA (1989), ray width is determined on the tangential section by counting the number of cells in the widest part of the rays, perpendicular to the ray axis. Unlike the vessel width, ray width decreased along the height of the tree in both eight-year-old wood (from 52.05 to 43.53 μm) and sixteen-year-old wood (from 70.20 to 50.50 μm) (Table 5). However, the number of ray cell remained almost similar 4 to 5 cells for both in eight-year-old wood and sixteen-year-old wood. The number of cells of ray width in eight-year-old wood and sixteen-year-old wood was classified into large and multiseriate (Table 8). The presence of multiseriate rays seems to be consistent in all stage of age and tree portion (Fig. 4).

Statistical significance: The analysis of variance (ANOVA) on the effects of tree portion and age and their interactions on the anatomical properties is shown in Table 9. All the main factors of tree portion and age were found to affect anatomical properties significantly except for number of vessel. The interaction effects of tree height and age shows significant interaction in anatomical properties for vessel and ray width. However, no significant interaction effect of on tree portion and age to the number of vessel and ray cells were seen.

Effects of tree portion: The Duncan's Multiple Range Test (DMRT) for effects of tree portion on the anatomical properties are shown in Table 10. There is no significant difference between number of vessel and tree portion. Schoch *et al.* (2004) define vessel as a tube-like series of water-conducting cells (with bordered pits) which are axially joined by perforation plates in the cell end walls. The correlation analysis (Table 11) further revealed that the number of vessel showed

Table 8: Ray width classification with respect to its size category, age and tree portion

Category	Ray Width (No. of cells)	Age and tree portion
Few and uniseriate	Less than 1	
Medium and multiseriate	Between 1 and 3	
Large and multiseriate	Between 4 and 10	8T, 8M , 8B, 16T, 16M and 16B
Larger and multiseriate	More than 10	

T: Top, M: Middle, B: Bottom, 8: Eight years old, 16: Sixteen years old

Table 9: Summary of the ANOVA on Anatomical Properties

				Ray width	
SOV	df	No. of vessel (mm^{-2})	Vessel width(μm)	Width (μm)	No. of cells
Tree portion (TP)	2	0.82^{ns}	17.78**	44.93**	12.70**
Age (A)	1	15.15**	19.96**	71.52**	18.92**
TP x A	2	0.10^{ns}	6.34*	10.27**	1.77^{ns}

ns: Not significant at p>0.05, *Significant at p<0.05, **Highly significant at p<0.01

Table 10: DMRT analysis of tree portion effect on vessels and rays

			Ray width	
Tree portion	No. of vessel (mm^{-2})	Vessel width (μm)	Width (μm)	No. of cells
Top	41^a	169.57^a	47.02^c	3.90^b
Middle	43^a	154.33^b	52.68^b	4.15^b
Bottom	43^a	152.17^b	61.12^a	4.60^a

Means with same letter down the column are not significantly different at p<0.05

Table 11: Correlation coefficients of tree portion and age effect on vessels and rays

			Ray width	
	No. of Vessel in (mm^{-2})	Vessel width (μm)	Width (μm)	No. of cells
Tree portion (TP)	0.06^{ns}	0.28**	-0.61**	-0.49**
Age (A)	0.45**	-0.39**	0.55**	0.43**

ns: Not significant at p>0.05, *Significant at p<0.05, **Highly significant at p<0.01

Table 12: Summary of t-test of age on anatomical properties effect on vessels and rays

			Ray width	
Age	No. of vessel in (mm^{-2})	Vessel width (μm)	Width (μm)	No. of cells
8	37.91^{b}	168.67^{a}	48.43^{b}	3.97^{b}
16	48.10^{a}	154.68^{b}	58.78^{a}	4.47^{a}

Means with the same letter down the column are not significantly different at p<0.05

insignificant correlation with tree portion (r = 0.06). According to Adammopolos *et al.* (2007), this tendency was also observed in almost all stem heights of juvenile and mature wood in black locust. For vessel width there was no significant different between bottom and middle portions but shows significant difference with top portion. Table 11 shows that vessel width had a positive correlation (r = 0.28**) with tree portion from bottom to top. This is due to the lower density in eight-year-old wood and top portion had contributed to larger vessel width. According to Bowyer *et al.* (1982), lower density wood recorded bigger vessel size or more percentage void volume and contributes to small number of vessel.

Tree portion was found to affect ray width significantly. Overall, the bottom portion had the bigger ray width. The correlation analysis (Table 11) further revealed that the ray width showed a negative correlation (r = -0.61**) with increased of tree height from bottom to top portion. Number of ray cell showed similar trends to effect of vessel width on tree portion. The number of ray decreased with tree portion. The correlation analysis further revealed that number of ray cell was negatively correlated (r = -0.49**) with tree height. This shows that upper portion had less number of cells. According to Metcalfe and Chalk (1979), bottom portion of tree consisted bigger ray because of the main function of ray is to store fat, protein and sugar to translocate these relatively large molecular nutrients among nearby cells for growth. Cato *et al.* (2006) reported that cell wall thickness was strongly correlated with vessel and ray width, thus increase wood density at all heights and rings assayed.

Effects of age: Table 12 shows the effects of age on the anatomical properties of *Leucaena leucocephala* wood. The statistical analysis showed significant differences in anatomical properties between the age variable. The number of vessels per square millimeter in sixteen-year-old wood is higher than eight-year-old wood. Vessels per square millimeter is inversely correlated with vessel width, where with smaller vessel width more vessels per square millimeter are found. The correlation analysis (Table 11) further revealed that the vessels per square millimeter showed a positive correlation with increased of age (r = 0.45) and vessel width showed negative correlation (r = -0.39). This indicate that sixteen-year-old tree with high density wood had smaller vessels and higher number of vessels per square millimeter. Bowyer *et al.* (1982), in their study recorded large number of vessel in higher density wood.

Table 13: Intercorrelation coefficients of anatomical board properties

		Major axis		Minor axis			
Properties	Variable	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)
Anatomical	No. of vessel	-0.34*	-0.37**	-0.09^{ns}	-0.15^{ns}	-0.14^{ns}	-0.12^{ns}
	Vessel width	0.22*	0.23*	0.05^{ns}	-0.06^{ns}	-0.02^{ns}	0.07^{ns}
	Ray width	-0.29**	-0.25*	-0.16^{ns}	-0.12^{ns}	-0.16^{ns}	0.004^{ns}

ns: Not significant at p>0.05, *Significant at p<0.05, **Highly significant at p<0.01

Ray width and ray cell were found to be significantly affected by age. Ray width increased 21% as the age of *Leucaena leucocephala* tree increased from eight-year-old to sixteen-year-old. The correlation analysis (Table 11) further revealed that the ray width showed a positive correlation with increased of age (r = 0.55**). The number of ray cell also exhibit significant different between eight-year-old and sixteen-year-old wood. The correlation analysis further revealed that the number of ray cell showed a positive correlation with increased of age (r = 0.43**). According to Miller (1999) wood rays are strips of short horizontal cells that extend in a radial direction. These groups of cells conduct sap radially across the grain most easily seen on edge grained in older tree. In oaks and sycamores, the rays are conspicuous and add to the decorative features of the wood. The rays also represent planes of weaknesses along which seasoning checks readily develop.

Intercorrelation coefficients: The results indicated that the effects of the anatomical properties of *Leucaena leucocephala* on board properties were insignificant except for MOR and MOE in major axis (Table 13). Number of vessel showed a significant effect on MOR and MOE in major axis (r = -0.34* and -0.37**). Higher number of vessel per mm^2 gave negative impact to bending properties because of the board becomes too stiff and brittle. Normally, higher density woods have more number of vessels. According to Muszynski and McNatt (1984) wood density was one of the most important factor that affected mechanical properties of particleboard. For vessel width, MOR and MOE in major axis showed positive correlation (r = 0.22* and 0.23*). This may be due to bigger vessel width encouraging better resin penetration into wood during hot pressing, thus producing better mechanical properties. According to Marra (1992) for a good resin bonding a sufficient amount of resin penetration into wood cell is desirable. MOR and MOE in major axis significantly correlated with ray width (r = -0.29** and -0.25*). This implied that wider ray width from high density wood, produced strands which were smaller and shorter strands during stranding process and reduced bending properties. Furthermore, high wood density also produced low resin bonding efficiency because of more extractive present in ray. According to William (1928), wood structures of denser wood characterize by wider ray width and had numerous crystals. Generally, the board properties depend on the variation of anatomical properties only for bending properties in major axis.

CONCLUSIONS

This study revealed that anatomical properties of *Leucaena leucocephala* wood were found to be affected by age and tree portion significantly except for the number of vessels. The correlation between anatomical and board properties showed that the effect of anatomical properties of *Leucaena leucocephala* on board properties were found insignificant except for MOR and MOE. Although the correlation of some anatomical properties was significant, the correlation coefficients were relatively small thus indicating the loose association between the factors and board properties.

It could be deduced that the board properties had less association with anatomical properties but were more dependent on the resin content, board density and strand size used in the study.

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