PROPERTIES OF *ACACIA MANGIUM* PLANTED IN PENINSULAR MALAYSIA

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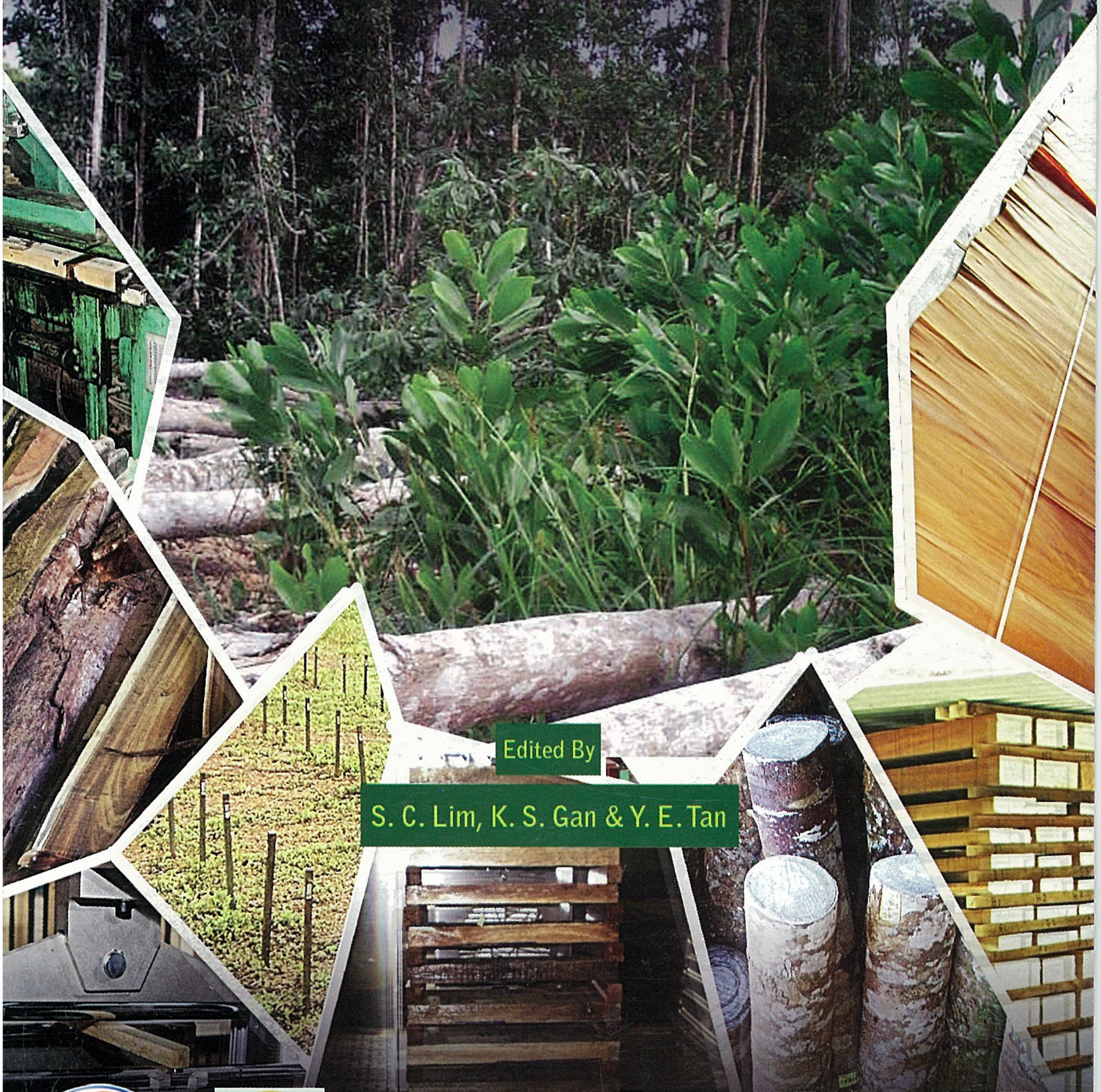
PROJECT NO. PD 306/04(1)



Edited By

S. C. Lim, K. S. Gan & Y. E. Tan

National Resources & Environment Malaysia (NRE)

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2011

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PREFACE

The project, entitled IMPROVING UTILIZATION AND VALUE ADDING OF PLANTATION TIMBERS FROM SUSTAINABLE SOURCES IN MALAYSIA PROJECT NO. PD 306/04(1), was jointly funded by the International Tropical Timber Organization (ITTO) and the Malaysian Government. It was a collaborative research project undertaken by the Forest Research Institute Malaysia (FRIM) as the leading agency, together with the Timber Research & Technical Training Centre (TRTTC), Sarawak, and the Forest Research Centre (FRC), Sabah, as collaborative partners. The Forestry and Forest Products Research Institute (FFPRI), Japan, provided technical guidance and expert training to project members as well as the dispatch of their experts to Malaysia.

The project focused on improved utilization and value adding of selected plantation-grown timbers in the three regions of Malaysia, namely Peninsular Malaysia, Sarawak and Sabah, through systematic evaluation of their basic physical and other properties. During the project period, plantation-grown *Acacia mangium* from Peninsular Malaysia, engkabang jantong (*Shorea macrophylla*) from Sarawak, and teak (*Tectona grandis*) from Sabah were assessed.

This report on the properties of *Acacia mangium* formed part of the output of the project. The results were obtained using the harmonized testing methods proposed during the earlier part of the project.

We would like to express our sincere appreciation to ITTO, the Government of Japan and the Malaysian Government for funding the project; the Director General, Forest Research Institute Malaysia (FRIM), the Director, Forest Department, Sabah, the Director, Forest Department, Sarawak, and the National Project Director for their support; the Forestry and Forest Products Research Institute (FFPRI), Japan, for providing training facilities; and finally, to fellow project members for their help and guidance.

S. C. Lim, K. S. Gan, & Y. E. Tan

INTRODUCTION

S. C. Lim, K. S. Gan & Y. E. Tan

The project, entitled "Improving Utilization and Value Adding of Plantation Timbers from Sustainable Sources in Malaysia," was jointly funded by the International Tropical Timber Organization (ITTO) and the Malaysian Government. It was undertaken by the Forest Research Institute Malaysia (FRIM) as the leading agency; and the Timber Research & Technical Training Centre (TRTTC), Sarawak, and the Forest Research Centre (FRC), Sabah, as collaborative partners.

The first part of the project involved the formulation of a set of harmonized testing methods for the evaluation of basic timber properties of plantation-grown timbers. Details of the testing methods have since been published by Tan et al. (2010). It is therefore recommended that readers should also make reference to this manual for better understanding of the methods and procedures of tests used.

Researchers involved in the formulation of the testing methods also carried out the actual evaluation of the properties of the plantation timbers based on Tan et al. (2010).

This present book is the compilation of technical reports on *Acacia mangium,* one of the three species chosen under the project, with the following topics: (a) wood anatomy and quality studies, (b) mechanical properties, (c) sawing and machining properties, (d) accelerated durability studies, (e) treatability, (f) veneering properties, (g) drying properties, (h) finger jointing and bonding properties, and (i) chemical properties.

Acacia mangium plantations in Peninsular Malaysia

Acacia mangium Willd., belonging to the sub-family Mimosoideae of the family Leguminosae, is native to Australia, Papua New Guinea and Indonesia. The species was first introduced to Sabah in 1967 as a fire-break species. However, with the anticipated shortage of sawlogs for the production of general utility timber before the end of the century, a plantation programme known as the Compensatory Forest Plantation Programme (CFPP) was initiated by the Forestry Department in Peninsular Malaysia in 1982 (Muhammad 1986). The CFPP planned to establish about 188 000 ha of forest plantation using *A. mangium, Gmelina arborea* and *Paraserianthes falcataria* as the main species. These species are expected to yield general utility sawlogs at the rate of 210 m^3 per hectare at the age of 15 y (Yong 1984). To date, a total of 51 768 ha of *A. mangium* have been planted in Peninsular Malaysia, mainly in the states of Johore, Negeri Sembilan, Pahang and Selangor (Ho et al. 1999).

Recently, in support of the initiative to promote forest plantations, the Ministry of Plantation Industries and Commodities has in 2006 initiated a financing programme for the development of commercial forest plantations. This programme is handled by a special purpose vehicle known as Forest Plantation Development Sdn Bhd (FPDSB), a wholly owned company by Malaysian Timber Industry Board (MTIB). The purpose of this soft loan is to encourage more companies to participate in forest plantations which promises attractive and profitable income opportunities, employment generation and the contribution of environmental enhancement through ecological balance. In fact, commercial forest plantation is the way forward for the timber-based industries in Malaysia which aim to increase their production in the future to meet the government's target of national export value earning amounting to RM53 billion by 2020 (Zaini 2010).

Acacia trees are renowned for their robustness and adaptability, which make them good plantation species (Figures 1 and 2). Work on the diseases, soil, growth, silviculture treatments, seeds and their establishment has long been documented by Weinland and Ahmad Zuhaidi (1989). Studies on the properties and utilization of *A. mangium* appear to be lacking or incomplete resulting in a poor understanding of the timber. With the fast maturing *Acacia* plantations in the country, there is urgency to find the best way to utilize this timber resource. Some preliminary work has been done in the past but it is felt that more has to be carried out so that this species is better understood and can be utilized efficiently.

Figure 1 An *Acacia mangium* tree with fairly tall and clear bole

Figure 2 A typical *Acacia mangium* plantation (Kemasul forest plantation area)

Logs of *Acacia mangium*

The evaluation of the properties of plantation-grown *A. mangium* in Peninsular Malaysia was based on the 20-y-old logs obtained from Kemasul Forest Reserve in the state of Pahang (Figure 3) and 16-y-old logs from Ulu Sedili Forest Reserve, Johore (Figure 7). Average diameters of the 20-y-old and 16-y-old trees were 37.9 cm and 32.5 cm respectively. Trees from both sites were found to grow to about 30 m high with a clear bole up to 6–12 m high.

Normally, the log is quite straight until the height of about 6 m or slightly higher and after that, the bole becomes quite curvy and often tapers. The log, if not processed within two to three weeks, may develop serious end-splitting due to the gradual release of growth stresses as a result of drying during storage (Figure 4).

Many of the trees may contain fluted boles at the bottom ends (Figures 5 and 6) and thus, may cause some problems in sawing and affect the rate of recovery. Quite a number of the logs are also found to contain hollow cores (Figure 7). When viewed from the ends of the logs, the proportions of sapwood are unexpectedly low (Figure 8).

Figure 3 20-y-old logs from Kemasul, Pahang

Figure 4 *Acacia mangium* logs with split ends

Figure 5 Butt end of a log—fluted

Figure 6 Butt end of a log—fluted

Figure 7 Logs with hollow cores from Ulu Sedili, Johore

Figure 8 Logs with thin layers of sapwood from Ulu Sedili, Johore

Timber of *Acacia mangium*

Due to its fast-growing nature, *A. mangium* produces timber that tends to have a large number of knots (Figure 9). Colour of the wood tends to vary from light to dark brown (Figures 10, 11 and 12). Quarter-sawn material may be a bit rough due to the presence of interlocking grain. The timber is a light hardwood timber. The density is reported to increase with age (Table 1)(Lim & Gan 2000).

Table 1 Basic density values of *Acacia mangium* at various ages from different locations

Age (y)	Average basic density/range (kg m^{-3})	Location
2	421	FRIM
5	290–500	Batu Arang, Selangor
6	340–500	Ulu Sedili, Johore
8	350–580	Ulu Sedili, Johore
8	530	Indonesia
9	389–535	Sabah
9	420	Sabah
9	483	Sabah
12	570	Sabah
14	467–675	FRIM
16	522	Ulu Sedili, Johore
20	623	Kemasul, Pahang

Figure 9 Knots on the surface of *Acacia* planks

Figure 10 Sapwood on the planks of *Acacia* wood

*Note:- All forms, figures and tables referred to in this paper are as in Chapter 1 of the manual *Testing Methods for Plantation-Grown Tropical Timbers*. FRIM, Selangor, Malaysia (Tan et al. 2010).

Figure 11 *Acacia* wood—light brown in colour

Figure 12 *Acacia* wood—dark brown in colour

Uses of *Acacia* timber

In the early days when information on the properties of *Acacia* timber was very much lacking, the timber was used for low-value products such as pallets, core veneer, hidden and secondary parts of furniture, sawdust for fuel (Figure 13) and chips for export (Figure 14). However, the need to add value to products that use acacia timber has resulted in the use of the timber for the manufacture of furniture (Figure 15), bent wood (for furniture)(Figure 16) , garden furniture, laminated products, floor boards, solid door, laminated veneer lumber (LVL) and many other products.

Figure 13 Sawdust for fuel

Figure 14 *Acacia* chips for export

Figure 15 Furniture from solid *Acacia* wood

Figure 16 *Acacia* bent wood for furniture

REFERENCES

Ho, K. S., Hamdan, H., Tan, Y. E. & Mohd. Shukari, M. 1999. *Acacia mangium* for timber and a case study of utilisation. Paper presented at the Fifth Conference on Forestry and Forest Products, 1999 Series, Utilisation of Plantation Timber: Sentang: Potential Timber for the Future, 20 April 1999, Auditorium FRIM. 9 pp.

Lim, S. C. & Gan, K. S. 2000b. Some physical properties and anatomical features of 14-year-old *Acacia mangium*. *Journal of the Tropical Forest Products* 6 (2): 206–213.

Muhammad Jabil 1986. Forest plantation and future timber supply in Peninsular Malaysia. Keynote address presented at the Ninth Malaysian Forestry Conference, 13-17 Oct. 1986, Sarawak.

Tan, Y. E., Lim, N. P. T., Gan, K. S., Wong, T. C., Lim, S. C. & Thilagawathy, M. (Eds) 2010. *Testing Methods for Plantation Grown Tropical Timbers*. FRIM, TRTTC & FRC. 155 pp.

Weinland, G. & Ahmad Zuhaidi, Y. 1989. *An Annonated Bibliography on Acacia mangium*. Research Pamplet No.102, Forest Research Institute Malaysia, Kepong, Malaysia. 104 pp.

Yong, C. T. 1984. Compensatory plantation in Peninsular Malaysia. Pp. 25–44 in Liew, T. C., Udarbe, H. T., Tang, H. T., Rita, T. I. E. & Lee, Y. F. (Eds) *Proceedings of Seminar on Forest Plantation Development in Malaysia,* 9–14 July 1984, Kota Kinabalu, Sabah.

Zaini, A. R. 2010. Forest plantation programme in Malaysia – the way forward. Paper presented at the Seminar and Workshop on Improved Utilization of Tropical Plantation Timbers, 23–25 March 2010, Kuala Lumpur. 9 pp.

WOOD ANATOMY AND QUALITY

S. C. Lim & K. S. Gan

INTRODUCTION

Following the launching of the Compensatory Forest Plantation (CFPP) in 1982 by the Forestry Department Peninsular Malaysia, by 1999, a total of 51 768 ha of *A. mangium* (Figure 1) had been planted in Peninsular Malaysia, mainly in the states of Johor, Negeri Sembilan, Pahang, and Selangor (Ho et al. 1999). *Acacia* species normally demand full light for good development and may be stunted when grown in shade. Generally, *Acacia* trees are renowned for their robustness and adaptability. Despite some early studies on the properties of *A. mangium* wood, certain aspects require further work to enhance the utilization of the timber.

Figure 1 A typical *Acacia mangium* plantation (20-y-old)

The main objectives of the present study are (1) to test the standard procedures as formulated in the manual for harmonized testing methods jointly developed by the scientists from FRIM, TRTTC and FRC (Tan et al. 2010) and (2) to evaluate the anatomical features and quality of the plantation-grown *A. mangium* timber from two different locations and at two different ages.

MATERIALS AND METHODS

Trees, 16 y old and 20 y old, were obtained from Ulu Sedili, Johore (Figure 2) and Kemasul Forest Reserve in Mentakab, Pahang (Figure 3) respectively. Methods of tree sampling were based on the selection as specified in Tan et al. (2010).

Figure 2 16-y-old logs from Johore

Figure 3 20-y-old logs from Pahang

For each age group, a total of six trees, each from the bottom of the tree until 5-m height, were taken. Before the discs were sawn, a shallow groove along the length of the log was cut using a chain-saw to ensure that the positions of the samples were consistent throughout the length of the log (Figure 4). Discs of 50 mm were taken then from the bottom, middle and top ends of the 5-m log for both wood anatomy and quality studies.

Figure 4 Cutting a groove throughout the length of the log using a chain-saw

Before the samples were cut for various studies, the discs were first assessed by measuring their diameters (Table 1) and widths of sapwood and heartwood so that the percentages of the sapwood and heartwood could be determined (Figure 5). The percentage of sapwood was calculated based on the following formula:

% of sapwood = $(R^2 - r^2)/R^2 \times 100$ where R = radius of the disc and r = radius of the heartwood.

Table 1 Diameters of the discs obtained

Tree No.	20-y-old		Tree No.	16-y-old	
	Bottom end (cm)	Top end (cm)		Bottom end (cm)	Top end (cm)
1	39	32	7	29	27
2	26	18	8	24	23
3	34	24	9	30	26
4	29	26	10	25	22
5	36	26	11	25	22
6	39	28	12	28	24

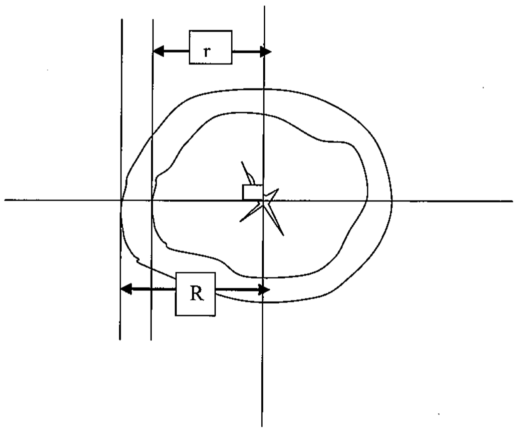


Figure 5 Measurements for the determination of sapwood and heartwood percentages

From each disc, samples 2 × 2 × 5 cm were taken according to Figures 6 or 7 below:

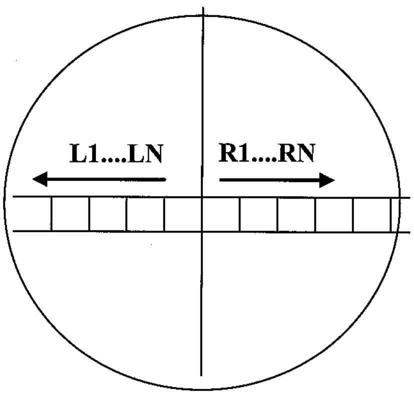


Figure 6 Sampling for log with pith at centre

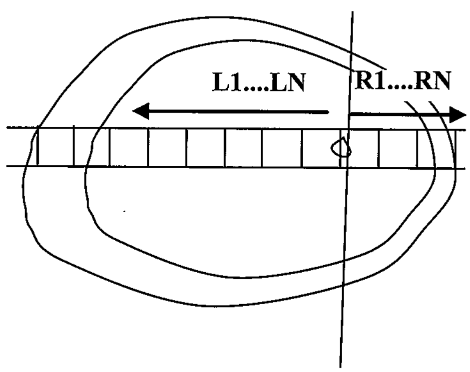


Figure 7 Sampling for log with eccentricity

Figure 6 was adopted for discs which were fairly rounded whereas Figure 7 was meant for discs with eccentricity. From each sample, a sample of 1 cm^3 was cut for density determination and the remaining portion was used for slide preparation for the anatomical and fibre morphology studies.

The basic density was determined by dividing the oven-dry weight by the green volume of the sample. The oven-dry weight was obtained by drying the sample in an oven at 103 ± 2 °C until constant weight. The volume was obtained by the water displacement method.

For the fibre morphology study, samples were cut into small match-stick-sized splinters and then macerated in a 1:1 solution of 30% volume hydrogen peroxide and glacial acetic acid for about 3 hr or until the splinters became white. The macerated fibres were then washed with distilled water and stained with 1% safranin for easy observation. For each sample, 25 fibres were randomly selected and measured.

For the anatomical studies, blocks of 1 cm^3 were first softened by boiling for about 2 hr before being sectioned to about 15-µm thickness using a sliding microtome. The sections were stained with 1% safranin and studied using a normal compound microscope. Features of the wood were examined using the guidelines as given in Wheeler et al. (1989).

RESULTS AND DISCUSSION

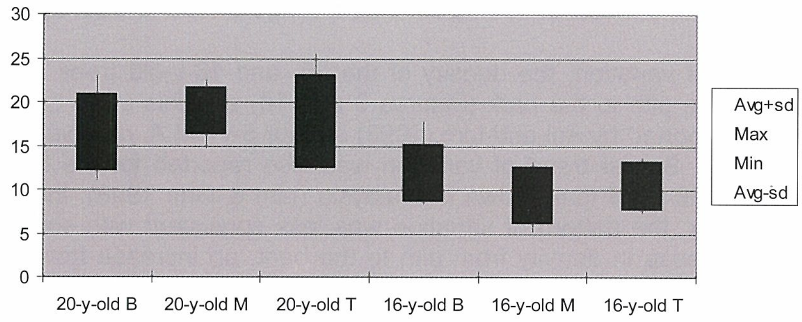
Sapwood percentage

Sapwood is a pathway for the movement of water and nutrients from the roots of the tree to the leaves. A stem must have a sufficiently large transverse area of sapwood to compensate evaporative water losses from the leaves (Sellin 1996). However, from the utilization point of view, the amount of sapwood not only affects its value and aesthetic properties but also its properties. The most significant feature of sapwood is its lack of resistance to insect and fungal attacks (Brazier 1971).

In this study, the 20-y-old *A. mangium* trees consisted of 11.18 to 25.48% of sapwood with average percentages of sapwood for the bottom, middle and top discs of 16.52, 18.60 and 17.72% respectively. There is a tendency for an increase in the percentage of sapwood with height (Figure 8).

For the 16-y-old *A. mangium*, the percentage of sapwood ranged from 5.3 to 17.8%. Average percentages of sapwood for the bottom, middle and top discs were 11.9, 9.4 and 10.5% respectively. Unlike the 20-y-old *A. mangium*, at 16 y old, the bottom end of the log appeared to contain the highest percentage of sapwood as compared with the middle and top ends.

When the amounts of sapwood of the two ages are compared (Figure 8), it appears that the 20-y-old trees contained a higher proportion of sapwood than the 16-y-old trees. The result appears to be contrary to those of other studies on plantation-grown timbers where a lower percentage of sapwood was recorded for the older trees. Bhat (1995), in his study on 8-y-old teak, reported a mean heartwood percentage of 30.1% (sapwood 69.9%). He further reported an increase in the heartwood percentage of teak with age as follows: 50.3, 61.2 and 83% for trees of ages 13, 21 and 55 y respectively. Lim and Gan (2000a) also observed a decline in the sapwood percentage of Malaysian-grown teak from 53.7 to 31.0% for trees of 8- and 28-y-old respectively.



Note: B= bottom, M = middle, T = top end of the log

Figure 8 Average sapwood percentages of six trees each of the 20- and 16-y-old *Acacia mangium*

Density variation

Average basic density, standard deviation and range values of the 16- and 20-y-old trees are shown in Table 2.

Table 2 Basic density values of the 16- and 20-y-old *Acacia mangium* from two different locations

Tree No.	20-y-old		Tree No.	16-y-old	
	Mean ± SD ($kg\ m^{-3}$)	Range ($kg\ m^{-3}$)		Mean ± SD ($kg\ m^{-3}$)	Range ($kg\ m^{-3}$)
1	626 ± 102.4	412–840	7	527 ± 100.2	341–723
2	642 ± 88.3	383–818	8	552 ± 115.8	320–757
3	613 ± 113.3	401–830	9	496 ± 116.8	249–751
4	630 ± 93.3	443–800	10	550 ± 122.6	401–831
5	627 ± 116.1	395–793	11	520 ± 123.9	329–803
6	611 ± 101.8	387–771	12	492 ± 121.0	297–811
Mean	623 ± 102.6	383–840	Mean	522 ± 116.9	249–831

For the 16-y-old trees, the basic density ranged from 249 to 831 kg m^{-3} with an average of 522 ± 116.9 kg m^{-3}, whereas for the 20-y-old, the basic density ranged from 383 to 840 kg m^{-3} with an average of 623 ± 102.6 kg m^{-3}. The average density obtained is comparable to that of rubberwood (*Hevea brasiliensis*) which has density of 560 to 640 kg m^{-3} (Wong et al. 2002). The density of plantation-grown *A. mangium* appears to vary with age and location of growth. For example, 5-y-old *A. mangium* from Batu Arang, Selangor, had a density range of 290 to 500 kg m^{-3} (Ani & Lim 1993); 8-y-old trees from East Kalimantan, Indonesia, had a mean density of 530 kg m^{-3} (Scharai-Rad & Kambey 1989); 9-y-old trees from Sabah had a density range of 389 to 535 kg m^{-3} (Ani & Lim 1992); 14-y-old trees from FRIM's campus had a density range of 467 to 675 kg m^{-3} (Lim & Gan 2000b) and 13-y-old trees from Sarawak with a mean of 471 kg m^{-3} had a range of 420 to 585 kg m^{-3} (Tukau & Fujii 2000).

On the radial variation, the density of the 20- and 16-y-old trees appeared to increase from the pith to the bark (Figures 9 and 10) and this trend of variation is similar to that reported by Ani and Lim (1993) on four 5-y-old *A. mangium* from Batu Arang, Selangor. Similar trend of variation was also reported for the 8- and 16-y-old but not the 28-y-old teak grown in Malaysia (Lim & Gan 1998). In the case of the 28-y-old teak, the pattern of variation was less consistent with some samples showing an increase in density from pith to the bark, an increase from the pith to the intermediate region before decreasing to the bark and a decrease from the pith to the bark. However, of the various patterns of density variation, Pashin and de Zeeuw (1980) reported that an increase in density from pith to bark is most frequently observed in softwood and hardwood timbers.

On the longitudinal variation, the bottom end of the tree appeared to have the highest density for both the 20- and 16-y-old trees (Figures 11 and 12). For the 20-y-old trees, the density tended to decrease towards the middle portion before increasing to the top end of the log except for two trees where the density decreased gradually from the bottom to the top end. For the 16-y-old trees, the variation of density in the longitudinal direction was less consistent where three different patterns were observed, ie an increase of density towards the middle portion before decreasing towards the top, a decrease of density towards the middle portion before increasing toward the top and a decrease from the bottom end towards the top end. The types of variation mentioned have also been reported by Lim and Gan (2000a) and Panshin and de Zeeuw (1980).

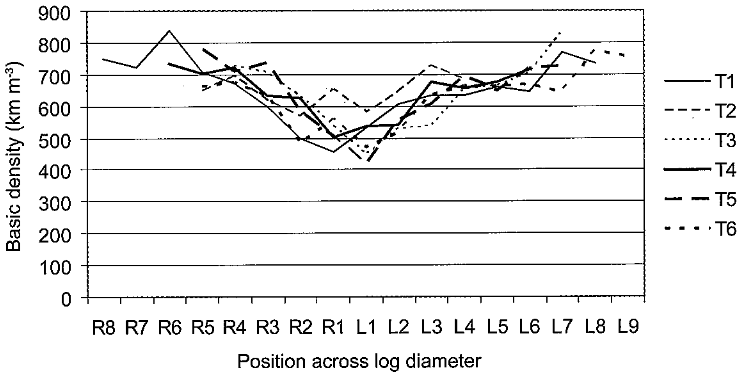


Figure 9 Variations of density in the radial direction (R1 and L1 are positions near pith) of the 20-y-old *Acacia mangium*

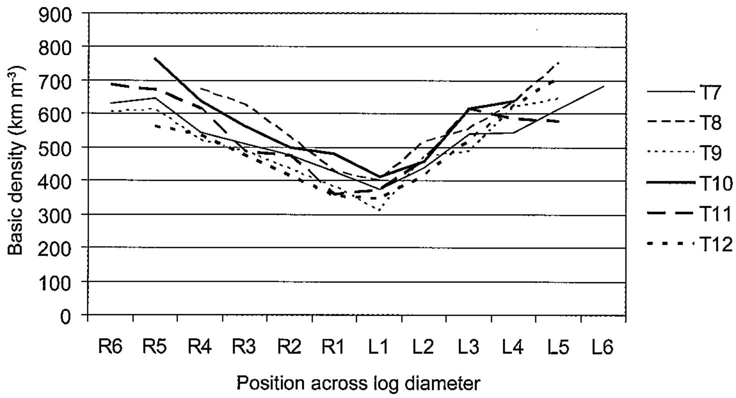


Figure 10 Variations of density in the radial direction (R1 and L1 are positions near pith) of the 16-y-old *Acacia mangium*

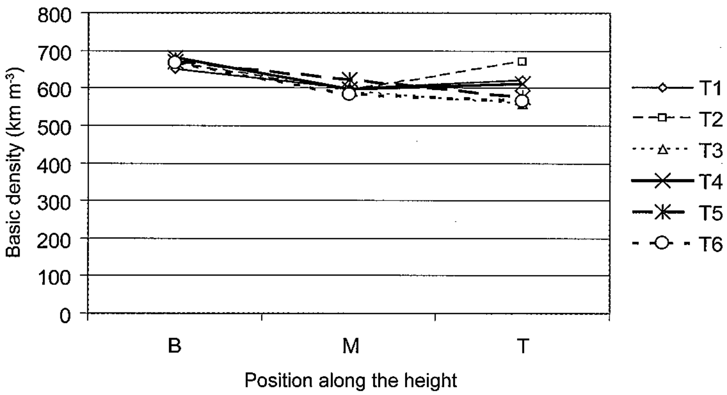


Figure 11 Variations of density along the height of the 20-y-old *Acacia mangium*

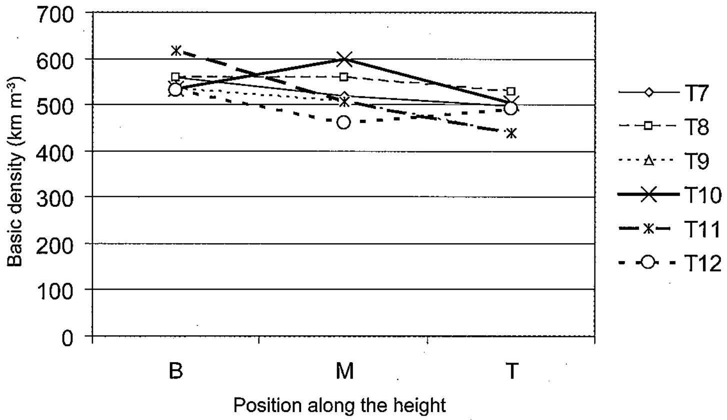


Figure 12 Variations of density along the height of the 16-y-old *Acacia mangium*

Fibre morphology

Results of the fibre morphology of the 16- and 20-y-old *A. mangium* are shown in Table 3. The mean fibre length of trees 1 to 6 (age: 20 y) was 1048 µm with a range of 375 to 1600 µm, mean diameter of 20 µm with a range of 10 to 45 µm, mean lumen of 12.0 µm with a range of 3.0 to 30.0 µm and mean fibre-wall thickness of 8 µm with a range of 3 to 12.5 µm, whereas for the 16-y-old *A. mangium* (trees 7–12), the mean fibre length was 954 µm with a range of 550 to 1950 µm, mean diameter of 20.3 µm with a range of 5.0 to 37.5 µm, mean lumen of 11.2 µm with a range of 3.0 to 30.0 µm and mean fibre-wall thickness of 9.2 µm with a range of 3.0 to 14.5 µm. The average figures are comparable with those of 14-y-old *A. mangium* as reported by Lim and Gan (2000b) with the values of 1030 and 1076 µm for the length, 21.7 and 22.4 µm for the diameter, 7.9 and 8.7 µm for the fibre-wall thickness. Other studies on *A. mangium* showed variable results. For example, Mohd. Hamami et al. (1993) reported that the mean fibre lengths of 4- and 8-y-old *A. mangium* were 934 µm and 1018 µm respectively. Logan and Balodis (1982) reported a mean fibre length of 1080 µm for 9-y-old *A. mangium* planted in Sabah.

On the variation of fibre length from pith to position near bark, both the 16- and 20-y-old trees showed an initial increase in fibre length before decreasing towards the bark but in some cases, the increase occurred all the way towards the bark (Figures 13 and 14). On the variation in the longitudinal direction, the 20-y-old trees did not show much variation along the height. For the 16-y-old trees, however, three patterns of variation occurred with trees showing an increase of fibre length towards the mid-position of the stem before declining, an increase of fibre length to the top part of the stem and a decrease towards the mid-position of the stem before increasing towards the top part of the tree (Figures 15 and 16).

Table 3 Summary of fibre morphology

Tree No.	Fibre length (µm)	Diameter (µm)	Lumen (µm)	Fibre-wall thickness (µm)	Tree No.	Fibre length (µm)	Diameter (µm)	Lumen (µm)	Fibre-wall thickness (µm)
1	1138 (625–1150)	19.9 (12.5–35.0)	12.2 (3.0–27.5)	7.0 (3.0–12.5)	7	942 (55–1550)	21.0 (5.0–35.0)	11.0 (3.0–25.0)	10.0 (3.0–14.5)
2	1134 (750–1575)	19.6 (12.5–32.5)	13.5 (5.0–22.5)	6.2 (3.0–12.5)	8	988 (550–1525)	19.2 (10.0–32.5)	9.7 (3.0–25.0)	9.8 (5.0–14.5)
3	1130 (675–1600)	20.5 (12.5–32.5)	14.4 (5–25)	6.1 (3.0–2.5)	9	918 (625–1950)	21.0 (7.5–37.5)	12.3 (3.0–30.0)	8.6 (3.0–13.5)
4	1066 (525–1525)	21.0 (12.5–45.0)	12.5 (5.0–30.0)	8.1 (5.0–12.0)	10	941 (625–1350)	18.8 (10.0–30.0)	9.9 (3.0–25.0)	8.9 (5.0–13.5)
5	923 (375–1525)	19.44 (10.0–35.0)	9.0 (3.0–20.0)	9.7 (5.0–12.5)	11	986 (575–1750)	19.8 (10.0–30.0)	11.4 (3.0–22.5)	8.4 (3.0–13.0)
6	897 (475–1375)	19.7 (7.5–37.5)	10.3 (3.0–30.0)	9.3 (3.0–12.5)	12	951 (550–1450)	21.8 (10.0–37.5)	12.6 (3.0–27.5)	9.2 (3.0–173.5)
mean	1048 (375–1600)	20 (10.0–45.0)	12 (3.0–30.0)	8.0 (3.0–12.5)	mean	954 (550–1950)	20.3 (5.0–37.5)	11.2 (3.0–30.0)	9.2 (3.0–14.5)

Note: Trees 1-6 (20-y-old collected from Kemasul, Pahang); trees 7-12 (16-y-old collected from Ulu Sedili, Johor).

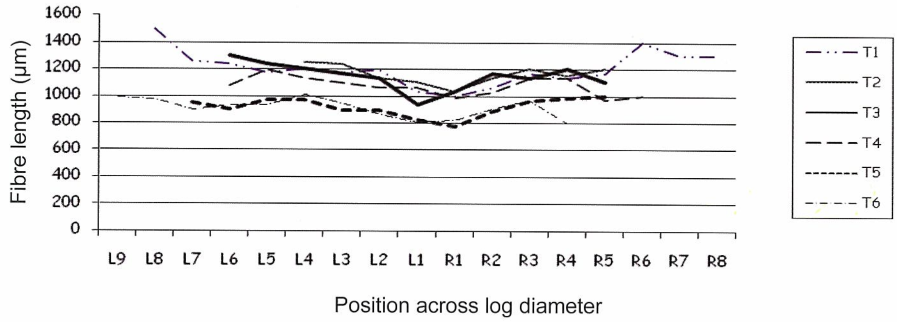


Figure 13 Variations of fibre length in the radial direction (R1 and L1 are positions near pith) of the 20-y-old *Acacia mangium*

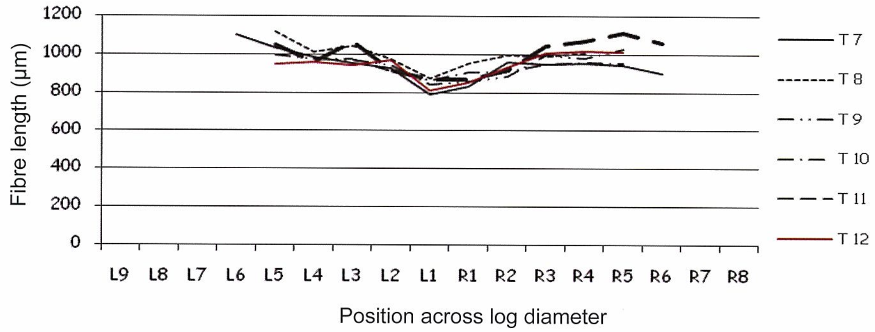


Figure 14 Variations of fibre length in the radial direction (R1 and L1 are positions near pith) of the 16-y-old *Acacia mangium*

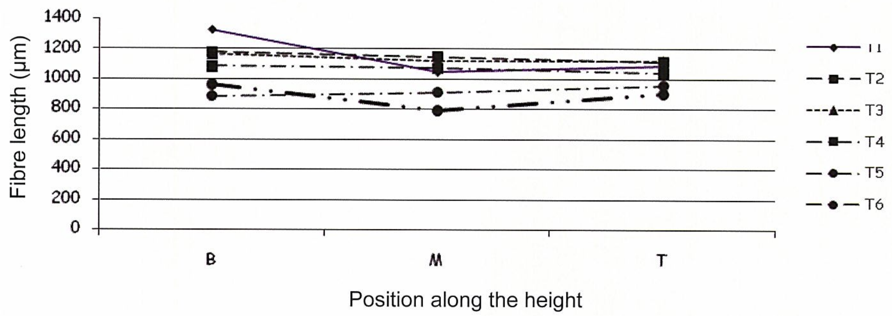


Figure 15 Variations of fibre length along the height of the 20-y-old *Acacia mangium*

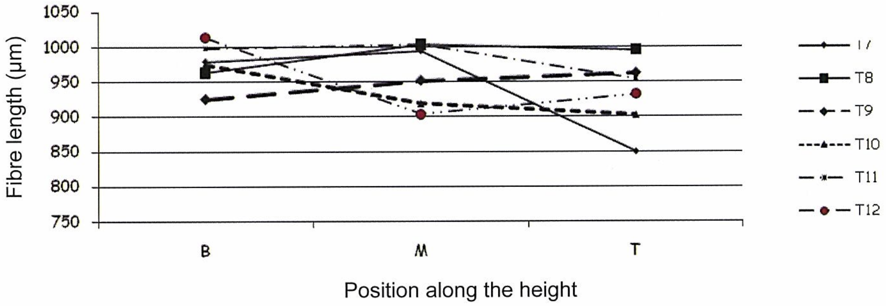
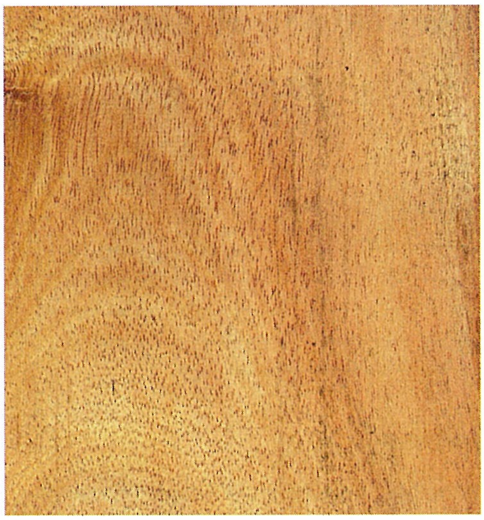


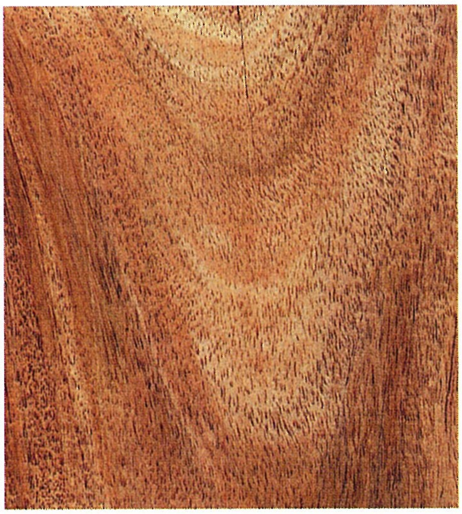
Figure 16 Variations of fibre length along the height of the 16-y-old *Acacia mangium*

Macroscopic features

Growth rings are absent or vaguely present. The heartwood is light brown to golden brown, darkening on exposure (Figures 17, a, b, c & d), sharply differentiated from the sapwood which is white to light yellow and with a width ranging from 0.6 cm to 2.5 cm (Figure 18a). Texture is moderately fine and even. Grain is straight to interlocked. Wood surface is fairly lustrous with striped figure on radial surface. Vessels are generally oval in shape, moderately fine and barely visible to the naked eye; solitary and in radial multiples of 2–3, seldom more; tyloses generally absent. Parenchyma is mainly as scanty paratracheal to very thinly vasicentric (Figure 18b). Rays are fine and barely visible to the naked eye. Ripple marks are absent.



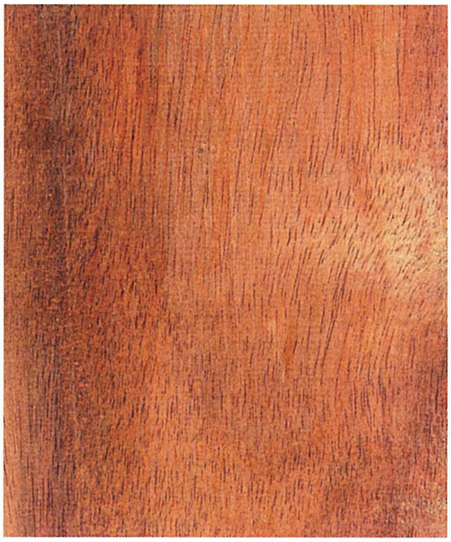
(a) Golden brown figure with vague growth rings



(b) Dark brown figure with vague growth rings

Figure 17 Colour images of *Acacia mangium*

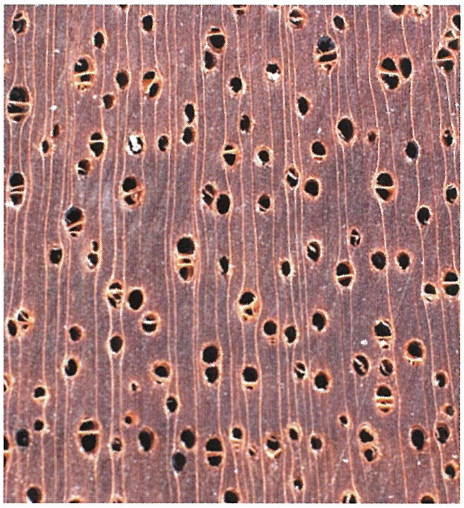
(c) Interlocked grain (rough surface)



(d) Without figure—dark brown

Figure 17 (continued)

(a)



(b)

Figure 18 (a) *Acacia mangium* disc with a layer of sapwood, slight brittle heart at centre, (b) Macroscopic features

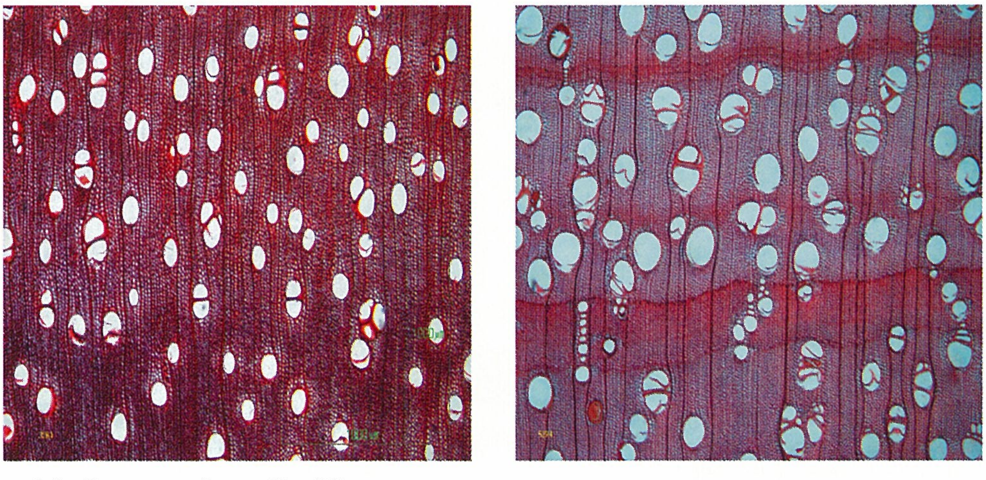
Microscopic features

Examination of the microscopic features of trees 1 to 6 (20-y-old) provides the following description of *Acacia mangium* (Figure 19, a–d).

Growth rings rather indistinct in some, others may be marked by layers of thick-walled fibres or reduced vessel sizes. Vessels diffuse, moderately few to moderately numerous, mainly oval, sometimes round, solitary and in radial multiples of 2–3 (-4), occasionally up to 8, clusters of vessels are common, average tangential diameter of 168 µm (range 100–260 µm), perforation simple; intervessel pits alternate, 7 µm diameter (range 5–10 µm), usually with coalescent apertures and also vestured; vessel-ray pits and vessel-parenchyma pits similar and bordered; tyloses absent or sparse; dark-brown deposits present. Fibres 1048 µm (375–1600 µm) long, non-septate, thin- to thick-walled, 8 µm thick with few simple pits mainly confined to the radial walls. Parenchyma predominantly paratracheal, scanty to vasicentric, occasionally aliform, strand length of 2 to 4 cells. Rays, 7 per mm (range 4–10 per mm), mostly 1–2 cells wide, rarely 3, average 187 µm (range 70–360 µm) high, homocellular. Silica absent. Prismatic crystals present in chambered axial parenchyma cells.

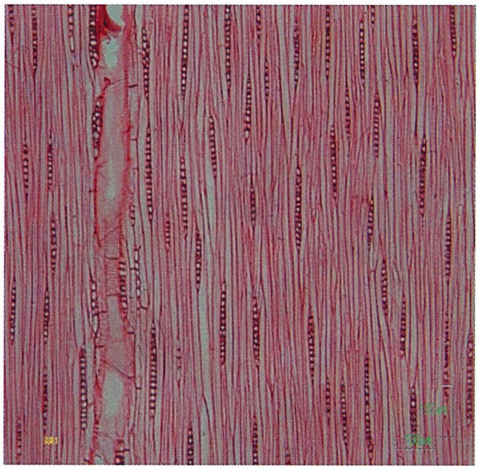
For trees 7 to 12 (16-y-old), the microscopic features of the trees are described below (Figure 20:a–d):

Growth rings rather indistinct, sometimes marked by layers of thick-walled fibres or reduced vessel sizes. Vessels diffuse, moderately few to moderately numerous, mainly oval, sometimes round, solitary and in radial multiples of 2–3 (-4), occasionally up to 8, clusters of vessels are common, average tangential diameter of 137 µm (range 60–250 µm), perforation simple; intervessel pits alternate, 6.5 µm diameter (range 5–10 µm); usually with coalescent apertures; vessel-ray pits and vessel-parenchyma pits similar and bordered;tyloses absent or sparse; dark-brown deposits present. Fibres 954 µm (550–1950 µm) long, non-septate, thin- to thick-walled, 9 µm thick with few simple pits mainly confined to the radial walls. Parenchyma predominantly paratracheal, scanty to vasicentric, occasionally aliform, strand length of 2 to 4 cells. Rays, 8 per mm (range 6–10 per mm), mostly 1–2 cells wide, rarely 3, average 207 µm (range 90–470 µm) high, homocellular. Silica absent. Prismatic crystals present in chambered axial parenchyma cells.



(a) Cross-section with diffuse pores (b) Cross-section with growth layers

Figure 19 Photomicrographs of the 20-y-old *Acacia mangium*



(c) Tangential section

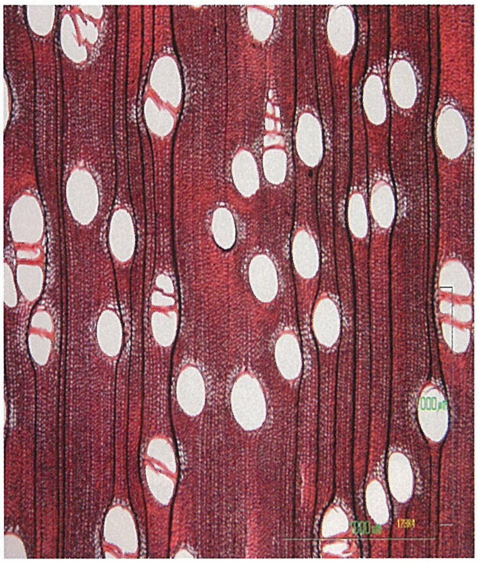
(d) Radial section

Figure 19 (continued)

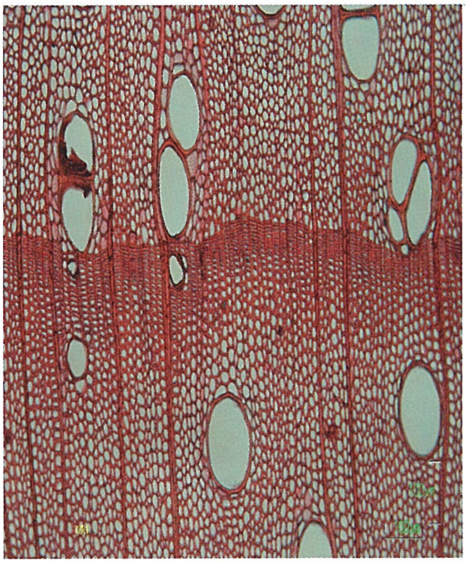
Details of the anatomical features of trees 1–6 (20-y-old) are shown in Table 4 below:

Table 4 Average values of some anatomical features of trees 1 to 6

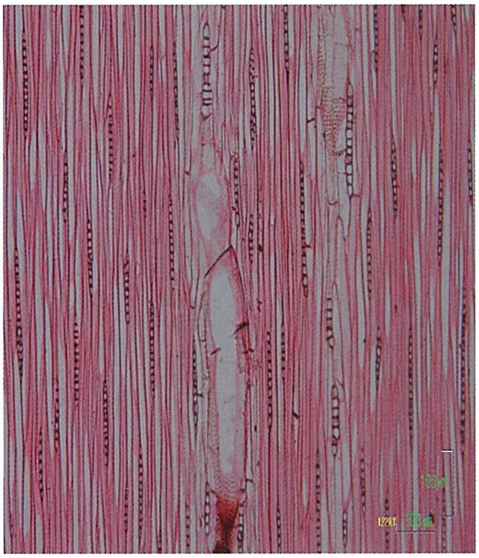
No.	Feature	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	Mean
1	Intervessel pit, μm	6 (5–8)	7 (5–10)	6 (5–8)	6 (5-8)	7 (5–10)	7 (5–10)	7 (5–10)
2	Vessel diameter, μm	173 (13–220)	177 (110–250)	164 (100–200)	182 (120–230)	144 (80–210)	170 (130–260)	168 (100–260)
3	Vessels, mm^{-2}	9 (5–14)	8 (5–12)	10 (6–13)	10 (7–12)	12 (9–15)	8 (5–10)	10 (5–15)
4	Ray height, μm	204 (70–510)	167 (110–300)	171 (110–300)	205 (120–360)	189 (120–270)	188 (100–340)	187 (70–360)
5	Rays, mm^{-1}	8 (5–10)	6 (4–9)	6 (4–9)	6 (–8)	7 (4–9)	7 (4–10)	7 (4–10)



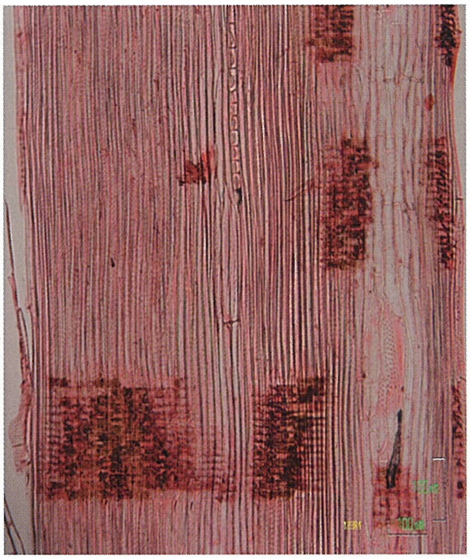
(a) Cross-section of tree 12—without growth layer



(b) Cross-section of tree 7—with growth layer



(c) Tangential section with mainly uniseriate rays



(d) Radial section showing crystals in chambered parenchyma cells

Figure 20 (a–d) Photomicrographs of the 16-y-old *Acacia mangium*

Details of the anatomical features of trees 7–12 (16-y-old) are shown in Table 5 below:

Table 5 Average values of some anatomical features of trees 7 to 12

No.	Feature	Tree 7	Tree 8	Tree 9	Tree 10	Tree 11	Tree 12	Mean
1	Intervessel pit, µm	6.0 (5.0–10.0)	6.0 (5.0–10.0)	6.0 (5.0–8.0)	6.0 (5.0–10.0)	7.0 (5.0–10.0)	8.0 (5.0–10.0)	6.5 (5.0–10.0)
2	Vessel diameter, µm	127 (80–170)	114 (60–140)	108 (80–150)	129 (100–160)	170 (140–250)	176.0 (150–220)	137.0 (60–250)
3	Vessels, mm^{-2}	8.0 (6.0–10.0)	9.0 (6.0–110.0)	9.0 (7.0–10.0)	8.0 (6.0–10.0)	8.0 (6.0–10.0)	8.0 (6.0–10.0)	8.0 (6.0–11.0)
4	Ray height, µm	237 (120–440)	143 (90–220)	200.0 (120–380)	270.0 (170–470)	192.0 (140–300)	202 (140–320)	207.0 (90.0–470.0)
5	Rays, mm^{-1}	8.0 (6.0–9.0)	8.0 (6.0–9.0)	7.0 (6.0–10.0)	8.0 (6.0–9.0)	8.0 (7.0–9.0)	7.0 (6.0–9.0)	8.0 (6.0–10.0)

CONCLUSION

For the plantation-grown timber, the amount of sapwood is expected to be high due to the fast rate of growth and harvesting of the tree at a younger age. However, the percentages of sapwood for the 16- and 20-y-old *Acacia mangium* trees were found to be low, only from 5.3 to 17.8% and from 11.2 to 25.5% respectively. The 16-y-old trees had lower basic density of 522 ± 116.9 kg m^{-3} as compared with the 20-y-old trees with an average of 623 ± 102.6 kg m^{-3}. In fibre length, the 20-y-old had an average length of 1048 µm whereas the 16-year-old tree had a shorter average length of 954 µm. Trees of both ages showed shorter fibre length near the pith than near the bark. Some variation in growth was seen in some trees that grew throughout the year whereas others seemed to grow in a periodic manner giving rise to growth layers.

ACKNOWLEDGEMENTS

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REFERENCES

ANI, S. & LIM, S. C. 1992. Wood Quality Study of 9-year-old *Acacia mangium* from Sabah. Report submitted to the Forest Department, Sabah.

ANI, S. & LIM, S. C. 1993. Variation in specific gravity of five-year-old *Acacia mangium* from the Batu Arang plantation, Selangor, Malaysia. *Journal of the Tropical Forest Science* 6(2): 203–206.

BHAT, K. M. 1995. A note on heartwood proportion and wood density of 8-year-old teak. *Indian Forester* 121(6): 514–517.

BRAZIER, J. D. 1971. Sapwood – what is it and can it be used? Reprinted from *Forestry Supplement of Timber Trade Journa*l. Department of Environment, England. 2 pp.

HO, K. S., HAMDAN, H., TAN, Y. E. & MOHD. SHUKARI, M. 1999. *Acacia mangium* for timber and a case study of utilisation. Paper presented at the 5th Conference on Forestry and Forest Products, 1999 series, Utilisation of Plantation Timber: Sentang: Potential Timber for the Future, 20 April 1999, FRIM Auditorium. 9 pp.

LIM, S. C. & GAN, K. S. 1998. Density variation of Malaysian-grown teak. *Journal of the Tropical Forest Products* 4(2): 141–145.

LIM, S. C. & GAN, K. S. 2000a. Density and sapwood variation of Malaysian-grown teak. Paper presented at the XXI IUFRO World Congress, 7–12 August 2000, Kuala Lumpur. 11 pp.

LIM, S. C. & GAN, K. S. 2000b. Some physical properties and anatomical features of 14-year-old *Acacia mangium*. *Journal of the Tropical Forest Products* 6(2): 206–213.

LOGAN, A. F. & BALODIS, V. 1982. Pulping and paper making characteristics of plantation-grown *Acacia mangium* from Sabah. *Malaysian Forester* 45: 217–236.

MOHD. HAMAMI, S., FARIDAH HANUM, I. & NOR AINI, A. S. 1993. Anatomy of *Acacia mangium* grown in Malaysia. *IAWA Journal* 14(3): 245–251.

PANSHIN, A. J. & DE ZEEUW, C. 1980. *Textbook of Wood Technology*. Fourth edition. Mcgraw-Hill, New York. 722 pp.

SCHARAI-RAD, M. & KAMBEY, E. 1989. The wood of *Acacia mangium* Willd. Its properties and possible uses. GFG-Report No. 14, Indonesia.

SELLIN, A. 1996. Sapwood amount in *Picea abies* (L.) Karst. determination by tree age and radial growth rate. *Holzforschung* 50:291–296.

TAN, Y. E., LIM, N. P. T., GAN, K. S., WONG, T. C. & LIM, S. C. (Eds) 2010. *Testing Methods for Plantation Grown Tropical Plantation Timbers*. FRIM, TRTTC and FRC. 155 pp.

TUKAU, A. S. & FUJII, T. 2000. Physical and anatomical characteristics of *Acacia mangium* Willd. planted in Sarawak, Malaysia. Paper presented at the XXI IUFRO World Congress, 7–12 August 2000, Kuala Lumpur, Malaysia. 12 pp.

WHEELER, E. A., BAAS, P. & GASSON, P. E. 1989. IAWA list of microscopic features for hardwood identification. *IAWA Bulletin* n.s.10(3): 219–332.

WONG, T. M., *revised by* LIM, S. C. & CHUNG, R. C. K. 2002. *A Dictionary of Malaysian Timbers*. Malayan Forest Records No. 30, Forest Research Institute Malaysia, Kepong. 201 pp.

MECHANICAL PROPERTIES

M. K. Mohamad Omar & A. W. Mohd. Jamil

INTRODUCTION

It is imperative to know the range of strength and elastic moduli for fast-grown species in order that the benefit of harvesting them earlier than normal-grown species is not offset by poor structural performance.The strength and elastic properties of *Acacia mangium* need to be known for the accurate design of its structural components, for buildings, bridges or furniture. A series of mechanical testings were conducted on two batches of *A. mangium* that were of ages 16 and 20 y, from Johore and Pahang respectively. The performance of the timber at both ages was examined with the intention to determine that younger age trees can be felled but still possess the adequate structural capabilities.

MATERIALS AND METHODS

The evaluation of the mechanical properties of 20-y-old *Acacia mangium* from Pahang and 16-y-old *A. mangium* from Johore in green and dry conditions was made as a means for comparison. Immediately after arrival from both plantation sites the logs were processed to avoid biological and weathering damage (Figure 1). Each log was cut to 2.5-m length. From the logs, sticks having dimensions of 30 by 30 mm were produced at the FRIM's sawmill (Figure 2). These sticks meant for the evaluation of mechanical properties in green condition were sent directly to the timber processing workshop to be cut into test dimensions based on BS 373 (Figure 3). For mechanical properties in dry condition the logs were cut into flitches having thickness of 30 mm. The flitches were decided instead of sticks to avoid twisting during the drying process.

For the 20-y-old batch the flitches for dry condition were brought to a roofed, open-air section of the Timber Engineering Lab and stacked for drying. Each layer of flitch was separated by at least two pieces of timber separator to allow more air flow. The drying process was monitored by weighing representative flitches every three weeks, and a constant weight would mean that the rate of water expulsion was stabilized. But the process took a long time, roughly about six months, for the weight to stabilize. Therefore, due to that experience we decided to expedite the drying for the second batch (16-y-old) by using a solar assisted kiln. In the drier, the layers of flitches were separated by at least two pieces of timber separator to allow for more air flow. Similar with the first batch air-drying process, the weights of a selected set of flitches were monitored every three weeks. Once the weights were stabilized the flitches were cut into test specimen dimensions (Figure 4), and the mechanical properties as for the green condition were determined.

The evaluation of the mechanical properties of the first batch (Batch 1, M1, Logs No. 10, 32, 57, 77,78 and 79) of the 20-y-old *A. mangium* from Pahang and of the second batch (Batch 2, Logs No. 12,13,39,69,72 and 88) of the 16-y-old *A. mangium* from Johore was done in green and dry conditions.

Figure 1 Acacia logs ready for breakdown at the sawmill

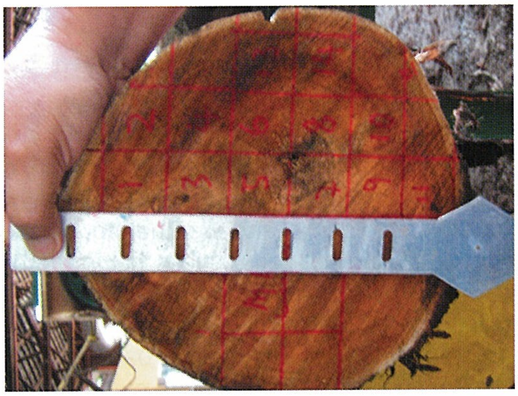

Figure 2 Log divided into sticks of 30×30 mm dimensions

Figure 3 Each stick cut into test specimen sizes according to BS 373

Figure 4 Band-saw used to cut each flitch into sticks

From the logs, sticks having dimensions of 30 by 30 mm were produced at the FRIM's sawmill. Those sticks meant for the evaluation of mechanical properties in green condition were sent directly to the timber processing workshop to be cut into test dimensions based on BS 373 (refer to Figure 5 for log to flitch and flitch to stick cutting configurations).

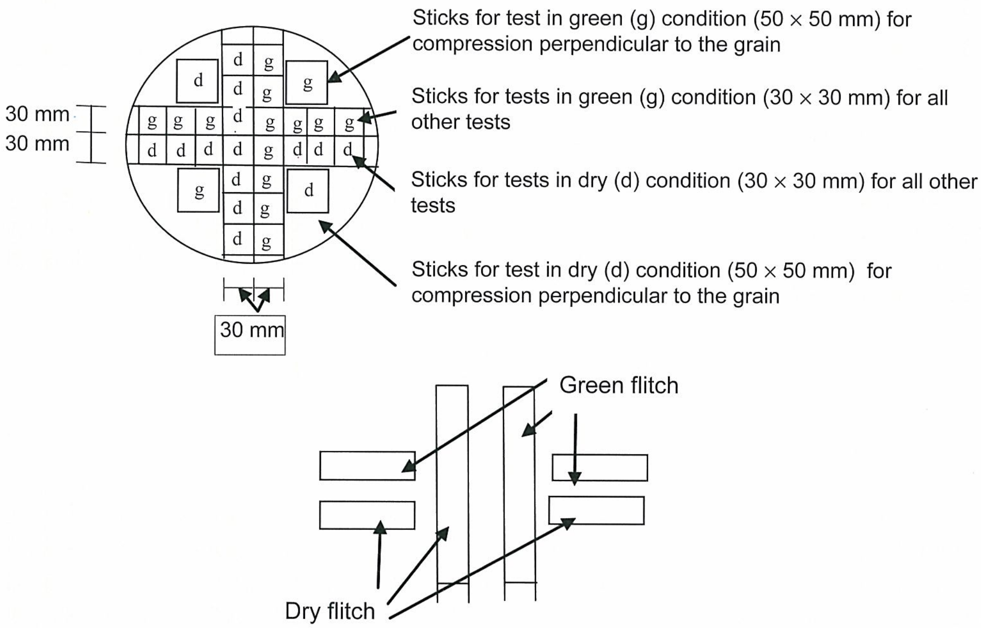

Figure 5 Log to flitch and flitch to stick cutting configurations

Once the weights were stabilized, the flitches were cut into test specimen dimensions, and mechanical properties similar to green condition were determined.

Mechanical tests based on BS 373 for the first batch (from Pahang) were performed on the green specimens in the last week of May 2008 and ended after a duration of about three weeks. Mechanical tests for the dry condition were performed on the dry specimens in December 2008 and ended in January 2009.

For the second batch (from Johore), mechanical tests were conducted on the green specimens in February 2009 and ended after a duration of about two weeks. The dry specimens were tested at the end of June 2009 after being dried in the solar-assisted kiln since February.

The tests performed were as follows (Table 1):

Table 1 Tests performed

		Number of specimens			
		20-y-old batch (Pahang)		16-y-old batch (Johore)	
	Type of test	Green	Dry	Green	Dry
1.	Static bending	53	43	38	38
2.	Compression parallel to the grain	53	43	38	41
3.	Compression perpendicular to the grain	100	66	24	28
4.	Shear parallel to the grain (radial & tangential)	106	86	74	82
5.	Hardness	53	43	76	38
6.	Tension parallel to the grain	52	38	31	26

Problems faced during drying of *Acacia mangium*

It was observed that drying of specimens either by the air-dry method or the solar assisted kiln was very time consuming. Furthermore, even though the outer layer of the flitches were dry, the core material was still wet. This led to the high standard deviation in the moisture content of the dry specimens.

SPECIFIC TESTS AND RESULTS

Static-bending test

The static-bending test was carried out using the three-point bending method (Figures 6 and 7) whereby each test specimen for both green and dry conditions was cut to the dimensions 20 × 20 × 300 mm. The distance between the points of support of the test piece was 280 mm, and the load was applied at the middle of the test span. A constant loading speed of 6.0 mm min^{-1} was applied throughout the test. The test specimen was supported at the ends such that it would be quite free to follow the bending action and would not be restrained by friction which would resist the bending and tend to introduce longitudinal stresses. The deflection of the beam at mid-length was measured with reference to the outer points of loading (Figure 6).

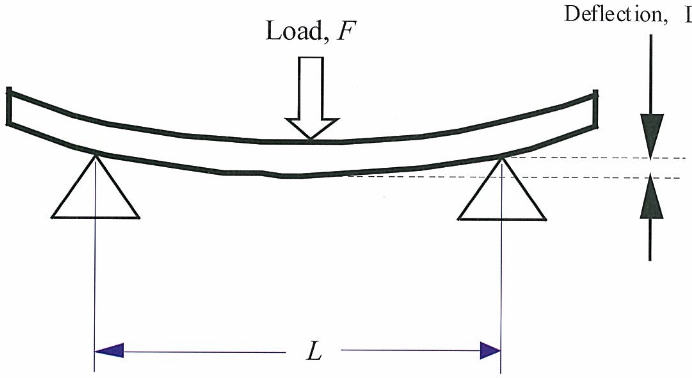

Figure 6 Static-bending test by three-point bending method

The modulus of rupture (MOR) and modulus of elasticity (MOE) in megapascal (1MPa = 1 N/mm^2) were calculated using the following formulae respectively:

$$\text{MOR} = \frac{3}{2}\frac{FL}{WT^2} \quad \text{.... Eqn. 1}$$

where, L : span, in mm
F : maximum load, in N
W : width, in mm
T : depth, in mm

$$\text{MOE} = \frac{L^3}{4WT^3}\frac{\Delta F}{\Delta I} \quad \text{.... Eqn. 2}$$

where, L : span, in mm
$\frac{\Delta F}{\Delta I}$: slope of graph, in N/mm
W : width, in mm
T : depth, in mm

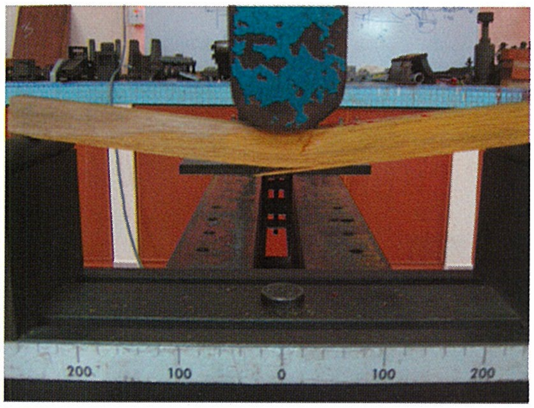

Figure 7 Set-up for the static-bending test

Green condition

For the 20-y-old batch (from Pahang) in green condition, the highest average modulus of elasticity (MOE) and modulus of rupture (MOR) from the static-bending test were 11 432 and 109.5 MPa respectively for Log No. 10 specimens. The lowest moduli were for Log No. 57, where the average modulus of elasticity and modulus of rupture were 10 194 and 93.5 MPa respectively. The average value of MOE in the green condition was 10 838 MPa (SD=1814 MPa) while it was 10 764 MPa (SD=2226 MPa) in the dry condition (Figure 8). This phenomenon was quite strange where the green values were higher than the dry values, but probably this was due to the high standard deviation for the dry specimens. The average value of MOR in the green condition for the 20-y-old batch was 102.5 MPa.

For the 16-y-old batch (from Johore) in green condition, the highest average modulus of elasticity (MOE) and modulus of rupture (MOR) from the static-bending test were 10 421 and 86.4 MPa respectively. The lowest moduli were for Log No. 88, where the average modulus of elasticity and modulus of rupture were 7736 and 68.8 MPa respectively. The overall average values for all of the 16-y-old logs in green condition were 9307 MPa for the MOE and 79.5 MPa for the MOR (Figures 8 and 9).

Dry condition

For the first batch (from Pahang) in dry condition, the highest average modulus of elasticity (MOE) and modulus of rupture (MOR) from the static-bending test were 11 881 and 117.6 MPa respectively for Log No. 57 specimens. The lowest moduli were for Log No. 32, where the average modulus of elasticity and modulus of rupture were 10 263 and 99.3 MPa respectively. The overall average MOE and MOR were 10 764 MPa and 111.1 MPa respectively (Figures 8 and 9).

For the second batch (from Johore) in dry condition, the highest average modulus of elasticity (MOE) and modulus of rupture (MOR) from the static-bending test were 11 847 and 108.4 MPa respectively from Log No. 12. The lowest moduli were for Log No. 72, where the average modulus of elasticity and modulus of rupture were 9500 and 80.1 MPa respectively. The average dry MOE and MOR values for this batch were 10 347 MPa and 96.6 MPa respectively (Figures 8 and 9).

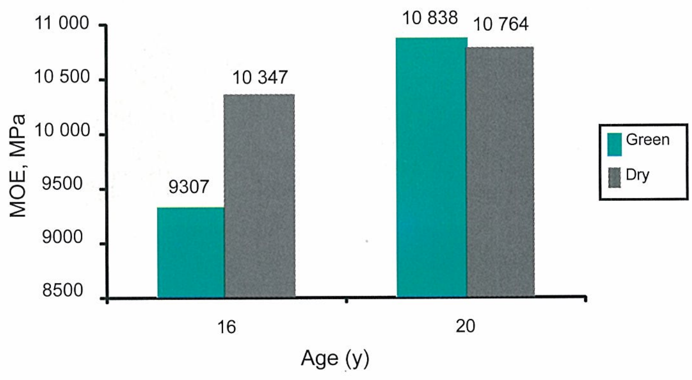

Figure 8 Average modulus of elasticity values of the 16-y-old and 20-y-old batches

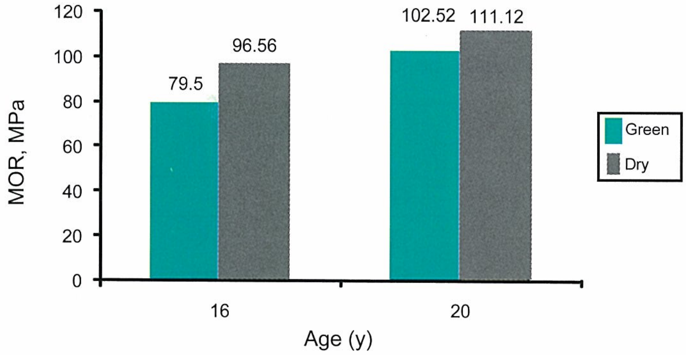

Figure 9 Average modulus of rupture values of the 16-y-old and 20-y-old batches

Table 2 Average modulus of elasticity and modulus of rupture values

	Acacia mangium (Johore) 16-y-old	*Acacia mangium* (Pahang) 20-y-old	*Acacia auriculiformis* (Selangor)
Avg. MOE, green (MPa)	9307 (2149)	10 838 (1814)	13 900
Avg. MOE, dry (MPa)	10 347 (1670)	10 764 (2226)	13 500
Avg. MOR, green (MPa)	79.5 (15.2)	102.5 (15.2)	89
Avg. MOR, dry (MPa)	96.6 (19.6)	111.1 (14.6)	103

As a comparison, the MOE and MOR of green *A. auriculiformis* from Sungai Buloh as published in Trade Leaflet 34: *The Strength Properties of Some Malaysian Timbers* are 13 900 and 89 MPa respectively (Table 2). This shows that the MOE of *A. auriculiformis* is higher than that *A. mangium* but it is otherwise for the MOR of the 20-y-old trees. However, the difference is not very large.

The results are summarized in Tables 3a and 3b below.

Table 3a Static bending (20-y-old batch, Pahang)

Log No.	Avg. modulus of elasticity, MPa		Avg. modulus of rupture, MPa	
	Green	Dry	Green	Dry
10	11 432	10 795	109.5	111.1
32	10 281	10 263	96.8	99.3
57	10 194	11 881	93.5	117.6
77	11 058	10 673	108	110.5
78	10 736	10 387	103	109.5
79	10 775	10 903	98.1	107.7
Overall average Note: Number in brackets is the standard deviation	10 838 (1814)	10 764 (2226)	102.5 (15.2)	111 (14.6)

Table 3b Static bending (16-y-old, Johore)

Log No.	Avg. modulus of elasticity, MPa		Avg. modulus of rupture, MPa	
	Green	Dry	Green	Dry
12	10 393	11 847	86.4	108.4
13	8990	9815	76.0	97.0
39	10 421	10 337	86.3	102.1
69	9324	10 525	81.1	98.8
72	8612	9500	76.1	80.1
88	7736	9646	68.8	92.6
Overall average Note: Number in brackets is the standard deviation	9307 (2149)	10 347 (1670)	79.5 (15.2)	96.6 (19.6)

The MOE and MOR of dry *A. auriculiformis* are 13 500 MPa and 103 MPa respectively. It shows that in the dry condition the MOE of *A. auriculiformis* is higher than that of *A. mangium* from Pahang and Johore in both green and dry condition but there is no significant difference between the values of MOR. Furthermore, it should be noted that even though it is common for most timber species to be having higher moduli values in dry as compared to green condition, this is not the case with *Acacia*. As shown above, the MOE of *A. auriculiformis* in green condition is higher than the MOE in dry condition. It can also be seen from Tables 3a and 3b that there are situations in which the green values are more than the dry values. For example, for logs No. 32 and 78 from Pahang and log No. 39 from Johore, the MOE values in the green condition are higher than in the dry condition.This phenomenon is quite interesting and might show that the viscoelastic properties of *Acacia* are unique.

Compression parallel to the grain

The test was carried out by imposing a vertical load onto the cross-sectional face of the specimen and parallel to the grain (Figures 10 and 12). The dimensions of the test specimen were 20 × 20 × 60 mm. The ends of the rectangular test specimen were smooth and normal to the axis of force to ensure the accuracy of results. The top compression platen was kept parallel to the bottom platen throughout the test. A constant loading speed of 0.6 mm min^{-1} was applied during the test.

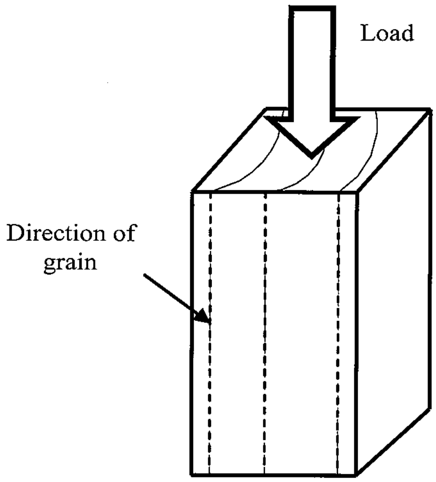

Figure 10 Compression-parallel-to-the grain test

The compressive stress at maximum load in megapascal was calculated using the formula as follows:

Compressive stress at maximum load = $\frac{F}{A}$ ... Eqn. 3

where,

F : maximum load, N
A : cross-sectional area, mm^2

The values of compression parallel to the grain are given in the following Tables 4a and 4b, and illustrated in Figure 11.

Table 4a Compression parallel to the grain (20-y-old batch, Pahang)

Log No.	Avg. maximum compressive stress, MPa	
	Green	Dry
10	44.1	45.8
32	41.8	49.5
57	40.1	58.5
77	45.2	55.5
78	47.3	50.2
79	42.1	57.7
Overall average Note: Number in brackets is the standard deviation	43.4 (8.0)	52.9 (7.9)

Table 4b Compression parallel to the grain (16-y-old batch, Johore)

Log No.	Avg. maximum compressive stress, MPa	
	Green	Dry
12	37.8	51.3
13	33.4	45.0
39	38.5	47.8
69	41.1	45.1
72	35.0	39.9
88	29.2	46.3
Overall average Note: Number in brackets is the standard deviation	35.9 (8.3)	46.0 (7.4)

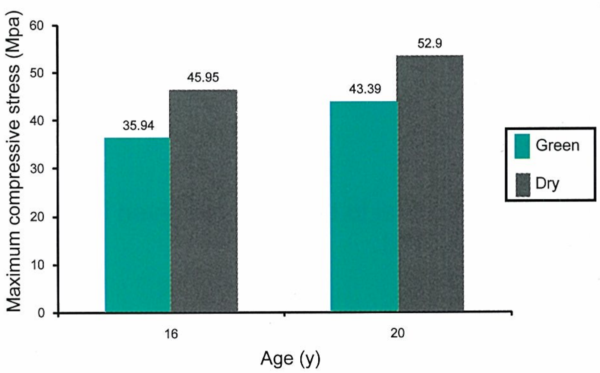

Figure 11 Average values of compressive stress parallel to the grain

In general, the values of average maximum compressive stress of *A. mangium* from both locations, Pahang and Johore, were higher for the dry than the green conditions. But the green and dry values were higher for the logs from Pahang than from Johore. The highest average maximum compressive stress for the green condition was 47.3 MPa for log No. 78 from Pahang, while the highest average maximum compressive stress for the dry condition was 58.5 MPa for log No. 57 also from Pahang.

Figure 12 Compression-parallel-to-the-grain test

Compression perpendicular to the grain

The specimen size for this test was 50 × 50 × 50 mm as shown in Figure 13. The test was made by loading the specimen between parallel compression platens, and the load was perpendicular to the loading face as well as the grain. A constant loading speed of 0.6 mm min^{-1} was applied during the test. The load compression curve was plotted to the point when the deformation of the test piece reached 2.54 mm. The load at 2.54-mm deformation was recorded.

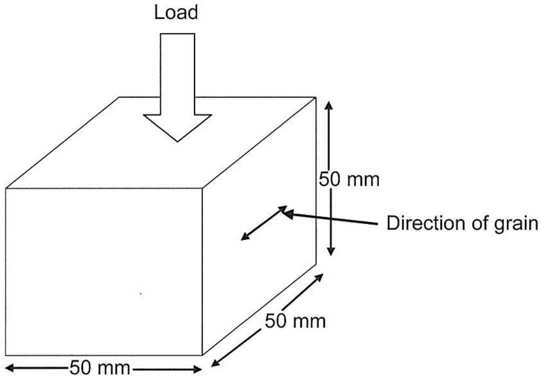

Figure 13 Compression-perpendicular-to-the-grain test

The results of compression perpendicular to the grain are presented in the following Tables 5a and 5b and illustrated in Figure 14.

Table 5a Compression perpendicular to the grain (20-y-old batch, Pahang)

Log No.	Green	Dry
	Avg. compressive stress @ 2.54-mm deformation, MPa	Avg. compressive stress @ 2.54-mm deformation, MPa
10	8.1	9.6
32	5.2	8.5
57	6.0	7.8
77	8.4	9.2
78	6.0	10.4
79	9.4	8.6
Overall average	7.2 (1.7)	8.9 (1.0)

Table 5b Compression perpendicular to the grain (16-y-old batch, Johore)

Log No.	Green	Dry
	Avg. compressive stress @ 2.54-mm deformation, Mpa	Avg. compressive stress @ 2.54-mm deformation, Mpa
12	5.0	5.3
13	5.2	5.8
39	6.6	8.0
69	5.6	6.5
72	5.7	7.3
88	3.8	4.5
Overall average	5.4 (0.8)	6.4 (1.3)

Generally the values of average compressive stress at 2.54-mm deformation for the dry condition were higher than for the green condition, except for log No. 79 from Pahang where the value at green condition was 9.4 MPa as compared with 8.6 MPa for the dry condition. The maximum value in green condition for this test was 9.4 MPa for log No. 79 from Pahang, while the maximum value for the dry condition was 10.4 MPa for log No.78 also from Pahang.

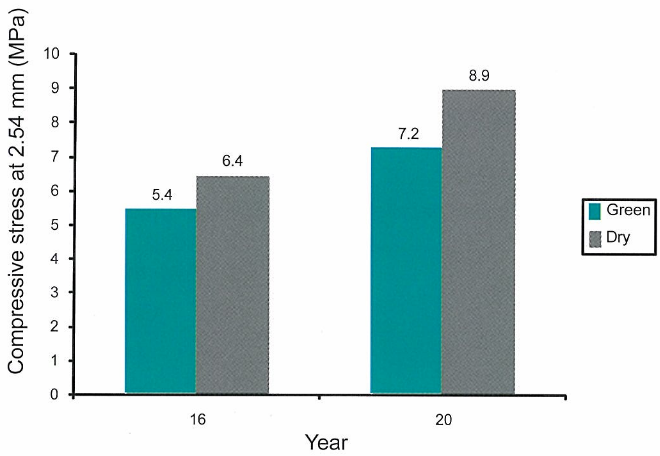

Figure 14 Average values of compression perpendicular to the grain

Shear parallel to the grain

The test was performed by introducing a shear failure along a plane parallel to the tangential direction of the grain of each specimen and also with the plane of shear failure parallel to the radial direction on another matching specimen (Figure 15). The results of shear stress on both radial and tangential specimens were averaged to represent a shear stress value of one specimen. A constant loading speed of 0.6 mm min^{-1} was applied during the test. Each test specimen was a cube of 20-mm sides.

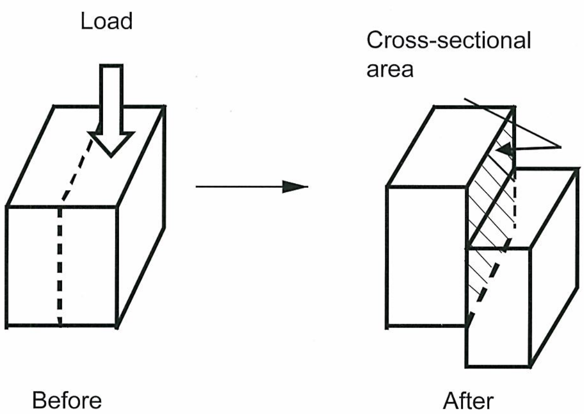

Figure 15 Shear-parallel-to-the-grain test

Shear stress at maximum load in megapascal was calculated using the formula as follows:

Shear stress at maximum load = $\frac{F}{A}$ ... Eqn. 4

where,

F: maximum load, N
A: cross-sectional area, mm^2

The results of shear parallel to grain are given in the following Tables 6a and 6b and illustrated in Figure 16.

Table 6a Shear parallel to grain (20-y-old batch, Pahang)

Log No.	Avg. maximum shear stress, MPa	
	Green	Dry
10	11.4	15.9
32	11.2	15.5
57	10.0	15.9
77	11.8	16.9
78	13.1	16.1
79	10.9	16.3
Overall average	11.3	16.0
Note: Number in brackets is the standard deviation	(1.9)	(1.6)

Table 6b Shear parallel to grain (16-y-old batch, Johore)

Log No.	Avg. maximum shear stress, MPa	
	Green	Dry
12	8.5	13.4
13	7.9	12.7
39	8.9	13.0
69	9.2	11.9
72	7.4	10.5
88	7.1	11.9
Overall average	8.2	12.2
Note: Number in brackets is the standard deviation	(1.9)	(2.1)

The average maximum shear stress values of dry condition were generally higher than those of green condition, and this was true for both the Pahang and Johore specimens. The maximum average shear stress in green condition was 13.1 MPa for log No.78 from Pahang and the maximum average shear stress in dry condition was 16.9 MPa for log No. 77 also from Pahang.

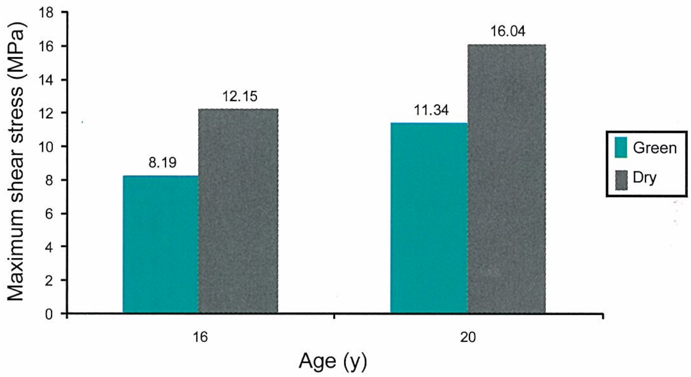

Figure 16 Average values shear stress parallel to the grain

Hardness

The test was carried out such that the loading head with a hemispherical end of a steel bar, 11.28 mm in diameter, was forced onto the test specimen (Figure 17). A constant loading speed of 3 to 6 mm min^{-1} was used during the test. The load was applied on the radial and tangential surfaces of the test specimen to a depth of 5.64 mm. The radial and tangential surfaces were chosen to closely represent the true radial and tangential directions of the grain. The load corresponding to the penetration depth of 5.64 mm was then noted for each specimen, and the load values for the radial and tangential penetrations were averaged.

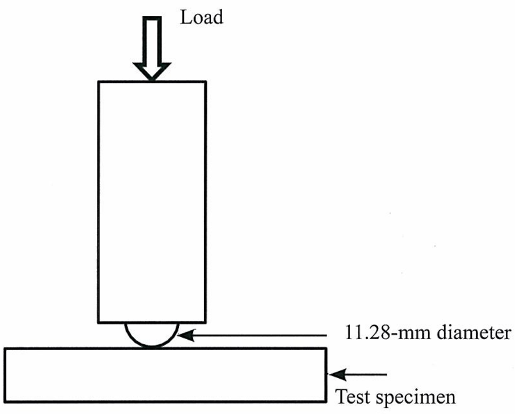

Figure 17 Hardness test

Tables 7a and 7b give the hardness test results which are illustrated in Figure 18.

Table 7a Hardness (20-y-old batch, Pahang)

Log No.	Load @ 5.64-mm identation, kN	
	Green	Dry
10	3.6	2.0
32	3.3	2.2
57	3.1	2.1
77	3.5	2.1
78	3.7	2.0
79	3.0	2.1
Overall average	3.4	2.1
Note: Number in brackets is the standard deviation	(0.5)	(0.4)

Table 7b Hardness (16-y-old batch, Johore)

Log No.	Load @ 5.64-mm identation, kN	
	Green	Dry
12	3.1	3.4
13	3.1	3.4
39	2.9	3.1
69	2.8	2.9
72	2.7	2.8
88	3.1	3.1
Overall average	3.1	3.0
Note: Number in brackets is the standard deviation	(0.7)	(0.7)

The load values to depict the hardness of specimens in green condition were generally higher than in dry condition. The maximum load value in green condition was 3.7 kN while the maximum load value in the dry condition was 4.0 kN, both values for log No. 78 from Pahang.

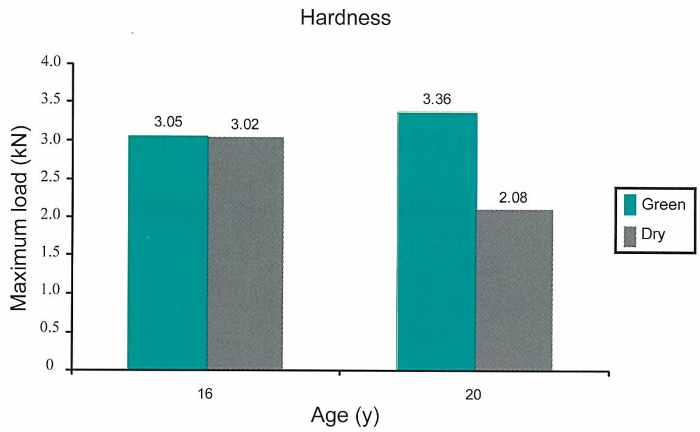

Figure 18 Average values of hardness strength

Tension parallel to the grain

The form and dimensions of the test piece for determining the tension parallel to the grain strength are illustrated in Figure 19.

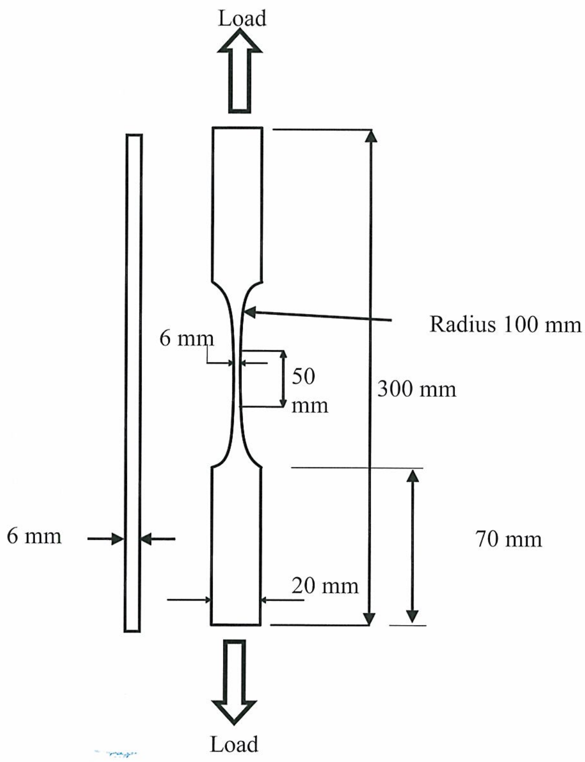

Figure 19 Tension-parallel-to-the-grain test

The actual dimensions at the minimum cross-section were measured. Tension force parallel to grain was applied such that the failure in tension happened at the minimum cross-section. The test piece was held on both ends by toothed and self-aligning grips. The load was applied to the test piece at a constant head speed such that the specimen would break in 1.5 to 2 min from the start of loading.

Tensile stress at maximum load in megapascal was calculated using the formula as follows:

Tensile stress at maximum load = $\frac{F}{A}$ ... Eqn. 5

where,

F : maximum load, N
A : cross-sectional area, mm^2

The tension-test results are presented in Tables 8a and 8b and illustrated in Figure 20.

Table 8a Tension parallel to grain (20-y-old batch, Pahang)

Log No.	Avg. maximum tensile stress, MPa	
	Green	Dry
10	83.0	138.2
32	68.2	125.3
57	76.4	127.4
77	76.7	140.9
78	71.5	136.5
79	91.8	128.2
Overall average	79.5	133.2
Note: Number in brackets is the standard deviation	(23.7)	(33.9)

Table 8b Tension parallel to grain (16-y-old batch, Johore)

Log No.	Avg. maximum tensile stress, MPa	
	Green	Dry
12	110.5	125.1
13	82.4	122.8
39	95.0	153.7
69	105.3	88.1
72	112.6	133.2
88	73.8	75.2
Overall average	95.1	113.3
Note: Number in brackets is the standard deviation	(33.6)	(40.5)

Generally, the dry specimens in tension showed higher stress values as compared with the green specimens except for log No. 69 from Johore. The green average maximum tensile stress of log No. 69 seemed to be higher than the dry values. This could be attributed to existence of defects in the dry specimens which had caused the average maximum value to be low. The highest average maximum tensile in green condition was 112.6 MPa for log No. 72 from Johore while the highest average maximum tensile in dry condition was 153.7 MPa for log No. 39 also from Johore.

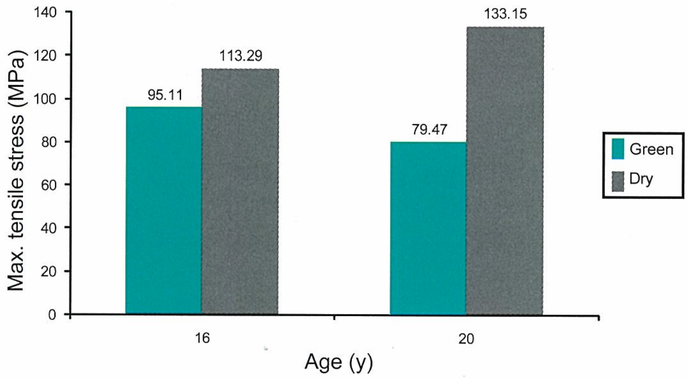

Figure 20 Average values of tensile stress parallel to the grain

Density and specific gravity

The specific gravity values of the 20-y-old specimens were slightly higher than those the 16-y-old specimens. For the dry condition the specific gravity values were 0.51 and 0.58 for the 16- and 20-y-old specimens respectively. For the green condition, the specific gravity values were 0.50 and 0.56 for the 16- and 20-y-old specimens respectively. The specific gravity of the tested *A. mangium* in dry condition is slightly lower than that (0.63) of of *A. auriculiformis*.

The density and specific gravity results are given in the following Tables 9a and 9b, and illustrated in Figures 21 and 22. Figure 23 shows some samples being dried in the oven.

Table 9a Density and specific gravity (20-y-old batch, Pahang)

Log No.	Avg. density at test, kg m^{-3}		Avg. S.G	
	Green	Dry	Green	Dry
10	1087	674	0.57	0.57
32	1045	658	0.55	0.57
57	1085	690	0.54	0.6
77	1088	667	0.57	0.58
78	1101	659	0.59	0.57
79	1089	664	0.55	0.58
Overall average Note: Number in brackets is the standard deviation	1083 (73)	673 (51)	0.56 (0.06)	0.58 (0.05)

Table 9b Density and specific gravity (16-y-old batch, Johore)

Log No.	Avg. density at test, kg m^{-3}		Avg. S.G	
	Green	Dry	Green	Dry
12	1110	583	0.51	0.50
13	1038	595	0.51	0.52
39	1061	620	0.53	0.53
69	1092	598	0.51	0.51
72	1029	627	0.47	0.49
88	1053	605	0.45	0.52
Overall average Note: Number in brackets is the standard deviation	1065 (70)	608 (116)	0.50 (0.07)	0.51 (0.09)

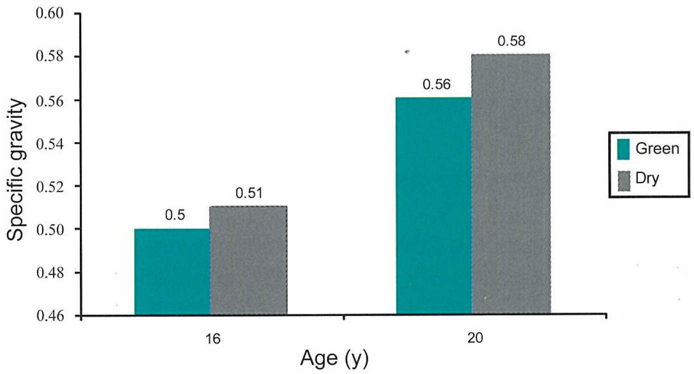

Figure 21 Average specific gravity values

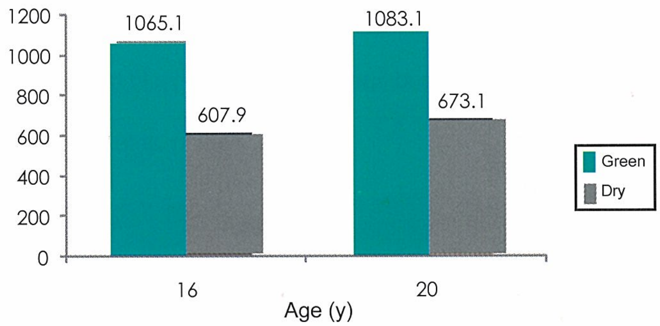

Figure 22 Average density values

Figure 23 Determination of SG and density by the oven-dry method

Moisture content

The moisture content as well as the density and specific gravity of the test specimens were determined by the oven-dry method. The dimensions were similar to those for the compression-parallel-to-the-grain test. The initial mass values of the specimens were taken before the latter were oven-dried for a period of about three to four days. The final mass values of the specimens were taken when they were found to have stabilized such that no further decrement of mass was noted. The average moisture content values of the green specimens were near to 100% for the 20-y-old batch while those of the green 16-y-old batch were more than 100%. The targeted moisture content value for dry condition was below 19%. Tables 10a and 10b show the moisture contents of the 20- and 16-y-old samples respectively.

Table 10a Moisture content (20-y-old batch, Pahang)

Log No.	Avg. moisture content %	
	Green	Dry
10	91.5	17.9
32	90.0	15.6
57	102.6	15.2
77	91.3	14.5
78	93.1	15.2
79	100.0	14.8
Overall average	94.5 (18.3)	15.8 (2.3)

Table 10b Moisture content (16-y-old batch, Johore)

Log No.	Avg. moisture content %	
	Green	Dry
12	121.5	21.3
13	103.0	14.1
39	102.0	15.9
69	114.9	17.9
72	120.9	31.1
88	139.3	15.2
Overall average	116.7 (22.9)	19.9 (10.7)

Overall results

The specific gravity of the tested *A. mangium* is slightly lower as compared with the specific gravity of 0.63 for *A. auriculiformis*. The values of compression parallel to grain and shear parallel to grain are comparable for both species. But the values of compression perpendicular to grain and hardness are higher for *A. auriculiformis*. Trade Leaflet No. 34 does not have the tension value for *A. auriculiformis;* therefore no comparison has been made. The values of compression parallel to the grain are lower than those of *A. auriculiformis* while the values of shear parallel to grain are higher. The Janka hardness value of *A. mangium* is only about one third that of *A. auriculiformis*. The overall results for the tests performed on *A. mangium* are as shown in Table 11.

Table 11 Overall test results for the 16- and 20-y-old *Acacia mangium*

Age group	Cond.	MC	Density	Specific gravity	Static bending		Comp par. to grain	Comp. perp. to grain	Shear par. to grain	Hard-ness	Tension par. to grain
					MOR	MOE		Stress@ 2.54-mm deform.			
		(%)	(kg m^{-3})		(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(kN)	(MPa)
16-y-old	G	116.7 (22.9)	1065 (70)	0.50 (0.07)	79.5 (15.2)	9307 (2149)	35.9 (8.3)	5.4 (0.8)	8.2 (1.9)	3.1 (0.7)	95.1 (33.6)
	D	19.9 (10.7)	608 (116)	0.51 (0.09)	96.6 (19.6)	10 347 (1670)	46.0 (7.4)	6.4 (1.3)	12.2 (2.1)	3.0 (0.7)	113.3 (40.5)
20-y-old	G	94.5 (18.3)	1083 (73)	0.56 (0.06)	102.5 (15.2)	10 838 (1814)	43.4 (8.0)	7.2 (1.7)	11.3 (1.9)	3.4 (0.5)	79.5 (23.7)
	D	15.8 (2.3)	673 (51)	0.58 (0.05)	111.1 (14.6)	10 764 (2226)	52.9 (7.9)	8.9 (1.0)	16.0 (1.6)	2.1 (0.4)	133.2 (33.9)

Note: Cond.=condition, G=Green, D=dry

CONCLUSION

In general, there was no significant difference in the values of MOE and MOR in the dry condition between the 20-y-old and 16-y-old trees. But there was some difference in the MOE and MOR in the green condition where the 20-y-old batch had higher values than the 16-y-old batch. For comparison, the MOE of *A. auriculiformis,* as taken from Trade Leaflet No. 34, is higher than that of *A. mangium,* but it is otherwise for the MOR of the 20-y-old trees. However, the difference is not very large. Normally, a dry timber would show higher strength or elasticity than a green timber, but this is not the case with *A. mangium*. This can be seen in the hardness strength values where the green values are higher than the dry values for both the 16- and 20-y-old batches. The MOE and MOR in the green condition are also higher than in the dry condition for the case of the 20-y-old trees. This phenomenon also happens to many other species as reported in the literature and is not unique to *A. mangium* only. This is due to the linocellulosic attributes of such species in which the existence of moisture may have caused the increments of the above said properties.

SAWING AND MACHINING PROPERTIES

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INTRODUCTION

Assessment of sawing properties, although not a new exercise, could be found in the literature and references, mainly from North America, Europe and Australasia, while limited publications on sawing in the tropics are also published by some ASEAN countries, for instance. On the other hand, evaluations of machining properties have been around for ages and chief among those referred to is the relevant ASTM standard. As plantation forestry is gaining more attention as an alternative source of raw materials for the wood-based industries in many nations nowadays, sawing efficiency and machining properties have become essential, especially when dealing with plantation logs which are relatively smaller in diameter but higher in material variability due to their juvenile nature. The adoption of a suitable harmonized set of testing methodology on sawing and machining such as those proposed by Tan et al. (2010a) is timely as it enables data derived to be comparable on a more scientific basis. Management decision may then be adjusted accordingly if the results obtained are less favourable.

This report summarizes the results obtained on sawing and machining studies conducted on two age groups of *Acacia mangium* obtained from Peninsular Malaysia using the standardized set of sawing and machining methodologies stated above.

MATERIALS AND METHODS

Acacia mangium trees

Trees, 20 and 16 y old, were collected from plantation sites located in Kemasul, Pahang, and Ulu Sedili, Johore, respectively, using the sampling procedure proposed in the project manual by Tan et al. (2010a). The trees represent the age group population selected from the site and are made up of an entire range of diameters available. They were marked before they were felled such that relevant information including tree/ ID number, total tree height, height at first branch, diameter at breast height (DBH) and tree condition was recorded and made referenced to when necessary. As proposed in the "Sampling of sample trees and allocation of logs for determination of basic properties of wood from tropical forest plantation" (Tan et al. 2010b), only specific logs allocated for sawing and machining were used in the studies. The logs were processed within one month after harvesting.

Sample preparation

After debarking, logs for sawing yield test were cut to 3.0-m length while for the sawing properties test, 2.0-m length as per the bucking pattern described in Tan et al. (2010b) was used. Five (5) flitches, each of 50.0, 75.0 and 100.0 mm thick, were sawn from green logs for the latter test. They were then kept in water or wrapped in plastic sheets to prevent undesirable drying. For the machining study, fifty (50) specimens for each of the six tests as per detail in the project manual were also prepared.

Equipment used

For the sawing yield and sawing properties tests, a band-saw with a log carriage was essential. The special equipment used for power measurement was HIOKI clamp-on power Hitester and tachometer, while stylus-type roughness meter was used for surface-roughness measurement. Other more basic items employed were measuring tape, micrometer, stopwatch, digital callipers, electronic balance and oven. In addition, permanent marker pen and data logger were also employed for marking and data-acquisition purposes.

Testing methodology

The sawing yield test, sawing properties test as well as wood machining study were conducted as stipulated in Chapter 4 of the project manual (Tan et al. 2010c). It should be pointed out that in view of possible lack of testing facilities or equipment in some centres at which the manual is targeted, apart from specifying some tests as optional as proposed in the relevant methodology, the following measures may be applied:

a) In the absence of log carriage, an equivalent device may be improvised such that the log or cant could be securely mounted and pushed through the band-saw.
b) The use of power meter in the power measurement may be optional or some simple measurements on the power, voltage or current readings could be captured.
c) The surface roughness, instead of using a stylus-type roughness meter, may also be measured using a chalk mark after which the number of cutter marks per unit length is counted.
d) If constant feed speed of the saw carriage could not be maintained due to lack of proper speed controlling device, the sawyer may try to keep within a range of a few specific carriage speeds

RESULTS AND DISCUSSION

The results of the sawing and machining studies are presented as follows:

Sawing properties

Recovery rates (volumetric yields)

As expected, the older and larger trees showed better recovery rates as depicted in Figure 1 above. These figures are much lower when compared with those of "baby-small" keruing at 53.1% (Wong 1998) and *Shorea macrophylla* (Teng et al. 2009), which averaged 58.7% (13 y old) and 60.3% (22 y old) respectively. This is mainly attributed to the fluted shapes and deterioration (from prolonged storage) of the *A. mangium* logs used in this study (Figures 2 and 3). The relatively low recoveries can also be explained by the occurrence of end-splitting of slabs during sawing as well as the sampling procedure adopted which specified logs to represent the whole range of diameters from the plot of interest for each study. On the other hand, the mean recovery rates of *A. mangium* were superior to that (32%) reported by Gan et al. in 1985 for rubberwood (*Hevea brasiliensis*).

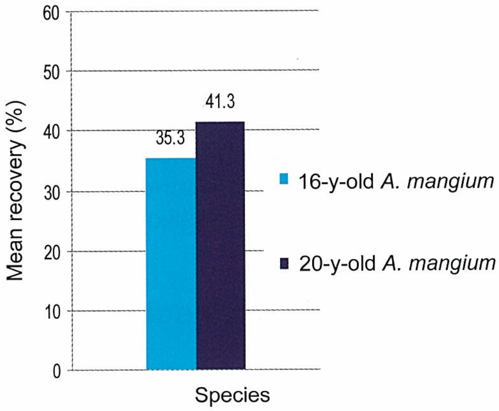


Figure 1 Mean recovery values of *Acacia mangium*

Figure 2 Fluted shapes of logs

Figure 3 Log deterioration

Timber grades (value yields)

The sawn-timber grades obtained for *A. mangium* in this study were better than expected given the occurrence of end-splits and log deterioration. The older logs consistently yielded more of the better grades of sawn timber, namely Select, Standard and Serviceable. For both age groups, more than 70% of the sawn timber were graded "Serviceable" or better as shown in Figure 4 below. This compares favourably with results obtained for baby-small keruing (28.6%) by Wong (1998) and for *S. macrophylla* (~60%) by Teng et al. (2009)

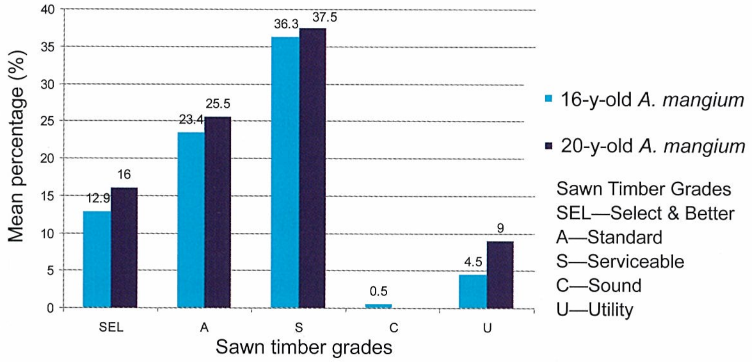


Figure 4 *Acacia mangium* timber grades based on Malaysian Grading Rules (MGR)

Sawing power

The sawing power consumption results of *A. mangium* indicated that with increase in feed speed, there was increase in net maximum power consumption but decrease in net integrated power consumption (Figures 5 and 6). Both power consumptions increased with specimen height. These results are considered normal. In comparison with *S. macrophylla*, power consumptions were generally higher due to the higher density of *A. mangium.* There was no significant difference in power consumption when cutting the outer, middle and inner parts of the logs.

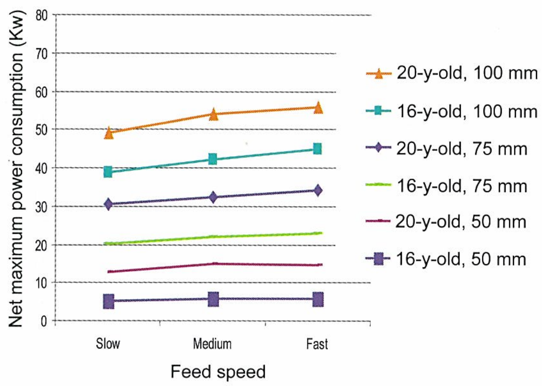


Figure 5 Net maximum power consumptions relative to feed speed of *Acacia mangium*

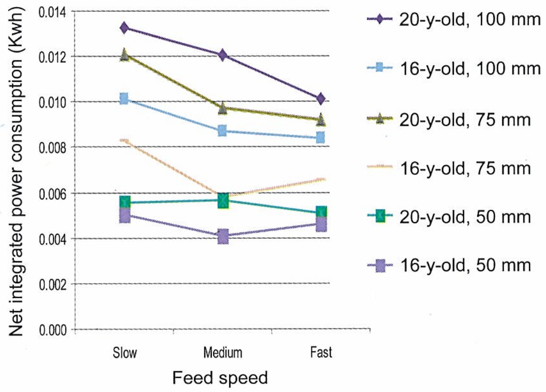


Figure 6 Net integrated power consumptions relative to feed speed of *Acacia mangium*

Surface quality

An unexpected finding is that the surface roughness of sawn *A. mangium* was highest at medium feed speed (Figure 7). Generally, sawn surface roughness of timber increases with feed speed. Specimen height did not appear to have effect on surface roughness, nor did grain direction or location of specimen within the log.

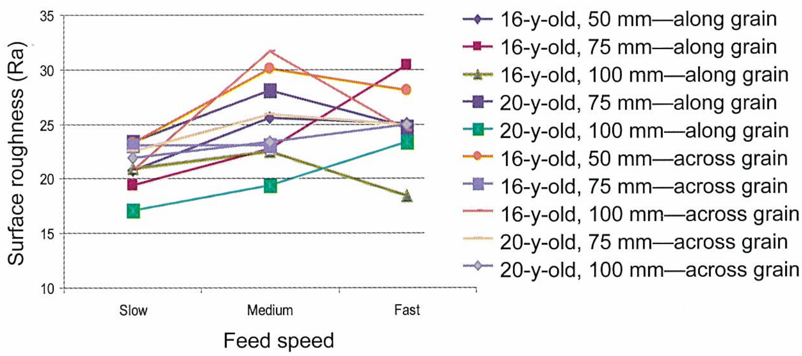


Figure 7 Surface roughness of *Acacia mangium* in relation to feed speed

Sawing accuracies

It is inferred from the results that the sawing accuracies were attributed more to the quality and condition of the bandmill setworks than to the physical properties of the timber (Figure 8). The relatively wide range of sawing deviations for *A. mangium* (Figure 9) could also be due to the absence of proper feed speed control in the bandmill used in this study.

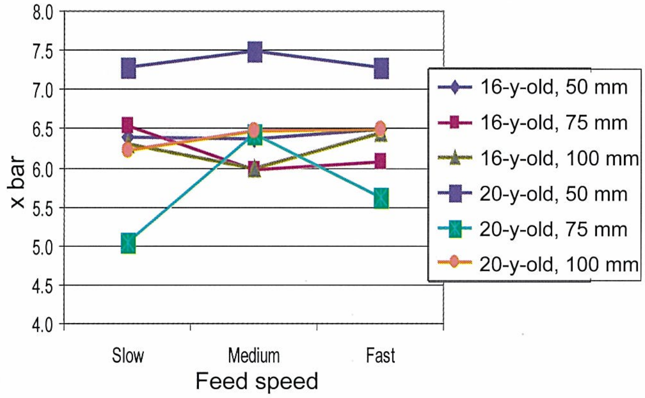


Figure 8 Sawing accuracies of *Acacia mangium*

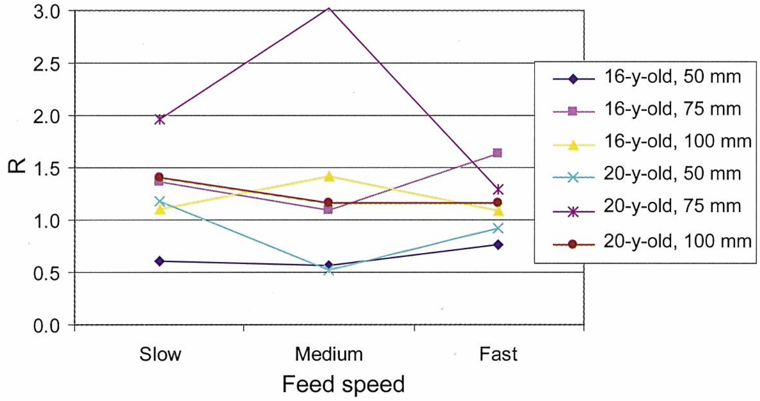


Figure 9 Sawing deviations of *Acacia mangium*

Machining properties

Planing properties

The test results showed that the best sharpness angle for *A. mangium* in terms of power consumption as well as surface quality was 40 degrees. Generally, *A. mangium* is assessed as "EASY" to plane. However, planing defects such as fuzzy grain, chip mark and torn grain were quite commonly observed as illustrated in Figures 10 and 11 respectively.

Figure 10 Fuzzy grain from planing test

Figure 11 Torn grain from planing test

Sanding properties

Acacia mangium is assessed as "EASY" to sand as the surface quality was consistently graded as 'good to excellent'. However, 'fuzzy' defect as shown in Figure 12 was observed in some specimens.

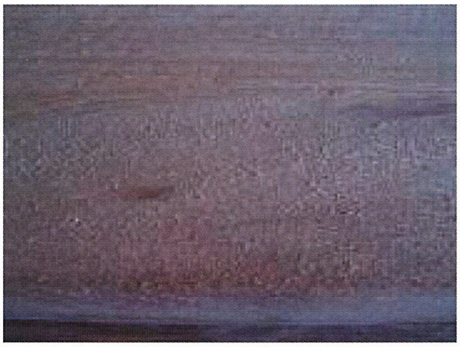


Figure 12 "Fuzzy" defect of sanding test

Boring properties

It was observed that *A. mangium* was "EASY" to bore and the quality of the bored surface was generally graded as 'excellent'. Boring defects shown in Figures 13 and 14 were sparingly observed.

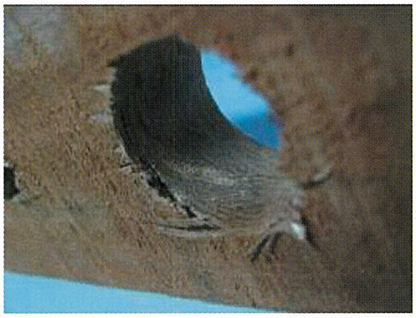


Figure 13 Tear-outs from boring test

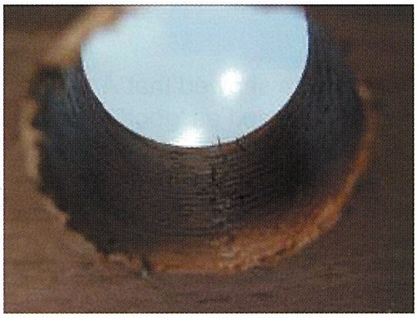


Figure 14 Crushing from boring test

Mortising properties

Acacia mangium is assessed as "EASY" to mortise and the quality of finish was generally graded as 'excellent'. Mortising defects such as crushing and tearing were observed in some specimens as shown in Figures 15 and 16 respectively.

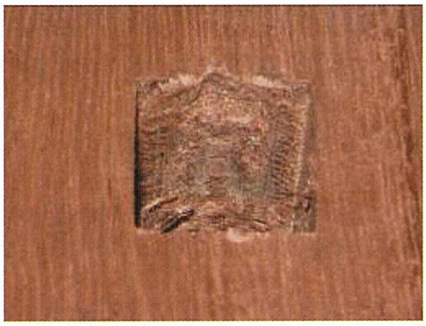


Figure 15 Crushing from mortising test

Figure 16 Tearing from mortising test

Shaping properties

Acacia mangium is assessed as "EASY" to shape and the shaped surface was generally graded as 'excellent'. However, defects of fuzzy grain (Figure 17) and rough end-grain (Figure 18) were observed in a few specimens.

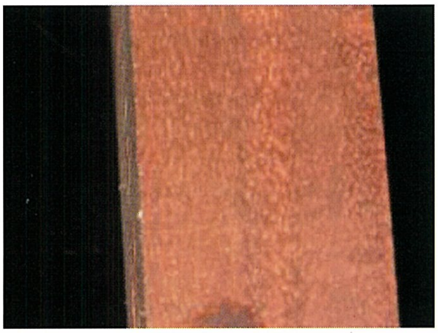


Figure 17 Fuzzy grain

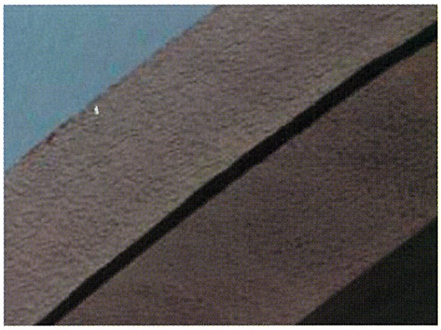


Figure 18 Rough end-grain

Turning properties

The test results showed that *A. mangium* timber was "EASY" to turn and the finished surface was graded as 'good to excellent'. There was no significant difference in the surface quality between the air-dried samples and samples conditioned to 12% M.C. for both age groups. Turning defects of fuzzy grain and torn grain were observed in some specimens as shown in Figures 19 and 20 respectively.

Figure 19 Turning defect of fuzzy grain

Figure 20 Turning defect of torn grain

CONCLUSION

Based on the testing methodologies adopted, both the sawing and machining properties of *A. mangium* were evaluated. The following inferences can then be drawn:

a) The mean yield recovery values for the 20- and 16-y-old *A. mangium* were 35.3 and 41.3% respectively, lower than that reported for "baby-small" keruing, *S. macrophylla,* but higher than that of rubberwood. However, the sawn-timber grades obtainable from this fast-growing species were compared favourably with those of "baby-small" keruing, plantation-grown *S. macrophylla,* of similar age.
b) The machining properties of *A. mangium* are generally good with most processing or finishes assessed as "EASY" or "excellent" respectively.

REFERENCES

Gan, L. T., Ho, C. Y. & Chew, O. K. 1985. Heveawood: sawntimber production and recovery studies. International Rubber Conference 1985, Kuala Lumpur.

Tan, Y. E., Lim, P. T., Gan, K. S., Wong, T. C., Lim, S. C. & Thilagawathy, M. (Eds) 2010a. *Testing Methods for Plantation Grown Tropical Timbers*. FRIM, TRTTC & FRC. 155 pp.

Tan, Y. E., Lim, P. T., Gan, K. S., Wong, T. C., Lim, S. C. & Thilagawathy, M. 2010b. Sampling of trees and allocation of logs. Chapter 1, pp. 1–10 in *Testing Methods for Plantation Grown Tropical Timbers*. FRIM, TRTTC & FRC.

Tan, Y. E., Lim, P. T., Gan, K. S., Wong, T. C., Lim, S. C. & Thilagawathy, M. 2010c. Sawing and machining. Chapter 4, pp. 45–78 in *Testing Methods for Plantation Grown Tropical Timbers*. FRIM, TRTTC & FRC.

TENG, X. Y., WONG, T. C. & CHAN, C. S. 2009. *Technical Report on Assessment of Sawing and Machining. Properties of Shorea macrophylla*. TRTTC, Sarawak, Malaysia.

WONG, T. C. 1998. Sawmill conversion study on baby-small keruing. Paper presented at TRTTC Technical Seminar 1998.

ASSESSMENT OF DURABILITY USING ACCELERATED TEST

U. Salmiah, K. Baharudin & A. Sabri

INTRODUCTION

An important limitation to the usefulness of wood is its susceptibility to decay. Weight loss is the most common method for assessing wood decay in the laboratory (Anagnost & Smith 1997). Weight loss is used to measure natural durability, fungal decay capability and decay rates, normally by basidiomycetes fungi. Basidiomycete decay fungi are actually decay fungi that can destroy wood by removing the ligno-cellulosic components of the wood structure, and hence affect wood strength. In Malaysia, the typical basidiomycete fungi are the white-rot decay fungi, while the brown-rot fungi are not common. However, it would be useful to determine the decay resistance of the wood samples based on the ability of the samples to resist both white-rot and brown-rot decay for practical significance to end-use conditions in above-ground contact. The main advantage of using laboratory accelerated decay test is in producing results in a shorter period compared with the outdoor graveyard method. The results are reproducible anywhere in the world as long as the conditions are controlled. Among the established methods are ASTM 2017, EN 113 and JIS K1571. The procedures in these methods are similar except of the different types of substrate or media used where ASTM 2017 uses soil as substrate while EN 113 uses agar and JIS K1571 sand. In conjunction with the ITTO objective of developing effective methods in determining durability, a modified method was introduced by incorporating relevant parts of ASTM 2017, EN 113 and JIS K1571. The main idea was to assess the suitability and effectiveness of the test procedures in evaluating the durability of tropical plantation timbers against decay fungi (Table 1).

MATERIALS AND METHODS

Materials

Wood species

The timber samples used for this experiment were 16-y-old and 20-y-old *Acacia mangium.* The samples were taken from logs below 4.5 m from the basal portions and only heartwood test samples were used in the tests. Heartwood samples free from fungal attack and defects such as knots were obtained and latter processed to 25 × 25 × 9-mm test blocks with the 9 mm in the grain direction (Table 2). Rubberwood (*Hevea brasiliensis*) was used as reference material.

Table 1 Adoption of modified accelerated laboratory test of natural decay resistance of wood based on presently practised test methods

	ASTM 2017-05	EN113-1996	JIS K1571	Adopted
Replicates	At least 6	30–45	9 for each fungus	20
Size of samples	25 × 25 × 9 mm	50 × 25 × 15 mm	20(R) × 20(T) × 10(L) mm	25 × 25 × 9 mm
Media of test	Soil + feeder strip	Agar	Glucose+malt extract agar + peptone (4+1+0.3 %) + sea sand	Malt extract agar + agar (2 + 2 %)
Exposure time	8–16 weeks determined by the weight loss of reference samples reaching > 50%	16 weeks	12 weeks	8–16 weeks determined by the weight loss of reference samples reaching > 50%
Growth chamber conditioning	25–27 ± 1 °C & RH 65–75 ± 2%	22 ± 2 °C & RH 70 ± 5%	26 ± 2 °C & RH ≥ 70%	25 ± 2 °C & RH 70 ± 5%
Timber samples conditioning prior and after test	Air-drying followed by conditioning at 20 - 30 ± 1 °C & RH 25–75 ± 2% preferably set the same as growth room	20 ± 2 °C & RH 65 ± 5% to constant mass with three additional samples oven-dried to calculate the theoretical dry mass of test samples	60 ± 2 °C in oven for 48 hr, both test and reference samples subjected to the same conditions	60 ± 2 °C in oven for 48 hr, both test and reference samples subjected to the same conditions

Table 2 Wood species and total of wood samples used in the test

Wood species	Fungus		
	Gloeophyllum trabeum	*Coriolus (Trametes) versicolor*	*Lentinus sajor-caju*
Acacia mangium (16 y old)	20	20	20
Acacia mangium (20 y old)	20	20	20
Hevea brasilensis (reference blocks)	10	10	10
Total	50	50	50

Test fungi

Two white-rot fungi, *Coriolus* (*Trametes*) *versicolor* (L. ex. Fr.) Pilat and *Lentinus sajor-caju* (a dominant and aggressive species in Malaysia), and brown-rot fungus *Gloeophylum trabeum* (Pers. ex. Fr.) were used for the tests (Table 2). The wood-decay fungi were isolated and the cultures were kept under controlled environment in the Mycology Laboratory, Forest Research Institute Malaysia.

Culture medium

Malt agar substrate (2% malt extract agar and 2% agar by weight) was used for culturing and subculturing the test fungus in Petri dishes. Following EN 113, this medium was also used as culture bottle substrate instead of soil (ASTM 2017) making it an agar-block-test method.

Methods

The bottles were loosely capped and steam sterilized at 121 °C for 30 min. The test fungi were allowed to grow before each test block was introduced with cross-section face down, in contact with the mycelium mat in the bottle. Prior to the test, all test blocks were sterilized at 100 °C for 20 min, weighed and conditioned to a constant weight in a conditioning room at 27 °C and 70% relative humidity. Twenty replicates for each fungus and 10 replicates of the control were prepared. Exposed blocks were then incubated in a dark growth room at controlled temperature of 25±2 °C and relative humidity at 70±5%. Weekly observations were made to ensure that there was no contamination and to observe any basidiome formation in the test bottles.

The levels of susceptibility (resistance) tested were grouped into four classes based on the weight losses caused by the fungi on the different timbers as shown in Table 3 below.

Table 3 Decay susceptibility classification (resistance classes) based on weight losses

Average weight loss (%)	Average residual weight (%)	Resistance class to specified fungus
0 to 10	90 to 100	Highly resistant
11 to 24	76 to 89	Resistant
25 to 44	56 to 75	Moderately resistant
45 to above	55 or less	Slightly resistant or non-resistant

Evaluation and interpretation of results

All blocks were conditioned before and after exposure in an oven at 60 ± 1 °C and their weights determined until constant. Following ASTM 2017, the weight loss was calculated based on the difference of oven-dry weights of test blocks before and after exposure. Measurements of the relative decay susceptibility or, inversely, of decay resistance, of the wood blocks were based on the weight losses.

RESULTS AND DISCUSSION

Results

Table 4 below summarizes the test weight losses of *A. mangium* after the exposure test.

Table 4 Mean weight losses of *Acacia mangium* wood blocks after exposure to the wood decay fungi

Trial	Fungus	Termination (weeks)	Mean weight loss (%)	
			16 y old	20 y old
Acacia mangium	*Lentinus sajor-caju (LT)*	16	35.20	10.32
	Coriolus (Trametes) versicolor (CV)	16	32.96	9.28
	Gloephyllum trabeum (GT)	16	10.20	8.70
Hevea brasiliensis (reference)	*Coriolus (Trametes) versicolor (CV)*	16	34.92	

Discussion

Normally the weight loss of the reference sample is used as a yardstick to terminate the test or relative comparison with the tested material. The rubberwood tested against the white-rot fungus *C. (T.) versicolor* had a weight loss of only 34.92% where 50% rate of decay was not achievable even at the end of the 16th week. This does not reflect lack of prevision in the procedure but rather a comparative value with the samples. The low weight loss could be due to several possible reasons that require further investigation; among these could be that hardwoods are less susceptible or more resistant to certain fungi.

The age of the tree does have a very clear effect on the durability of the wood against the decay fungi. In this evaluation, *A. mangium* can be classified based on the adopted test procedure as follows:

Table 5 Resistance classification of *Acacia mangium* to white- and brown-rot fungi

Fungus	*Acacia mangium*	
	16 y old	20 y old
Lentinus sajor-caju (LT) (white rot)	Moderately resistant	Highly resistant
Trametes versicolor (TV) (white rot)	Moderately resistant	Highly resistant
Gloephyllum trabeum (GT) (brown rot)	Highly resistant	Highly resistant

The data on the durability of naturally-grown *A. mangium* are not available as no in-ground contact graveyard field trial test has been conducted on this species yet. The only available data are on *A. auriculiformis* with an average service life of 3.5 years and falling into the moderately durable class (Mohd. Dahlan & Tam 1987).

Comments

The results of this study indicate that younger *A. mangium* trees are generally more susceptible to decay fungi with the heartwood more susceptible to white-rot fungi than brown-rot fungi.

CONCLUSION

The study demonstrated that the harmonized agar-block-test method can be used successfully for conducting accelerated decay test in the laboratory for plantation species such as *A. mangium.* This species based on the study done can be catergorized as moderately resistant. While internationally accepted test fungi such as *C. (T.) versicolor* and *G. trabeum* have been successfully used, the local strain white-rot fungus *L. sajor-caju* showed it was equally aggressive and provides an option for future testing of natural durability of wood against white rot. The study has shown that this harmonized method is fairly easy to conduct with little problem of contamination.

BIBLIOGRAPHY

Anagnost, S. E. & Smith, W. B. 1997. Hygroscopicity of decayed wood: implications for weight loss determinations. *Wood and Fiber Science* 29(3): 299–305.

ASTM Standards: D 1413. *Test Method for Wood Preservatives by Laboratory Soil-Block Cultures.*

ASTM Standards: D 2017-05. *Standard Test Method of Accelerated Laboratory Test of Natural Decay Resistance of Woods.*

EN 350-1: 1994E. *Durability of Wood and Wood-based Products—Natural Durability of Solid Wood—Part 1: Guide to the Principles of Testing and Classification of the Natural Durability of Wood.*

EN 113: 1996E. *Wood Preservatives—Test Method for Determining the Protective Effectiveness against Wood Destroying Basidiomycetes—Determination of the Toxic Values.*

JIS K1571. *Japanese Industrial Standard. Test Methods for Determining the Effectiveness of Wood Preservatives and the Performance Requirements.*

Mohd Dahlan, J. & Tam, M. K. 1987. *Natural Durability of Malaysian Timbers.* Timber Trade Leaflet No. 28.

Nicholas, D. D. & Crawford, C. 2003. *Concepts in the Development of New Accelerated Test Methods for Wood Decay.* © 2003 American Chemical Society.

TREATABILITY

U. Salmiah, J. K. Lai, J. Sammy & K. Jenang

INTRODUCTION

Wood varies widely in its degree of treatability, especially of the sapwood and heartwood. Sapwood is generally treatable in comparison with heartwood where the presence of extractives and tyloses in the wood makes it difficult to treat. Durability of such timber could possibly be enhanced through wood preservative treatment where the success of the preservative treatment depends on whether sufficient amount of preservative can be imparted into the timber and how well the preservative distributes itself inside the timber. Such characteristic of the timber is referred to as the treatability of the timber.

The term treatability is correlated with permeability and although there is no established standard method to determine treatability of timber, the vacuum/pressure method is most commonly used. This method of treatment is more effective in optimizing penetration of preservatives. Treatability can be assessed by measuring retention and penetration of preservative in the heartwood. Wang and Degroot (1994) described factors attributing to the lowered heartwood treatability including the higher extractive content in the heartwood, the increased rate of irreversible aspirated pits in the heartwood, and, in addition, in hardwoods, the tylose formation in the heartwood. Treatability of a wood species is normally affected by the anatomical characteristics of the wood species, the characteristics of the treating fluids, and the method and parameters of the treating processes (Wang & Degroot 1994). With the treatability of the wood species determined, only then can it be classified into different groups with reference to ease of treatment. Only by doing so, the end-use applications of treated timber can then be made.

There are two objectives in this study, ie to assess the treatability of plantation species *Acacia mangium* and to develop method (s) to determine its treatability

MATERIALS AND METHODS

Materials

Acacia mangium of two age groups, viz 16 and 20 y, were collected from Ulu Sedili, Johore, and Kemasul, Pahang, respectively. CCA Tanalith C 10% solution wood preservative was used for treatment. The experiment was conducted using a laboratory-size wood treatment plant of 0.394- m^3 capacity. An alternative process using the vacuum-desiccator method was also carried out to investigate its feasibility.

Sample preparation

Timber samples were extracted following harmonized procedures and later processed into 20 × 20 × 45.7 cm test specimens (refer Figure 1). Only clear heartwood specimens free from knots and other noticeable defects were selected. Test specimens were air-dried to moisture content of less than 20%. The test specimen dimensions specified followed ASTM D1758-96 *Standard Method of Evaluating Wood Preservatives by Field Tests with Stakes* with slight modification. In the vacuum-desiccator method, specimen dimensions were 2 × 2 × 10 cm. All test specimens were end-sealed with Duco automotive paint to prevent end/longitudinal penetration by the wood preservative. A total of 20 specimens comprising a minimum of three trees per replicate were selected for each treatment group.

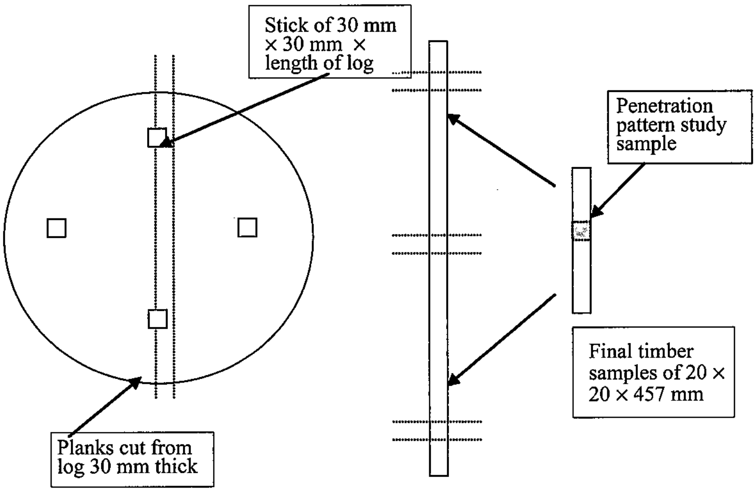


Figure 1 Test sample preparation from logs

Preservative formulation and preparation

A 10% copper-chrome-arsenic wood preservative solution was prepared by diluting one part CCA to 10 parts of water (Table 1).

Table 1 CCA preservative used

Preservative	Solution strength	Active ingredients
Tanalith C (CCA Type C)	10%	Copper sulphate 35% Potassium dichromate 45% Arsenic pentoxide 20%

Methods

Treatment processes and evaluation

Vacuum-pressure method

The Full-Cell (Bethell) Process was used in the evaluation of the treatability of *A. mangium*. The schedule used comprised an initial vacuum of -85 kPa for 60 min, followed by 1400 kPa pressure for 120 min and a final vacuum of -85 kPa for 30 min. This is equivalent to treatment to refusal, a term used to describe the timber's inability to absorb anymore preservative even if the time of treatment is prolonged. The test was carried out in a small capacity 0.394- m^3 pressure impregnation plant.

Vacuum-desiccator method

The vacuum-desiccator method involves a vacuum phase at -85 kPa of 60 min with the test specimens submerged in the preservative as shown in Figure 2.

Acacia mangium was then evaluated by calculating the retention and penetration achieved after the treatment process. The retention is obtained by the difference between the final weight of the specimen after treatment and the initial weight of the specimen before treatment divided by its volume.

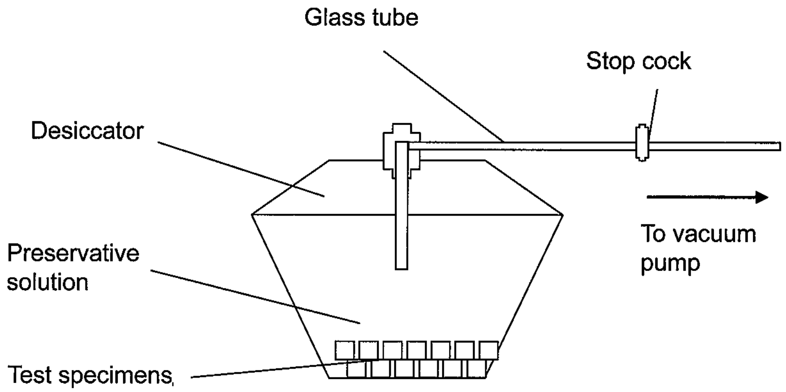


Figure 2 Wood permeability test—vacuum-desiccator set-up

Evaluation of results

Treatability is then determined as follows:

$$\text{Treatability, in litres m}^{-3} = \frac{(W_2 - W_1)}{G * V} \times 1000$$

where,

W_1 – weight before treatment
W_2 – weight after treatment
G – specific gravity of wood preservative (measured with a hydrometer)
V – volume of specimen

The species was classified following: MS544: PART 10:2003 Code of Practice for Structural Use of Timber: Part 10: Preservative Treatment of Structural Timber Classification (Table 2).

Table 2 Treatability classification

Permeability class	Absorption of preservative in litres m^{-3} of timber
Very easy	Over 320
Easy	240–320
Average	160–240
Moderately difficult	80–160
Difficult	Less than 80

Although the preservative adsorption expressed in litres m^3 is a good indicator of how easy the wood can be treated, it is also equally important to assess how well the preservative distributes itself within the wood cells. A qualitative method following Australian / New Zealand Standard AS/NZS 1605:2000 *Methods for Sampling and Analyzing Timber Preservatives and Preservative-treated Timber* was used to determine the spread of CCA in the wood. A small section measuring 50 mm from the treated specimen was first cut at the centre leaving a clean cross-section face. The cross-section was then sprayed with chrome azurol–S copper indicator. A clear royal blue colour indicates penetration while a reddish-brown colour indicates no penetration. Depth of penetration is referred to as the least perpendicular distance from the edges measured in millimeter. The penetration pattern is described as fully penetrated, in continuous band, scattered, patchy or confined to pores.

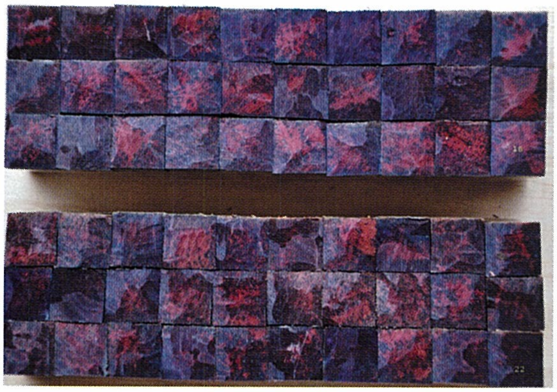
RESULTS AND DISCUSSION

The method employing the use of the Full-Cell Process to determine the treatability of the plantation species is rather straightforward. The results were analysed by calculating the preservative uptake in litres m^{-3} and determining the penetration pattern through the colorimetric test. Treatabilty was then classified in accordance with Table 2.

Table 3 summarizes the results of the treatment of *A. mangium*. From the treatability classification shown in Table 2, both age groups of *A. mangium* can be classified as having average permeability with a mean preservative load of 166 litres m^{-3} (16 y old) and 173 litres m^{-3} (20 y old) respectively. The preservative uptake for both age groups appears to be not significantly different. With the 10% CCA solution used in this study, this is translated into a dry-salt retention of more than 16 kg m^{-3} which is the minimum requirement set out for Hazard class H5 timber specified in MS544 (Appendix). However, in terms of chemical distribution within the wood's cross-section, the pattern of penetration of the preservative was scattered throughout, confining to pores, as shown in Figure 3. This shows that *A. mangium* treated with CCA fulfills MS544 hazard class H5 requirements but can definitely be used for hazard class H4, which requires a minimum of 12 kg m^{-3} and 12-mm depth of penetration.

Table 3 Summary of penetration and retention for wood species (pressure impregnation process)

Preservative	Wood species	Age group (y)	Loading, litres m^{-3}		Penetration pattern	
			Mean	Standard deviation	Depth	Pattern description
CCA-Tanalith C 10%	*Acacia mangium*	16	166	29.1	Fully penetrated	Scattered throughout whole cross-section
CCA-Tanalith C 10%	*Acacia mangium*	20	173	33.3	Fully penetrated	Scattered throughout whole cross-section



Full-Cell Method

Acacia mangium (16 y old)
Penetration scattered throughout whole cross-section

Acacia mangium (20 y old)
Penetration scattered throughout whole cross-section

Figure 3 Cross-section penetration patterns of treated *Acacia mangium*

When a treatment plant is not available, another option to conduct treatability study of wood species is by the use of an alternative simple method with only a vacuum desiccator. The method described earlier can give a good estimate of the

Appendix Hazard class selection guide

Hazard class	Exposure	Specific service conditions	Biological hazard	Typical uses	Minimum net dry-salt retention kg m^{-3}	Minimum depth of penetration, mm
H1	Inside, above ground	Completely protected from weather and well ventilated, and protected from termites	Insects other than termites (eg lyctids)	Framing, flooring, furniture, interior joinery	-	-
H2	Inside, above ground	Protected from wetting and leaching	Borers and termites	Framing, flooring, and similar uses in dry situations	5.6	12
H3	Outside, above ground	Subject to periodic moderate wetting and leaching	Moderate decay, borers and termites	Weather board, fascia, pergolas (above ground), window joinery, framing and decking	8	12
H4	Outside, in ground contact	Subject to severe wetting and leaching	Severe decay, borers and termites	Fence posts, greenhouses, pergolas (in ground) and landscaping timbers	12	12
H5	Outside, in ground contact with or in fresh water	Subject to extreme wetting and leaching and/ or where the critical use requires a higher degree of protection	Very severe decay, borers and termites	Retaining walls, piling, house stumps, building poles, cooling towers	16	25
H6	Marine waters	Subject to prolonged immersion in sea water	Marine wood borers and decay	Boat hulls, marine piles, jetty cross-bracing, landing steps and similar uses	32	25

* Table extracted from MS544: Part 10:2003

VENEER RECOVERY AND QUALITY

H. Hamdan

INTRODUCTION

The issues of global warming and ecosystem degradation have diverted forest industry players from sourcing raw materials from conventional natural forest to plantation forest. Malaysia, being bound to the international convention, has embarked on forest plantations for the last decades with *Acacia mangium* being the pioneer species planted. The properties and utilization of *A. mangium* have been widely discussed and studied (Wong et al. 1988, Ho et al. 1999, Lim et al. 2003). The recommended age for felling is 30 y but is not conclusive. Many studies have been carried out on 2- to 14-y-old trees (Lim et al. 2003) and one on 15-y-old trees (Wong et al. 1988).

Veneer recovery refers to the ratio of veneer volume to log volume, which is affected by the log diameter. This means that the bigger the diameter, the better the recovery (Kainama 1997). Veneer is manufactured from logs by slicing or peeling processes. The recovery is affected by several factors such as log diameter, wood species, age and quality (Sastrodiharjo 1977). Wood species with higher specific gravity are more difficult to peel than those with lower specific gravity (Kamil 1970).

MATERIALS AND METHODS

Materials

In this study, 16-y-old and 20-y-old *A. mangium* logs were obtained from Ulu Sedili, Johore, and Kemasul, Pahang, respectively. The billets were selected based on the biased block design.

Six billets from six trees for each age group were rotary peeled at Kin Heng Timber Industry Sdn Bhd, Ipoh, Perak, to obtain the veneer thicknesses of 1.5 mm and 2.4 mm and trimmed to 1.2 by 1.2-m size. Slicing of veneer from six blocks each was carried out at Lim Ah Soon Sdn Bhd in Semenyih, Selangor, to obtain the 0.6-mm and 2.5-mm thick veneers. The block preparation and peeling protocol were in-house methods.

The data collected for the peeled veneer were from the outer, middle and inner sections of the logs as shown in Figure 1 while those for the sliced veneer were based on randomized layering sampling with five replicates taken from each block (Figure 2).

Methods

Peeling process

All the billets were peeled without any pretreatment. Generally, the peeling process can be rated as easy although the presence of knots may hinder smooth operation. Due to the small diameter of the logs, recovery rate was low compared with the big, round peeler logs normally processed in plywood mills. The acacia being not in sufficiently circular shape had to be rounded first before usable veneers could be obtained. The rounding-up process led to wastage.

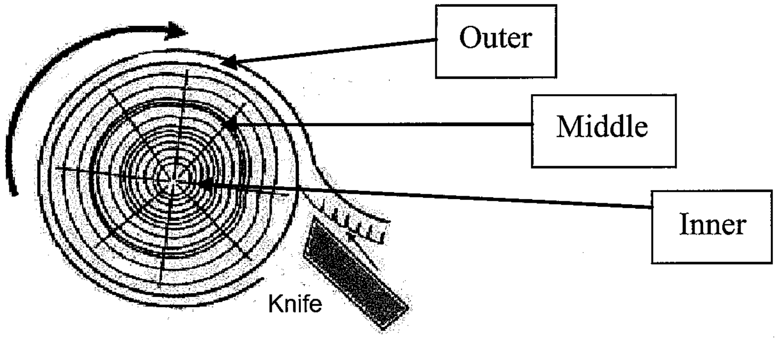


Figure 1 Peeled veneer locations

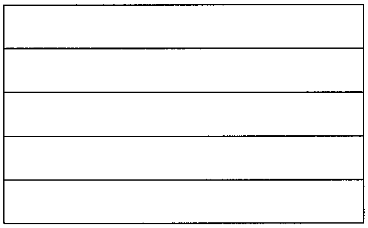


Figure 2 Sliced veneer sampling

Slicing process

In this process, the billets were cut into blocks of about 20 × 20 × 120 cm. The blocks were then boiled for about 24 hr to three days, after which they were maintained at 60 °C and left to cool about 4 to 6 hr prior to slicing.

Assessment

The veneers were assessed using the harmonized testing method developed by incorporating several international standards (Tan et al. 2010).

Peeled veneer yield

The volume of rotary peeled veneer (PV_v) converted into percentage was computed as:

$$PV_v = \pi \times L \times \left[\frac{D^2 - D_C^2}{4}\right] \times 10^{-6}\ \mathrm{m}^3$$

where, L= length of log (cm)
D= diameter of rounded up log (cm)
D_c=diameter of peeler core (cm)

Sliced veneer yield

The volume of sliced veneer (SV_v) converted into percentage was computed as:

$$SV_v = (V_p - V_{residual})\ m^3$$

where, V_p = volume of prepared block (m^3)
$V_{residual}$ = volume of residual block (m^3)

Volumetric shrinkage and surface roughness were determined for both the rotary and sliced veneer, while the *depth of peeler checks* was obtained only from the peeled veneer, all by adopting the following standards:

- JIS B0651: Geometrical Product Specifications—Surface Texture: Profile Method —Nominal Characteristics of Contact (Stylus) Instruments
- BS/AS/NZ Standard: Volumetric Shrinkage
- AS/NZS 2098.6:1996: Method 6: Depth of Peeler Checks in Veneer and Plywood

RESULTS AND DISCUSSION

Veneer recovery

Peeled veneer

The mean results for the recovery of peeled veneer are shown in Table 1 below. The yield of veneer was inversely proportionate to the age for the 1.2-mm veneer between the two age groups but not for the 2.4-mm veneer. While the common recovery for the logs was 50–60%, the high mean recovery observed from the 16-y-old logs peeled into 1.2-mm veneer was probably due to the larger than average log diameter (Table 1). A similar result was observed for the 2.4-mm peeled veneer of the 20-y-old logs. Another significant factor that significantly contributed to the higher recovery was probably the minimal defects observed on the veneers.

Table 1 Mean results for peeled veneer

Age of tree (y)	Veneer thickness (mm)	Shrinkage (%)		Yield (%)	Depth of peeler checks (%)	Surface roughness (µm)		
		Perpendicular	Thickness			R_a	R_{max}	R_z
16	1.2	6.27	1.25	79.05	59.68 (0.33)	12 (0.35)	101 (0.27)	66 (0.26)
	2.4	5.24	2.36	66.97	58.35 (0.27)	18 (0.40)	130 (0.35)	84 (0.34)
20	1.2	4.49	1.24	52.70	59.11 (0.29)	14 (0.39)	109 (0.29)	75 (0.28)
	2.4	5.12	2.47	73.90	56.17 (0.23)	16 (0.42)	120 (0.31)	81 (0.29)

Note: Values in parenthesis are coefficients of variance (CV)

With respect to peeler checks, the percentages recorded were almost uniform ranging from 56 to almost 60%. In the surface roughness study, the results consistently show that the R_{max}, R_z and R_a values were highest in the 16-y-old logs peeled at 2.4-mm thickness followed by the 20-y-old logs peeled at similar thickness.

Sliced veneer

From Table 2, the recovery values for all the sliced veneers were almost similar in both age groups and thicknesses although the 16-y-old logs sliced at 2.5 mm recorded a slightly higher recovery at about 43%. However, it can be inferred that the veneer yields obtained for both ages were relatively lower than the norm.

Table 2 Mean results for sliced veneer

Age of tree (y)	Veneer thickness (mm)	Yield (%)	Surface roughness (μm)		
			R_a	R_{max}	R_z
16	0.6	33.45	13 (0.59)	84 (0.20)	53 (0.23)
	2.5	42.96	11 (0.40)	83 (0.25)	52 (0.30)
20	0.6	34.38	19 (0.39)	115 (0.23)	74 (0.26)
	2.5	34.20	24 (0.54)	133 (0.27)	89 (0.32)

Note: Values in parenthesis are coefficients of variance (CV)

The results also consistently show that the R_{max}, R_z and R_a values for surface roughness were higher in veneers from the 20-y-old as compared with those from the 16-y-old logs.

CONCLUSION

During the peeling, the peeler operator requested that billets of more than 240-mm diameter be used, ideally of 300 mm and above, due to economics and higher recovery. Rounding-up of tapering and fluted billets also affected the recovery of veneer during peeling which also rejected any crooked billets.

From the above results, the veneer recovery of the peeled billets is relatively higher than that of to the sliced veneer. This is expected due to the processing method and the variation in grading quality of veneer obtained. The presence of knots is the main determinant, especially for the sliced veneer, that hinders the recovery percentage yield and to some extent might limit its application. The colour variation obtained was obvious with either light- or dark-coloured zones.

Observing the physical properties of the veneers, it can be deduced that the dimensional changes are comparable with those of other wood of similar density.

The surface roughness of the peeled veneer is higher than that of the sliced veneer from the 16-y-old logs; the high R_{max} at 133 recorded in the veneer from the 20-y-old logs could have been contributed by the veneer quality. However, in conclusion, if the billet/veneer quality (eg knots reduced) can be addressed, *A. mangium* has the potential to be commercially explored.

REFERENCES

HO, K. S., HAMDAN, H., TAN, Y. E. & MOHD. SHUKARI, M. 1999. *Acacia mangium* for timber and a case study of utilization. Paper presented at the 5th Conference on Forestry and Forest Products, 1999 Series Utilization of Plantation Timber. Sentang: Potential Timber for the Future, 20 April 1999, FRIM. 9 pp.

KAINAMA, E. 1997. Pengaruh kualita dan diameter dolog terhadap rendemen volume finir pada PT. Artika Optima Inti. Skripsi Fakultas Pertanian Universitas Pattimura Ambon.

KAMIL, R. N. 1970. *Kayu Agathis sebagai Bahan Baku Kayu Lapis*. Lembaga Penelitian Hasil Hutan No. 96, Bogor.

LIM, S. C., GAN, K. S. & CHOO, K. T. 2003. The characteristics, properties and uses of plantation timbers—rubberwood and *Acacia mangium*. *Timber Technology Bulletin No. 26*: 139–258.

SASTRODIHARJO. 1977. Pensyaratan bahan baku logs dan pengaruhnya terhadap rendemen eksport kayu jati gergajian. Proceedings diskusi umum. Manajamen Industri Penggergajian. Kelembagaan Penelitian Hasil Hutan Bogor, Indonesia Sawmill Association, Persatuan Sarjana Kehutanan Indonesia, Bogor.

TAN, Y. E., LIM, N. P. T., GAN, K. S. WONG, T. C., LIM, S. C. & THILAGAWATHY, M. (Eds) 2010. *Testing Methods for Plantation Grown Tropical Timbers*, FRIM, TRTTC & FRC. 155 pp.

WONG, W. C., HO, K. S. & WONG, C. N. 1988. *Acacia mangium* from Sabah for plywood and decorative panel manufacture: initial trials. *Journal of Tropical Forest Science* 1(1): 42–50.

specimen thickness was reduced to 20 mm and the results yielded were more consistent. But, even with reduced thickness, the specimen could not be dried to below 15% and there was still severe moisture gradient across the thickness. The coefficients of drying rates for the 16- and 20-y-old *A. mangium* were 0.19 and 0.16 respectively. Details of the DRT are presented in Table 2.

Table 2 Coefficients of drying rate for *Acacia mangium* of different ages

Age group (y)	Duration of drying
16	34.9 hr (MC dropped from 20 to 15%); Coefficient, *k* 0.19
20	37 hr (MC dropped from 20 to 15%); Coefficient, *k* 0.16

Quick-drying test (QDT)

The QDT involves assigning a degree of defect for each type of the defect/deformation (surface checks, internal checks and maximum deformation) of the specimen against patternized defect characteristics. The test was carried out by placing the specimen in a natural convection oven and the defect characteristics were monitored until constant weight. The summarized results of the QDT are presented in Table 3. These data were used to determine the initial drying condition (dry-bulb temperature and wet-bulb depression) and final dry-bulb temperature possible for the timber. A preliminary drying schedule can then be drawn up using these data and the timber information, particularly the initial moisture content.

Table 3 Degrees of defects assigned to *Acacia mangium* of different age groups

Age group (y)	Estimated duration of drying	Drying defects and other degrades
16	27-mm boards: 8.5 days (Initial MC 88—131%)	Prone to deformation (6/8), internal checks (5/6), surface checks (4/8)
20	27-mm boards: 12 days (Initial MC 76—110%)	Prone to deformation (7/8), internal checks (6/6), surface checks (1/8)

Preliminary drying schedules for the 20- and 16-y-old *A. mangium* are given in Tables 4 and 5 respectively. The drying schedules are not significantly different and the mildest of the two can be used; fine tuning of the preliminary schedule can be developed further.

Table 4 Preliminary drying schedule for the 20-y-old *Acacia mangium* based on the QDT

M.C.	DBT	WBT	WBD	EMC	RH
(%)	°C	°C	°C	%	%
Green to 75	45.0	43.0	2.0	18.3	89.0
75 to 65	45.0	42.6	2.4	19.1	86.0
65 to 55	45.0	41.6	3.4	15.1	81.0
55 to 45	45.0	40.2	4.8	13.0	74.0
45 to 35	45.0	38.1	6.9	10.9	64.0
35 to 30	45.0	35.0	10.0	8.4	52.0
30 to 25	48.0	35.4	12.4	7.2	43.0
25 to 20	56.0	37.0	19.0	6.3	40.0
20 to 15	65.0	47.0	18.0	5.2	37.0
15 to final	70.0	50.0	20.0	5.0	35.0
Equalizing	70.0	60.5	9.5	7.6	64.0
Conditioning	70.0	64.0	6.0	11.2	76.0

DBT – dry-bulb temperature
WBT – wet-bulb temperature
WBD – wet-bulb depression
EMC – equilibrium moisture content (%)
RH – relative humidity (%)

Table 5 Preliminary drying schedule for the 16-y-old *Acacia mangium* based on the QDT

M.C.	DBT	WBT	WBD	EMC	RH
(%)	°C	°C	°C	%	%
Green to 75	48	45	3	15.9	84.0
75 to 65	48	44.5	3.5	14.9	81.5
65 to 55	48	43.4	4.6	13.3	76.1
55 to 45	48	41.8	6.2	11.5	68.8
45 to 35	48	39.8	8.2	9.8	60.3
35 to 30	48	37	11	8.2	49.4
30 to 25	51	37.5	13.5	7.1	42.5
25 to 20	56	40	16	6.2	37.9
20 to 15	65	47	18	5.8	37.4
15 to final	70	50	20	5.3	35.1
Equalizing	70	59.5	10.5	8.6	60.0
Conditioning	70	64	6	11.5	75.0

Drying-schedule test (DST)

The main objective of the DST is to assess the timber quality dried using the preliminary drying schedule in order to develop a suitable schedule for a commercial kiln. At the end of the test, all specimens were checked and measured for defects such as checks, cupping, twisting and bow, then cross-cut to determine the individual moisture content, moisture distribution and case-hardening. If the dried timber quality is good, the initial wet bulb depression of the drying schedule may be increased to a larger value. However, if the timber quality is poor, the initial wet bulb depression of the schedule may be decreased. A total of three tests (runs), starting with the preliminary drying schedule, were recommended to be conducted in an experimental conventional kiln.

For both age groups of *A. mangium*, drying trials were conducted using the respective preliminary drying schedules developed based on the QDT results. The 20- and 16-y-old A. *mangium* were dried from green to the final target moisture content of 12% in 510 and 654 hr respectively (Table 6). The drying rates (%/day) of the two trials at the various moisture content ranges are presented in Table 7.

Table 6 Initial and final moisture contents of *Acacia mangium*

Age group (y)	Nominal thickness (mm)	Initial MC, %			Final, MC %			Duration (hr)
		Avg.	Min	Max	Avg.	Min	Max	
20	30	77.6	63.2	95.5	11.3	7.6	15.6	510
16	30	102.7	81.9	134.9	11.1	6.9	22.6	654

Table 7 Drying rates (%/day) of *Acacia mangium* at different moisture content ranges

Age group (y)	Moisture content range (%)		
	60–30	30–20	20–15
20	3.0	2.7	2.3
16	2.6	2.3	1.9

Both the drying trials yielded boards with insignificant drying defects such as bow, cup, twist and checks (surface, end and internal). However, both the drying trials were not successful due to the occurrence of severe moisture gradient or wet pockets. The percentages of boards having differences in MC between the core and shell are given in Table 8. Even after more than 20 days of drying, in some boards, particularly the quarter-sawn boards, the core moisture content was still above 30%. The proposed modification to the preliminary schedule as set out in the test method may not be able to alleviate the problem. This may require a different approach by conducting some treatments to increase permeability of the timber that ease drying like pre-drying or air drying. As such, only one drying trial using the preliminary schedule was conducted for each age group. Pre-steaming treatment and/or a period of air drying may be necessary before kiln drying.

Table 8 Percentages of boards after drying having differences between the core and shell MC at different levels

Age group (y)	Difference between core and shell MC		
	< 5 %	5–10%	> 10%
20	8.33	50.00	41.66
16	56.25	6.25	37.50

The various approaches or options to dry *A. mangium* will be conducted separately from this set drying characteristic evaluation.

20-y-old Acacia mangium

The initial moisture content of the acacia boards was 77.6 ± 10.6% (range 63.2 to 95.5%) and the final moisture content achieved after 510 hr of drying was 11.3 ± 2.5% (range 7.6 to 15.6%) (Table 6). The spreads of moisture contents of the boards are presented in Figure 2.

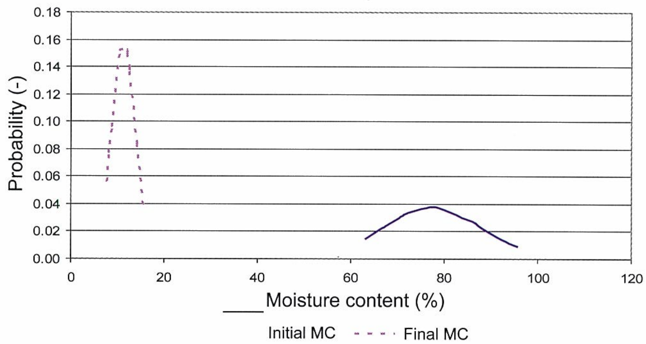


Figure 2 Spreads of moisture contents

The progressions of drying and temperature changes based on the preliminary schedule are presented in Figure 3.

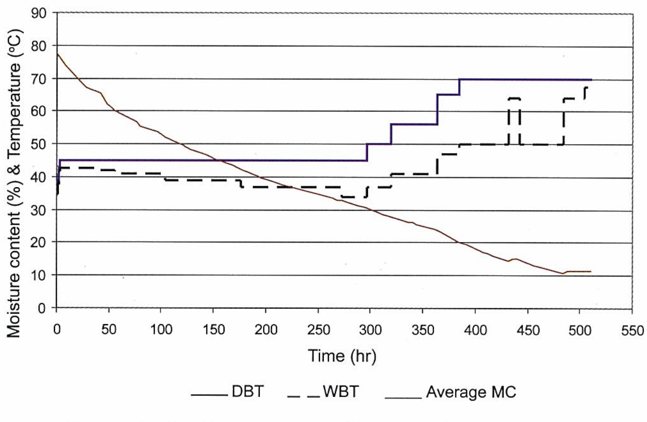


Figure 3 Drying curve and temperature changes

There was a wide range of average final moisture contents, from 6.3 to 20.2%. The higher moisture content boards were associated with the ones having high core moisture contents (Table 9). These were mostly quarter-sawn boards. However, occasionally, flat-sawn board may also have wet cores.

Table 9 Shell and core moisture contents of sample boards from the 20-y-old trees dried using the preliminary schedule

Board	Code	Average MC	Shell MC	Core MC	Difference (%)
Flat sawn	D14-1-1c	20.2	12.7	35.1	22.4
Flat sawn	D14-1-1b	12.0	10.1	15.9	5.8
Quarter sawn	D16-3-1a	17.3	12.3	27.5	15.2
Flat sawn	D13-5-1b	9.2	7.1	13.4	6.3
Diagonal sawn	D11-2-1(b)	10.4	8.6	13.9	5.3
Flat sawn	D11-5-1a	11.5	9.6	15.2	5.6
Diagonal sawn	D13-4-1a	10.4	8.7	13.7	5.0
Flat sawn	D17-1-1a	11.7	9.7	15.8	6.1
Flat sawn	D12-1-1c	15.7	11.8	23.6	11.8
Diagonal sawn	D16-4-1b	17.4	11.9	28.4	16.4
Quarter sawn	D12-3-2c	19.2	12.6	32.3	19.7
Diagonal sawn	D17-2-2b	6.3	6.5	6.1	-0.4

16-y-old Acacia mangium

The initial moisture content of the acacia boards was 102.7 ± 14.0% (range 81.9 to 135.0%) and the final moisture content achieved after 654 hr of drying was 11.1 ± 4.6% (range 6.9 to 22.6%) (Table 6). The spreads of moisture contents of the boards are presented in Figure 4.

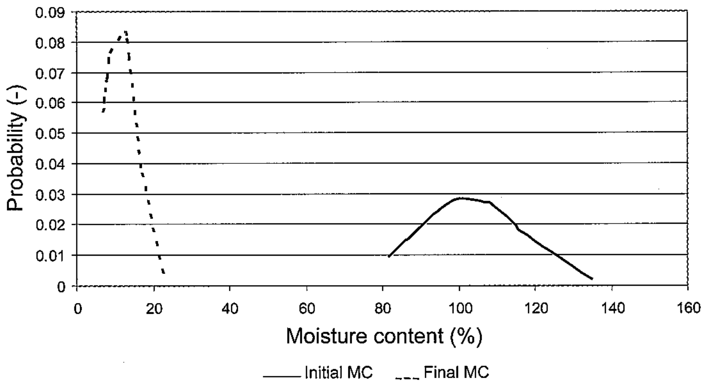


Figure 4 Spreads of moisture contents

The progressions of drying and temperature settings based on the preliminary schedule but including two periods of conditioning at 65/63°C (DBT/WBT) are presented in Figure 5.

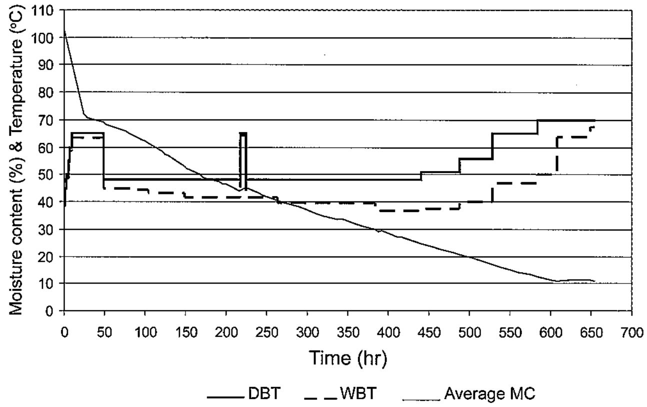


Figure 5 Drying curve and temperature changes

Similarly, there was a wide range of final moisture contents, from 6.3 to 24.4% among the 16-y-old boards. The higher moisture content boards were associated with the ones having high core moisture content (Table 10) and these were mostly quarter-sawn boards.

Table 10 Shell and core moisture contents (%) of sample boards from the 16-y-old trees dried using the preliminary schedule

Board	Code	Average MC	Shell MC	Core MC	Difference (%)
Diagonal sawn	E11-2-2A (a)	7.7	7.8	8.1	0.2
Quarter sawn	E18-3-1B (a)	17.2	10.2	25.7	15.5
Quarter sawn	E12-3-1B (b)	22.6	10.8	47.5	36.8
Diagonal sawn	E13-2-2A (b)	8.6	7.5	10.1	2.5
Diagonal sawn	E15-2-2 (B)	7.4	7.7	7.0	-0.6
Diagonal sawn	E8-2-2A (b)	7.3	6.9	7.8	0.9
Diagonal sawn	E14-2-2B (a)	13.4	8.5	20.2	11.7
Flat sawn	E8-4-1b (b)	6.4	6.5	6.2	-0.2
Diagonal sawn	E15-2-2A (a)	8.0	7.6	8.7	1.1
Quarter sawn	E14-3-1B (c)	8.9	8.0	9.1	1.1
Quarter sawn	E17-3-1B (b)	11.0	9.4	14.4	5.0
Quarter sawn	E10-3-1B (b)	23.4	11.4	42.0	30.5
Diagonal sawn	E13-2-2A (c)	10.0	8.6	11.9	3.4
Quarter sawn	E12-3-1A (b)	24.4	11.1	43.1	32.0
Diagonal sawn	E12-2-2B (a)	6.3	6.4	6.6	0.1
Quarter sawn	E15-3-1A (c)	22.8	9.7	47.3	37.5

CONCLUSION

Air drying of 30-mm *Acacia mangium* boards took about 150 days from green to air-dry moisture content of about 16.5% and could achieve uniform moisture content throughout the board. However, for 60-mm boards, it was not possible to attain air-dry condition even after one year of air drying, and there were occurrences of wet cores. Results of drying-rate test indicated that this timber dries slowly; if compared with another plantation timber, the drying rate was about two thirds of *Shorea macrophylla*. The drying-schedule test based on the quick-drying test results may be used as a starting point to dry *A. mangium* commercially. But the issue of wet cores, particularly on radial-sawn boards, still persists and needs further work. Kiln drying of 25-mm *A. mangium* boards from green to about 12% moisture content took about 25 days.

REFERENCE

TAN, Y. E., LIM, N. P. T., GAN, K. S., WONG, T. C., LIM, S. C. & THILAGAWATHY, M. (Eds) 2010. *Testing Methods for Plantation Grown Tropical Timbers*. FRIM, TRTTC & FRC. 155 pp.

KILN DRYING OF *ACACIA MANGIUM* PLANKS PRETREATED IN HOT WATER

K. S. Gan & R. Zairul Amin

INTRODUCTION

Drying assessment conducted previously under this project indicated that *Acacia mangium* dried very slowly and with high incidence of wet pockets, particularly on radial/quatersawn planks. Earlier drying trials included (a) kiln drying using the drying schedule developed using the quick-drying-test, (b) air drying to below fibre saturation point (FSP) prior to kiln drying and (c) incorporation of regular high humidity treatment during the drying process. It was found that the incorporation of high humidity treatment at regular intervals during the drying process did not improve the drying. However, air drying prior to kiln drying did improve the drying in terms of shorter drying time and lower incidence of wet pockets. There were claims by several parties in Sabah that boiling the *A. mangium* planks could solve the wet-pocket problem. However, there is no documented evidence of this pretreatment. As a result of this, various stakeholders requested that further work be carried out to solve this problem. During the PSC meeting on 22 March 2010, it was recommended that the project be extended in order to conduct addition work in this area. Thus, the facility to carry out preboiling was prepared and additional *A. mangium* logs were acquired from the open market and delivered to FRIM on 4 September 2010.

The objective of this drying trial was to evaluate if pretreatment in hot water bath of *A. mangium* planks prior to kiln drying could eliminate the occurrence of wet pockets.

MATERIALS AND METHOD

Two *A. mangium* logs were cut following the through-and-through cutting pattern as described in the testing manual (Tan et al. 2010) for the drying-schedule test. The flitches were cut to size (thickness 30 mm × width 120/150 mm × length 990 mm) for the drying test.

Pretreatment by boiling was conducted in a water tank heated by electric coil to 95°C and maintained throughout the process. The planks were submerged in the hot water for three hours. Weights of the planks were taken before and after treatment.

After removing from the hot water bath the planks were drip-dried and then charged into an experimental steam heated dryer. The drying schedule applied was the same as used in previous drying trials and is shown in Table 1.

Table 1 Drying schedule applied to dry *Acacia mangium*

MC (%)	DBT (°C)	WBT (°C)	WBD (°C)	EMC (°C)	RH (%)
Green to 75	45.0	43.0	2.0	18.3	89.0
75 to 65	45.0	42.6	2.4	19.1	86.0
65 to 55	45.0	41.6	3.4	15.1	81.0
55 to 45	45.0	40.2	4.8	13.0	74.0
45 to 35	45.0	38.1	6.9	10.9	64.0
35 to 30	45.0	35.0	10.0	8.4	52.0
30 to 25	48.0	35.4	12.4	7.2	43.0
25 to 20	56.0	37.0	19.0	6.3	40.0
20 to 15	65.0	47.0	18.0	5.2	37.0
15 to final	70.0	50.0	20.0	5.0	35.0
Equalizing	70.0	60.5	9.5	7.6	64.0
Conditioning	70.0	64.0	6.0	11.2	76.0

DBT – dry bulb temperature (°C)
WBT – wet bulb temperature (°C)
WBD – wet bulb depression (°C)
EMC – equilibrium moisture content (%)
RH – relative humidity (%)

RESULTS AND DISCUSSION

Pretreatment in hot water bath

Discussions with the people who claimed to have carried out the pretreatment by boiling *A. mangium* planks in Sabah indicated that the temperature of the heated water used was about 70 °C and not 100 °C as for boiling point water. In this study, the water temperature was set at 95 °C and not 100 °C to minimize any splattering. The planks were submerged into the water after this set temperature was achieved and kept for three hours (Figure 1). Generally, green *A. mangium* plank will sink in water. After the treatment, each plank lost an average of 400±189 g in weight or 14.1±6.7% in moisture content. The wood surface dried very quickily after the planks were removed from the hot water bath.

Figure 1 Placing the *Acacia mangium* planks into the treatment tank

Drying curve

The drying curve of the pretreated *A. mangium* is shown in Figure 2. The average initial and final moisture contents were 88.4±8.1% and 9.6±3.0% respectively. The drying process took about 502 hr or 21 days to accomplish. Compared with the previous drying trials (Gan & Zairul 2010) with and without regular high humidity treatments, the previous drying times were shorter by about 2 and 4 days respectively.

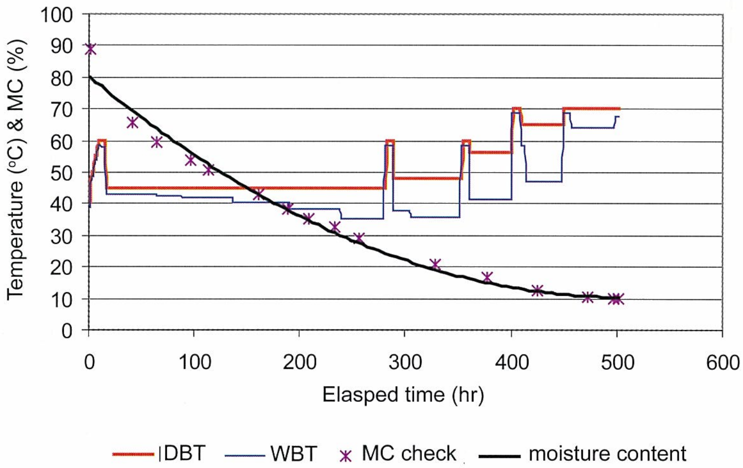


Figure 2 Drying curve of pretreated *Acacia mangium* and the temperature settings at various stages of drying

Wet pockets

Wet pockets were assessed by determining the difference in moisture content between the outer portion (shell) and the core of the plank. In the current drying trial, only 6.7% of the boards had wet cores with difference between shell and core MCs of more than 6% (Table 2). From these drying trials, there was a marked reduction in the occurrence of wet pockets when the planks were preboiled/soaked in hot water. However, the occurrence of wet pockets was not completely eliminated.

Table 2 Percentages of boards with differences between shell and core MCs at different levels

Difference between shell and core MCs (%)	Drying trials reported in Gan & Zairul (2010)			Current trial
	Run according to schedule	Regular high-humidity treatment	Pre-air-dried planks	
<3	50.0	30.4	81.3	86.6
3–6	12.5	17.4	8.3	6.7
>6	37.5	52.2	10.4	6.7

CONCLUSION

Boiling or soaking *A. mangium* planks in hot water prior to kiln drying did reduce the occurrence of wet pockets. From the test conducted, it was found that less than 10% of the planks had wet pockets. These occurred exclusively on true radial or quarter-sawn boards. It would be useful to explore if this pretreatment under different treatment durations and temperature settings could further reduce and eliminate the occurrence of wet pockets.

REFERENCES

GAN, K. S. & ZAIRUL AMIN, R. 2010. Drying of *Acacia mangium* using conventional kiln drying system. Paper presented at Seminar and Workshop on Improved Utilization of Tropical Plantation Timbers. 23–25 March 2010, Kuala Lumpur.

TAN, Y. E., LIM, N. P. T., GAN, K. S., WONG, T.C., LIM, S. C. & THILAGAWATHY, M. (Eds) 2010. *Testing Methods for Plantation Grown Tropical Timbers.* FRIM, TRTTC & FRC. 155 pp.

FINGER-JOINTING AND LAMINATION PROPERTIES FOR NON-STRUCTURAL PURPOSES

C. B. Ong & K. B. Ting

INTRODUCTION

Plantation timbers are becoming popular in the current wood industry due to their fast growths. One of the more popular plantation timbers is *Acacia mangium* which is being planted on a large scale in forest tree plantations in Peninsular Malaysia. Due to its fast-growing nature, *A. mangium* timber tends to have a higher count of defects such as knots and with its smaller log sizes results in lower recovery compared with timbers felled from the natural forest. Finger-jointing and lamination technology is useful to improve the recovery rate of *A. mangium* by cross-cutting defects and finger-jointing the shorter pieces to produce longer and higher quality timber. Smaller-sized logs can be laminated as well as larger or any timber sizes to suit the requirements of the respective mills.

At present, the wood industry in Malaysia is concentrating on using timber for non-structural applications such as mouldings, window and door frames. *Acacia mangium* is becoming popular in the furniture industry due to its attractive and uniformity in colour. With the introduction of finger-jointing and lamination technology, furniture mills are capable of producing different sizes and shapes following the designs and demands from the market. Even the appearance of finger joints, lamination lines and non-deteriorating defects such as sound knots is deemed to be aesthetically pleasing in the view of modern furniture buyers.

In this study to evaluate the adhesive bonds of *A. mangium* in the finger and laminate joints of non-structural products, the finger-jointed samples were subjected to bending and tensile tests, each with different service conditions for dry and wet uses. Laminated samples were subjected to block-shear and delamination tests, each with different service conditions for dry and wet uses as well. The test samples that met the respective requirements of the tests are considered to be capable of providing adequate bonds for uses under the various conditions.

MATERIALS AND METHODS

Materials

A total of 2820 samples of *A. mangium* were prepared using age groups of 20 and 16 y old. The samples were dried to less than 18% moisture content prior to finger-jointing or lamination processes. The average density of the 20-y-old age group was 680 kg m^{-3} and that for 16-y-old group was 598 kg m^{-3}.

For every age group, the samples were divided into four different groups for conducting four types of test, namely bending, tension, block-shear and delamination tests. In each of the test groups, the samples were bonded with three different types of adhesive, namely polyvinyl acetate (PVAc), emulsion polymer isocyanate (EPI) and phenol-resorcinol formaldehyde (PRF). The total number of samples for one test of one adhesive and service condition was 30.

In the finger-jointing process, the samples were finger-jointed using a finger-jointing machine. The samples were guided through a circular saw prior to being cut by a finger-profile cutter while being clamped to the machine carriage. The end pieces were cleaned to remove sawdust before being jointed with adhesive using a finger composer. Finger joints were left to cure prior to further processing and testing. In this study, only vertical joints were made (see Figure 1 (b)). The finger-joint configuration is shown in Figure 2.

In the lamination process, the samples were laminated flatwise using clamping jigs with proper pressures as advised by the adhesives' manufacturers. The laminated samples were left to cure prior to further processing.

The final sizes of the test samples for the respective tests were as follows:

- bending test – 312 × 19 × 13 mm
- tension test – 254 × 19 × 6 mm
- block-shear test – thickness (t) × 25 × 25 mm
- delamination test – thickness (t) × 75 × 100 mm

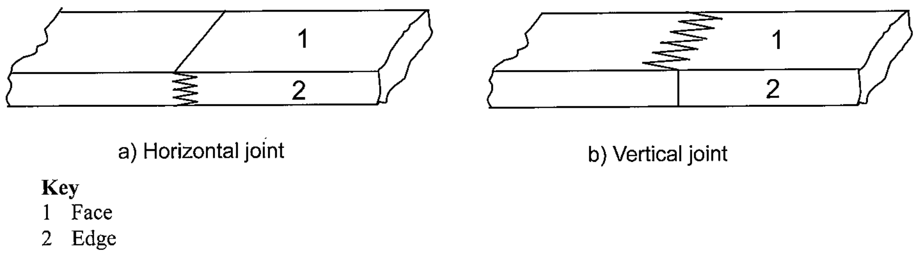
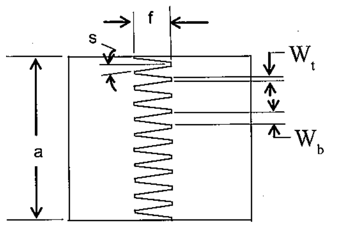


Figure 1 Types of finger joint



Key

a ,	height of joint	= 19 mm
f ,	length of finger	= 12 mm
W_t,	width of finger tip	= 1 mm
W_b,	width of finger base	= 3.5 mm
s ,	slope of finger	= 7°

Figure 2 Finger-joint configuration

Methods

All the test methods were carried out in accordance with the methodologies as stipulated in the testing manual (Tan et al. 2010). For finger joints, the samples underwent bending and tension tests while for laminated samples, block-shear and delamination tests were carried out.

Bending test

The finger-jointed samples were tested for the 4-point bending test after being treated in four service conditions, namely cured (dry), water-soak, boiling and vacuum-pressure conditions. Load was applied perpendicular to the face of the finger-jointed sample with span of 312 mm (see Figure 3). The capacity of the universal testing machine was not to be less than 10 kN and the loading speed was 12 mm min^{-1}. The modulus of rupture (MOR) for each sample was calculated after the test.

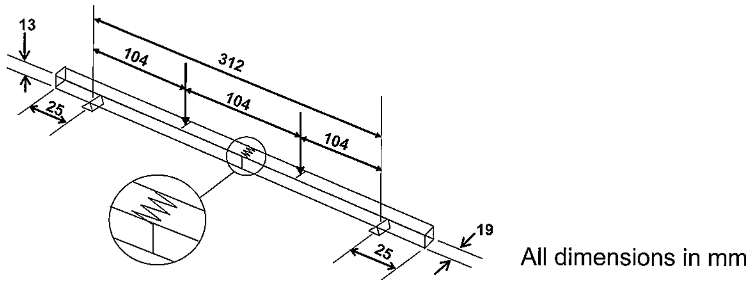


Figure 3 4-point bending test set-up

Tensile test

Prior to the tensile testing, the finger-jointed samples (Figure 4) were treated in six service conditions, namely cured (dry), water-soak, boiling, vacuum-pressure, elevated temperature (104 °C) and temperature-humidity (65 °C, 16% EMC) conditions. The universal testing machine has a capacity of not less than 10 kN and loading speed of 13 mm min^{-1}. The sample was gripped firmly by a jig over a length of 63 mm at both ends. The tensile strength in MOR was calculated and mode of failure was visually inspected and documented.

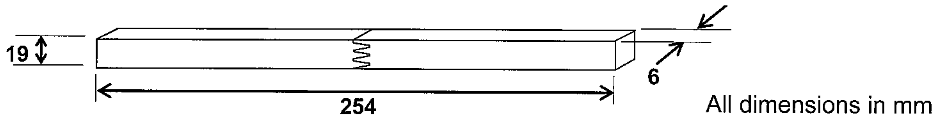
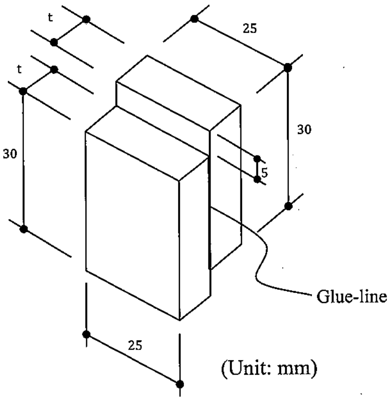


Figure 4 Tension test sample

Block-shear test

In the block-shear test, the samples were treated in five service conditions, namely cured (dry), water-soak, boiling, vacuum-pressure and elevated temperature (104 °C) conditions prior to testing. Laminated samples were processed into stair-step shape as shown in Figure 5 and load was applied to the glue-line until failure occurred. The shear strength (MOR) of the glue-line was calculated and the wood failure percentage was evaluated and documented.

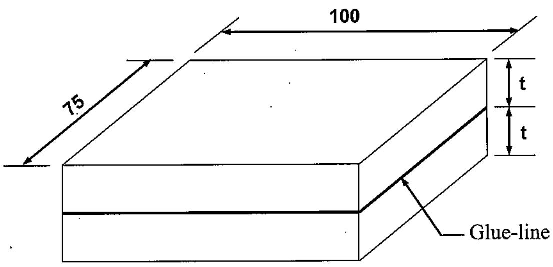


t: thickness
All dimensions in mm

Figure 5 Block-shear test sample

Delamination test

In the delamination test, the samples (Figure 6) were treated in four service conditions, namely 6 hr of water immersion, 24 hr of water immersion, boiling and vacuum-pressure conditions. After the respective treatments, the length of opened glue-line or delamination at the cross-section of each sample was measured and the ratio of delamination to the length of glue-line at the cross-section was calculated in percentage.



t: thickness
All dimensions in mm

Figure 6 Delamination test sample

RESULTS AND DISCUSSION

Bending test results

The MOR results of *A. mangium* for both age groups are shown in Table 1. The results show that the samples bonded with three different types of adhesive and treated in the four test conditions, namely cured (dry), water-soak, boiling water and vacuum-pressure conditions, satisfied the requirements of the strength values as stipulated in the manual. The average percentage of wood failure (WF) in bending test was actually not required in the manual.

Table 1 Bending test results

Test condition		Cured (dry)				Water soak			
Age group		16 y		20 y		16 y		20 y	
Test	Adhesive	MOR	WF	MOR	WF	MOR	WF	MOR	WF
Bending	NFJ	108.4	n.a.	111.1	n.a.	n.a.		n.a.	
	PVAc	83.2	51.7	72.9	50.7	81.4	58.3	87.5	55.3
	EPI	72.7	66.0	81.1	48.3	82.7	80.5	89.8	54.0
	PRF	74.3	80.7	94.3	64.0	n.a.		n.a.	
Required avg.		13.8	n.a.	13.8	n.a.	6.9	n.a.	6.9	n.a.

Test condition		Boil				Vacuum-pressure			
Age group		16 y		20 y		16 y		20 y	
Test	Adhesive	MOR	WF	MOR	WF	MOR	WF	MOR	WF
Bending	NFJ	n.a.		n.a.		n.a.		n.a.	
	PVAc	n.a.		n.a.		n.a.		n.a.	
	EPI	36.9	35.8	38.7	21.3	44.0	33.5	48.2	23.8
	PRF	59.4	74.7	67.2	69.3	62.3	75.0	82.7	70.7
Required avg.		9.7	n.a.	9.7	n.a.	9.7	n.a.	9.7	n.a.

MOR = modulus of rupture (MPa)
WF = wood failure (%)
n.a. = not available

NFJ = non-finger-jointed (solid wood)
PVAC = polyvinyl acetate
EPI = emulsion polymer acetate
PRF = phenol-resorcinol formaldehyde

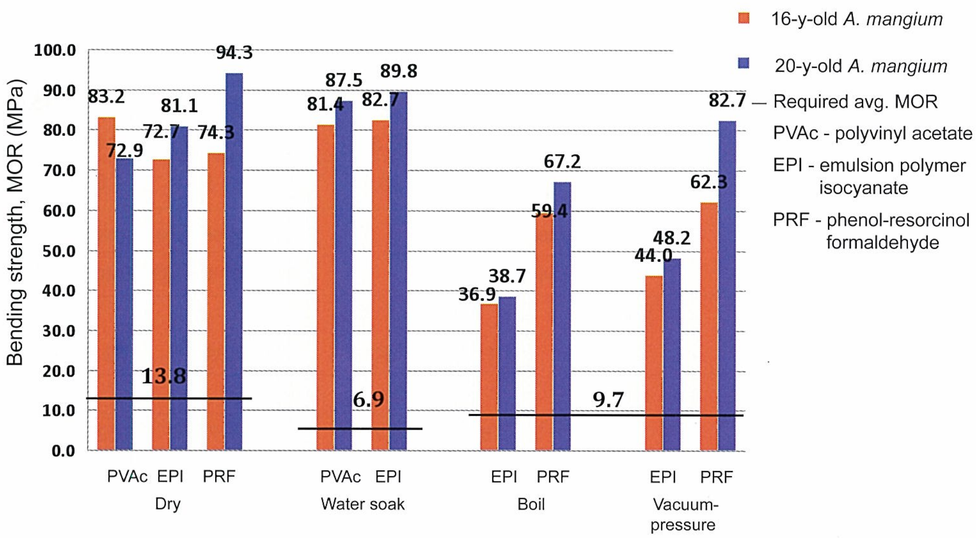


Figure 7 Bending strength (MOR) values with different adhesives and treatment conditions

Figure 7 shows the bending strength results with their respective test requirements. It also shows that the bending strength of the 20-y-old *A. mangium* is consistently higher than that of the 16-y-old except for samples bonded with PVAc adhesive tested in dry condition.

Tension test results

The tension test results for both age groups of *A. mangium* are provided in Table 2. The tensile strength of the samples bonded with the three different types of adhesive met the requirements as stipulated in the manual.

Table 2 Tension test results

Test condition		Cured (Dry)				Water soak			
Age group		16 y		20 y		16 y		20 y	
Test	Adhesive	TS	WF	TS	WF	TS	WF	TS	WF
Tension	Solid wood	125.1	n.a.	138.2	n.a.	n.a.		n.a.	
	PVAc	57.2	43.3	62.7	49.7	61.5	48.3	65.6	56.3
	EPI	57.8	53.7	63.6	43.3	60.5	71.0	67.4	51.0
	PRF	60.5	78.4	68.8	62.2	n.a.		n.a.	
Required avg.		13.8	30	13.8	30	6.9	15	6.9	15
Test condition		**Boil**				**Vacuum-pressure**			
Age group		16 y		20 y		16 y		20 y	
Test	Adhesive	TS	WF	TS	WF	TS	WF	TS	WF
Tension	Solid wood	n.a.		n.a.		n.a.		n.a.	
	PVAc	n.a.		n.a.		n.a.		n.a.	
	EPI	25.8	28.0	25.9	20.7	37.9	25.7	31.7	15.0
	PRF	48.5	78.0	56.9	70.3	56.8	68.7	62.1	60.0
Required avg.		11.0	25	11.0	25	11.0	25	11.0	25
Test condition		**Elevated temperature (104 °C)**				**Temperature-humidity (65 °C, 16% EMC)**			
Age group		16 y		20 y		16 y		20 y	
Test	Adhesive	TS	WF	TS	WF	TS	WF	TS	WF
Tension	Solid wood	n.a.		n.a.		n.a.		n.a.	
	PVAc	10.1	8.7	18.8	14.7	14.5	7.0	17.2	6.2
	EPI	53.4	64.0	64.2	30.7	46.5	48.7	47.3	14.0
	PRF	54.3	75.3	64.1	64.0	n.a.		n.a.	
Required avg.		6.9	n.a.	6.9	n.a.	5.2	n.a.	5.2	n.a.

TS=tensile strength (MPa), WF=wood failure (%), n.a.=not available

Figure 8 shows the tensile strength results with their respective test requirements. The tensile strength of the 20-y-old *A. mangium* is consistently higher than that of the 16-y-old except for samples bonded with EPI adhesive tested in vacuum-pressure condition.

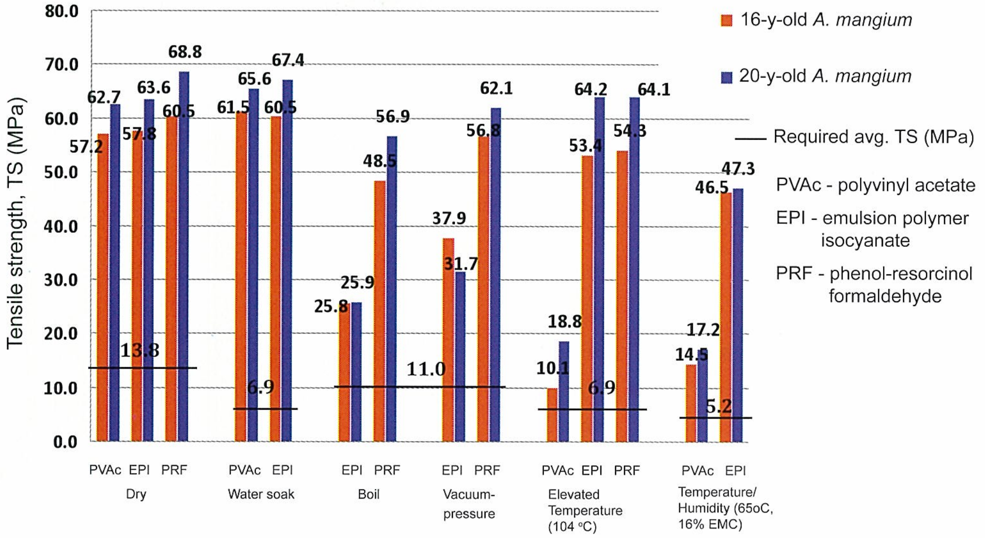


Figure 8 Tensile strength (MOR) values with different adhesives and treatment conditions

Figure 9 illustrates the average wood failure values of samples in the tension test with their respective test requirements. Almost all the samples met the minimum requirements of WF as stipulated in the manual, except for the EPI samples of the 20-y-old trees treated in boil condition and vacuum-pressure condition. There are no minimum requirements for test conditions of elevated temperature (104 °C) and temperature/humidity (65 °C, 16% EMC) as stated in the testing manual.

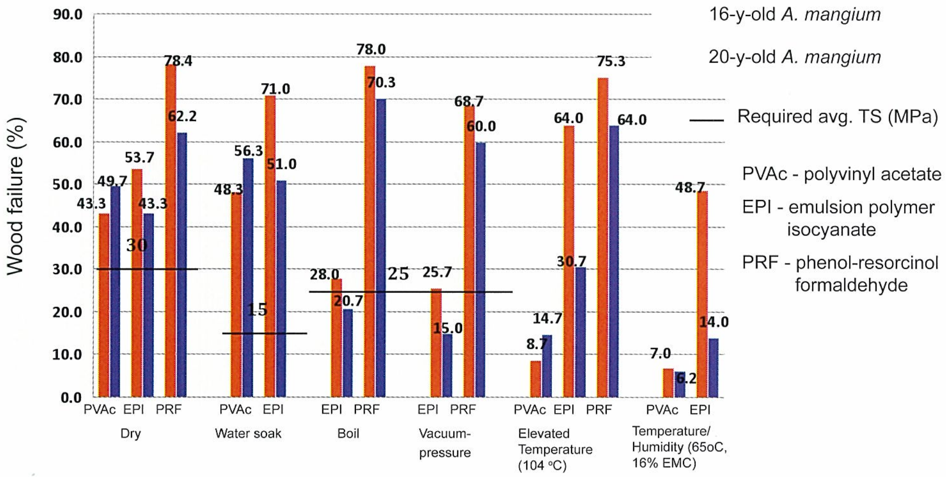


Figure 9 Wood failure percentages of samples in tension test

Table 3 gives the failure mode results of samples when tested in tension using different adhesives and treatment conditions. All samples bonded in PVAc failed mostly in mode 2, while all EPI samples also failed mostly in mode 2 except for the 16-y-old samples treated in boil condition which failed mostly in mode 1. The 16-y-old samples bonded in PRF failed mostly in mode 1 while the 20-y-old samples failed mostly in mode 2 except for samples treated with elevated temperature 104 °C which failed mostly in mode 1.

Table 3 Failure modes in tension test

Adhesive	Test condition	Age group (y)	No. of counts*						Total counts
			Mode						
			1	2	3	4	5	6	
PVAc	Dry	16	1	17	3	0	0	9	30
		20	0	18	2	4	2	4	30
	Water Soak	16	4	11	1	3	1	10	30
		20	2	11	2	6	3	6	30
	104 °C	16	1	25	0	1	2	1	30
		20	1	27	0	1	0	1	30
	65 °C	16	0	30	0	0	0	0	30
		20	0	29	0	0	0	1	30
EPI	Dry	16	3	15	5	0	7	0	30
		20	2	9	5	1	5	8	30
	Water Soak	16	1	15	3	1	1	9	30
		20	6	3	1	5	2	13	30
	Boil	16	23	4	1	1	1	0	30
		20	0	19	8	2	0	1	30
	Vacuum-Pressure	16	1	23	4	1	1	0	30
		20	0	18	7	3	0	2	30
	104 °C	16	3	12	12	0	0	3	30
		20	6	1	3	11	1	8	30
	65 °C	16	4	21	4	0	0	1	30
		20	0	15	4	1	1	9	30
PRF	Dry	16	15	3	3	0	6	3	30
		20	1	10	1	11	0	7	30
	Boil	16	17	0	3	0	1	9	30
		20	1	7	5	8	1	8	30
	Vacuum-Pressure	16	19	2	5	0	0	4	30
		20	4	10	6	2	0	8	30
	104 °C	16	16	0	6	0	3	5	30
		20	13	2	4	3	2	6	30

*No. of counts based on 30 specimens tested.

Block-shear test results

Table 4 shows the test results of shear strength for both age groups treated in five different conditions.

Table 4 Block-shear test results

Test condition		Cured (Dry)				Water soak			
Age group		16 y		20 y		16 y		20 y	
Test	Adhesive	SS	WF	SS	WF	SS	WF	SS	WF
Block Shear	PVAc	10.36	51.2	12.39	3.7	11.35	39.0	7.00	9.1
	EPI	13.48	40.3	12.82	27.3	11.54	61.7	11.72	86.5
	PRF	12.31	75.2	13.56	59.7	n.a.		n.a.	
Required avg.		5.32	30	5.32	30	2.66	15	2.66	15

Test Condition		Boil				Vacuum-pressure				Elevated temperature (104 °C)			
Age group		16 y		20 y		16 y		20 y		16 y		20 y	
Test	Adhesive	SS	WF	SS	WF	SS	WF	SS	WF	SS	WF	SS	WF
Block Shear	PVAc	n.a.		n.a.		n.a.		n.a.		1.39	4.8	1.12	5.2
	EPI	6.97	23.3	4.38	12.7	9.30	18.5	8.19	74.3	9.10	55.2	6.43	28.1
	PRF	8.25	81.7	10.20	64.7	10.76	77.3	12.90	70.0	10.41	81.8	11.88	54.0
Required avg.		4.44	25	4.44	25	4.44	25	4.44	25	3.55	20	3.55	20

SS = shear strength (MPa)
WF = wood failure (%)
n.a. = not available

Figure 10 presents the shear strength values for both age groups treated in five conditions and their minimum requirements. All the 16-y-old samples met the minimum requirements of shear strength values stipulated in the manual except for samples bonded with PVAc treated in elevated temperature condition. All the 20-y-old samples met the minimum requirements except for samples bonded with EPI treated in boil condition and samples bonded with PVAc treated in elevated temperature condition.

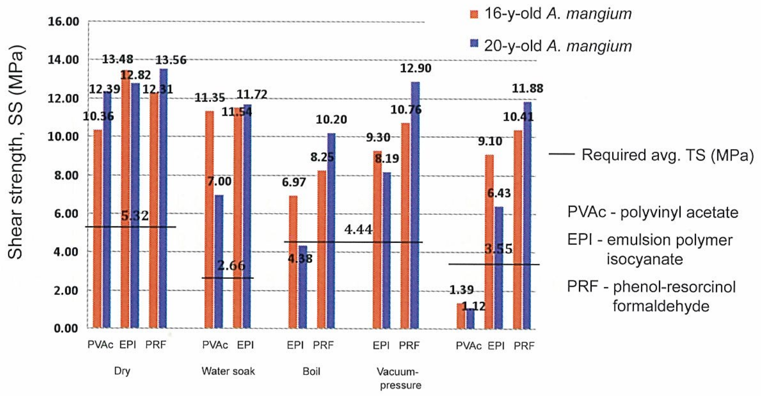


Figure 10 Shear strength (MOR) values with different adhesives and treatment conditions

Figure 11 depicts the average wood failures for all samples of both age groups bonded with the three types of adhesive treated in the five conditions. The 16-y-old age group met the required WF as stipulated in the manual except for samples bonded with EPI treated in boil condition and vacuum-pressure condition, and samples bonded with PVAc treated in elevated temperature condition. The 20-y-old age group met the required WF except for samples bonded with PVAc of dry condition, treated in water-soak and elevated temperature conditions, and for samples bonded with EPI in dry condition and treated in boil condition.

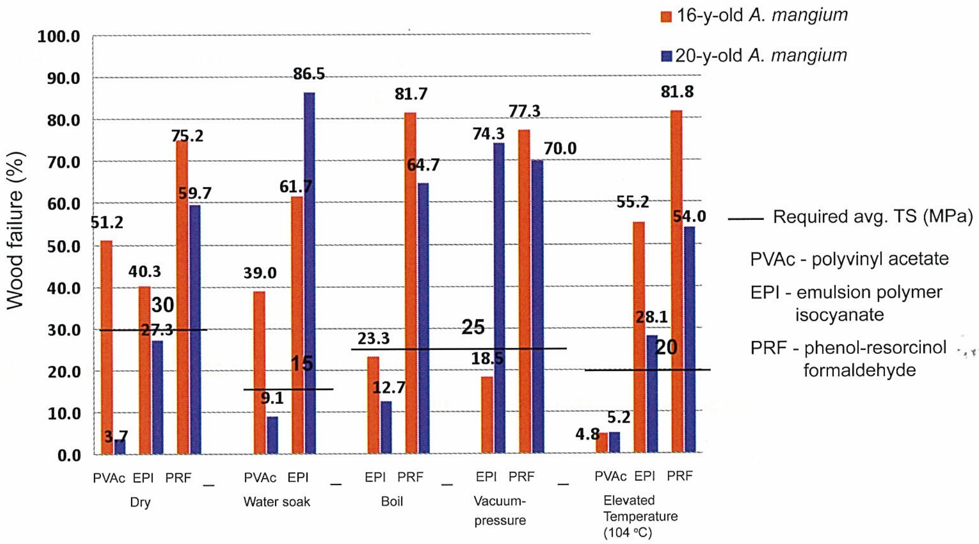


Figure 11 Wood failure percentages in block-shear test

Delamination test results

Table 5 gives the delamination test results for both age groups treated in four different service conditions.

Table 5 Delamination test results

Test condition		Immersion 6 hr		Immersion 24 hr		Boiling-water soak		Vacuum/ pressure	
Age group (y)		16	20	16	20	16	20	16	20
Test	Adhesive	Avg. delamination ratio (%)							
	PVAc	32.6	34.8	68.2	84.3	99.3	100.0	96.1	97.1
Delamination	EPI	9.7	15.4	34.4	35.7	52.9	77.6	71.8	78.5
	PRF	10.1	27.7	24.0	23.8	7.6	4.3	25.1	16.8

Avg. delamination ratio shall not exceed 10%.

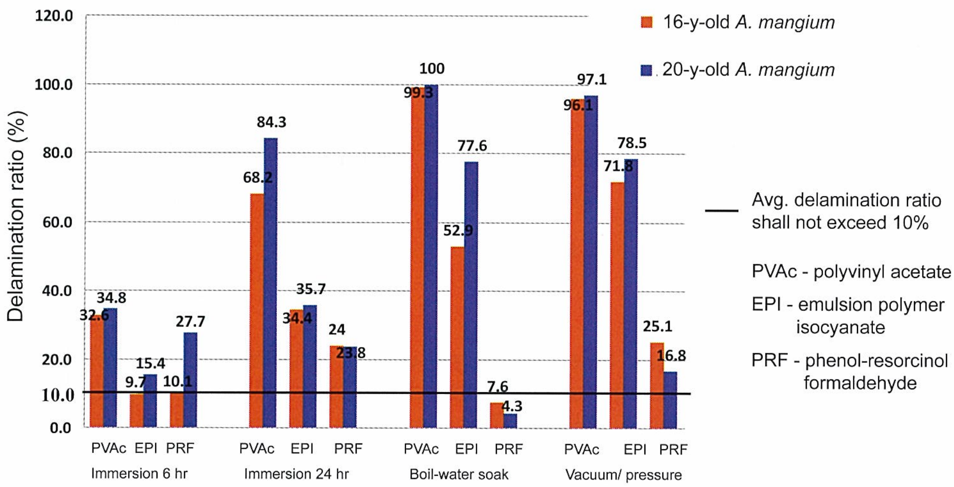


Figure 12 Delamination ratios (%) with different adhesives and treatment conditions

Figure 12 shows that only the 16-y-old samples bonded with EPI adhesives treated with immersion for 6 hr and PRF samples of both age groups treated with boiling-water soak met the requirements as stipulated in the manual.

Comparison of strength values between finger-jointed and solid samples

Table 6 shows the bending strength results of the finger-jointed samples with different adhesives compared to non-finger-jointed or solid *A. mangium*, both tested in dry condition. The bending strength values of the finger-jointed samples compared to solid wood show percentage strength ratios of more than 65% for age group of 20 y and more than 58% for age group of 16 y.

Table 6 Comparison of strength values of finger-jointed and solid samples in bending test

Age group	Finger-jointed						Solid wood	
	16 y			20 y			16y	20 y
Adhesive	PVAc	EPI	PRF	PVAc	EPI	PRF		
MOR (MPa)	83.2	72.7	74.3	72.9	81.1	94.3	125.1	111.1
Strength ratio (%)	66.5	58.1	59.4	65.6	73.0	84.9		

Table 7 gives the tensile strength results of the finger-jointed samples with different adhesives compared to solid *A. mangium*, both tested in dry condition. The tensile strength values of the finger-jointed samples compared to solid wood show percentage strength ratios of more than 45% for age group of 20 y and more than 52% for age group of 16 y.

Table 7 Comparison of strength values of finger-jointed and solid samples in tension test

Age group	Finger-jointed						Solid wood	
	16 y			20 y			16	20 y
Adhesive	PVAc	EPI	PRF	PVAc	EPI	PRF		
TS (MPa)	57.2	57.8	60.5	62.7	63.6	68.8	108.4	138.2
Strength ratio (%)	52.8	53.3	55.8	45.4	46.0	49.8		

The average bending and tensile strength values of solid *A. mangium* of both age group were tested and contributed by Mohamad Omar Mohamad Khaidzir of the Timber Engineering Laboratory, FRIM. These average strength values were taken from log No. 10 for age group 20 y while for age group 16 y, the results were from log No. 12.

CONCLUSION

The user must understand the selection of testing methods which depends on the requirement of specific product application. For example, if the end-use is meant for indoor usage with little or no water interruption and the surrounding humidity is low, it is not required for the user to test the product with the boil test.

The methodology adopted in this paper is suitable for use to evaluate the finger-jointing and lamination properties of tropical plantation species except that *A. mangium* may have problems in lamination properties. Its sensitivity to the influences of factors such as moisture content, drying stresses, smoothness of planing surfaces and adhesive curing may tend to delaminate the bonding if proper gluing requirements are not taken seriously.

In terms of wood failure for the tension and block shear tests, the samples tested may not fulfill all the requirements because the assessment of the areas and amounts tend to be subjective and depends on the operator's visual opinion. Thus it is recommended that results for tension and block shear tests shall be concentrated on the strength values rather than the wood failure percentages. The finger-jointing properties of *A. mangium* passed all the tests but its lamination properties showed otherwise. Further testing and research are needed to improve the lamination properties of this species.

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BIBLIOGRAPHY

ANONYMOUS. 1999. ASTM D5751-99 (1999). *Standard Specification for Adhesives Used for Laminate Joints in Nonstructural Lumber Products.*

ANONYMOUS. 2003a. ASTM D5572-95 (2003). *Standard Specification for Adhesives Used for Finger Joints in Nonstructural Lumber Products.*

ANONYMOUS. 2003b. JAS 2003, MAFF, Notification No. 234. *Japanese Agricultural Standard for Glued Laminated Timber.*

ANONYMOUS. 2006. ISO 17087:2006(E). *Specifications for Adhesives Used for Finger Joints in Non-structural Lumber Products.*

TAN, Y. E., LIM, N. P. T., GAN, K. S., WONG, T. C., LIM, S. C. & THILAGAWATHI, M. (Eds) 2010. *Testing Methods for Plantation Grown Tropical Timbers*. FRIM, TRTTC & FRC. 155 pp.

CHEMICAL COMPOSITION

M. P. Koh

INTRODUCTION

Knowledge of chemical composition is a guide to the understanding of the properties and behaviour of wood. This is especially important for the pulp and paper industry. The chemical consumption during pulping depends on the composition of the original wood. Wood chemistry also plays an important role in the biological decomposition of wood by fungi and attack by wood-boring insects.

The proximate chemical composition of *Acacia mangium* wood in Malaysia from earlier studies shows: holocellulose (69.4–73.8%), alpha-cellulose (44.0–49.5%), hot-water extractives (0.9–9.8%), pentosans (16.0–18.2%) and lignin (19.7–25%) (Peh et al. 1982, Jegatheswaran 1988, Alloysius 1989, Khoo et al. 1991). *Acacia mangium* in the Philippines gave hollocellulose (72.06–72.22%) (Fidel & Tamayo 1999).

Preliminary investigations showed that tannin in the bark of *A. mangium* has good reactivity with formaldehyde indicating good adhesive properties. Chew et al. (1992) noted that 5- to 9-y-old *A. mangium* bark has high tannin content (18–39%), justifying possible commercial utilization of tannin.

Several researchers have studied the technical feasibility of producing cement-bonded particle boards from *A. mangium.* Tachi et al. (1989) found that *A. mangium* has a cement-hardening inhibitor component called teracacidin, with 7, 8-dihydroxyl group that retards hardening even in the presence of calcium chloride. Rahim et al. (1991) reported that *A. mangium* has a low sugar content (0.54%), below the cement-setting inhibitor level of 0.5–0.6%.

This study determined the basic chemical compositions of the wood and bark of locally-grown *A. mangium* and compared them with those from the Philippines and Indonesia .

MATERIALS AND METHODS

Six trees each of *A. mangium* aged 20 y and 16 y were used. The wood samples were taken from the butt, middle and top portions of the logs as described in TAPPI-Hwd-76 *Sampling and Preparing Wood for Analysis.* These were chipped, dried and then ground in a Wiley mill using a 40-mesh screen.

Chemical analyses of the wood

The wood samples for analyses were prepared using a composite sampling method. The various components were analysed following standard test methods of the Technical Association of the Pulp and Paper Industry (TAPPI), as well as methods agreed upon in the various collaborative studies (Table 1).

Table 1 Wood components and their methods of analysis

Component	Method of analysis
Moisture content	MS 837: 2006: Solid Timber
Hot water solubility	TAPPI Test Method T 207 – OM 93
Alcohol/toluene extractives	TAPPI Test Method T 204 – OM 88
Acid insoluble lignin	TAPPI Test Method T222 – OM 88
Pentosans	TAPPI Test Method T 223 – CM 84
Holocellulose	Wise, Murphy and D'Addico Method

RESULTS AND DISCUSSION

The chemical composition of wood varies among species. Variation also exists within and between trees of the same species and these can be attributed to the age of the tree, genetic factors and ecological conditions of growth.

Basic chemical properties of the whole wood

Table 2 summarizes the basic chemical properties of *A. mangium* wood. The results are reported in percentages based on oven-dry weight of sample. The results indicate variations in chemical components among tree replicates in comparison with previous studies as well as those from the Philippines and Indonesia.

Table 2 Basic chemical properties of *Acacia mangium* wood

Age (y)	Timber ID	Hot water solubility (%)	Ethanol - toluene solubility (%)*	Hexane solubility (%)	Pentosans (%)	Lignin (%)	Hollocellulose (%)
20	10	7.75	8.22	0.72	16.56	25.25	79.99
	32	7.41	7.58	1.29	11.64	25.01	78.47
	57	6.72	9.29	1.12	9.96	24.46	78.44
	77	7.51	9.04	1.04	16.14	23.29	80.63
	78	6.36	9.34	1.17	18.31	26.38	81.85
	79	5.49	7.77	0.67	17.07	24.7	83.34
	20 y (ave)	6.87	8.54	1.00	14.95	24.85	80.46
16	72	5.33	7.54	1.3	14.97	28.25	79.87
	39	6.16	9.85	1.22	13.43	26.17	75.19
	10/2	5.34	8.18	1.25	13.57	27.26	79.23
	12	6.01	7.73	1.04	12.23	26.58	81.91
	13	5.15	7.44	1.11	16.18	24.55	83.81
	88	5.54	7.03	1.14	15.65	25.00	79.12
	16 y (ave)	5.59	7.96	1.18	14.34	26.31	79.86
Previous [1]		0.9–9.8	2.9–5.6	-	16.0–18.2	19.7–24.5	69.4–73.8
Philippines [2]		1.62–2.56	2.82–4.34	-	11.67–14.4	21.31–21.5	72.06–72.22
Indonesia [3]		3.30–6.00	3.70–6.77	-	14.88–17.84	26.72–32.12	69.4

Note:
* Benzene was the non-polar solvent used in earlier studies (below)
[1] Chew et al. 1992
[2] Fidel & Tamayo 1999
[3] Jamaludin et al. 2000

Wood extractives

Alcohol-toluene extractives: The alcohol-toluene extractable content of wood consists of fats, waxes, resins, oils and non-volatile hydrocarbons.

The 20-y-old *A. mangium* in general showed a higher ethanol-toluene extractive content compared with the 16-y-old sample. Toluene was used instead of benzene due to the concern of benzene being classified as possibly carcinogenic.

Local *A. mangium* had higher alcohol-benzene extractives (2.9–5.6%) than its Philippines counterpart (2.82–4.34%) but lower than the contents from Indonesia (3.70–6.77%). Materials with high alcohol-benzene(toluene) extractives (above 7%) are generally less acceptable for pulp and paper since they cause high pitch problems during papermaking.

Hot water extractives. The hot water extractable content of wood consists of tannins, gums sugars, pigments, salts and starch. The hot water extractive content of the 20-y-old acacia wood was higher than that of the 16-y-old trees. Previous studies of Malaysian mangium showed a bigger variation (0.9–9.8%) which is higher than those of the Philippines (1.62–2.56%) and Indonesian studies (3.30–6.00%). Wood with high hot water extractives gives less yield and consumes more pulping chemicals, hence not preferred by pulp mills.

Hexane extractives. Hexane extractives are made up of waxes, fats, resins and oils. These components affect the bonding of wood and hence are quite critical for plywood manufacture. Timbers 10 and 79 of the 20-y-old age group seem to contain less waxes and fats as shown by the lower amounts soluble in hexane.

Pentosans. It is noted that the 20-y-old trees in general had higher pentosan yields as compared with the 16-y-old trees with the exception of samples 32 and 57. Local *A. mangium* in previous studies gave higher pentosan contents (16–18.2%) than Philippines mangium (11.67–14.4%) but comparable with those from Indonesia (14.8 –17.84%). Part of the hemicelluloses or non-cellulosic carbohydrates of wood, pentosans contribute to the strength of pulp.

Lignin. Lignin is an undesired wood component for pulp and papermaking. Materials with high lignin require more pulping and bleaching chemicals, longer cooking time or higher processing temperature. The lignin contents of the 20-y-old (24.85%) and 16-y-old (26.31%) Malaysian *A. mangium* are higher than those of previous studies(19.7–24.5%) and from the Philippines (below 22%). *Acacia mangium* from Indonesia, however, had higher contents (26.72–32.12%) than the Malaysian samples.

Holocellulose. Holocellulose represents the total carbohydrate content of the wood. In the pulp and paper industry the holocellulose content is an important property requirement because it directly affects pulp yield. The holocellulose content of the 20-y-old (80.46%) as well as that of the 16-y-old (79.86%) Malaysian-grown mangium was higher than those from previous studies (69.4–73.8%) which compare favourably with those of the Philippine mangium (72.06–72.22%). The Indonesian mangium had lower holocellulose content (average 69.4%). Overall, *A. mangium* is an acceptable source of raw material for the pulp and paper industry.

CONCLUSION

Acacia mangium of age 20 y in general shows higher contents of hot water extractables as well as of ethanol-toluene solubles compared with 16-y-old *A. mangium*.

The average quantities of the other constituents do not vary significantly between the two age groups.

Timbers 10 and 79 of the 20 y age group seem to contain less waxes and fats as shown by the lower amounts soluble in hexane

It is noted that the 20-y-old trees in general have higher pentosan yields as compared with the 16-y-old trees with the exception of timbers 32 and 57.

In comparison with rubberwood, both age groups have comparable total extractables (toluene-ethanol solubility). The average pentosan as well as the average lignin contents for both age groups are lower. Correspondingly, the holocellulose contents are higher for both age groups.

BIBLIOGRAPHY

ALLOYSIUS, D. 1989. Pulp ond Paper Properties of 4-year-old *Acacia mangium.* B.Sc. For. Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

ANONYMOUS. 1984. TAPPI Test Method T 223 – CM 84. *Pentosans in Wood and Pulp.*

ANONYMOUS. 1988.TAPPI Test Method T 204 – OM 88. *Solvent Extractives of Wood and Pulp.*

ANONYMOUS. 1988. TAPPI Test Method T222 – OM 88. *Acid Insoluble Lignin in Wood and Pulp.*

ANONYMOUS. 1993. TAPPI Test Method T 207 – OM 93. *Water Solubility of Wood and Pulp.*

CHEW, L. T., NURULHUDA, M. N., SAIMIN, B. & YAMADA, N. 1992. Chemical properties of *Acacia mangium* barks of different ages and locations. Pp 7–12 in W. A. K. Wan Rashidah et al. (Eds) in *Proc. Second Chemistry Div. Seminar*, FRIM, Kepong, Selangor.

FIDEL, M. M. & TAMAYO, J. P. 1999. Chemical properties of *Acacia mangium*: implications for pulp and paper production. *FPRDI Journal* 25 [1 & 2] January – December 1999: 107–114.

JAMALUDIN, M., ADI, S. & OSLY, R. 2000. Sari hasil penelitian mangium (*Acacia mangium* Willd). http://www.deut.go.id/SAR%20Hasil%20PENELITIAN%20 MANGIUM%20.

JEGATHESWARAN, R. 1989. Effects of Extractive Content on Reduction on Some Mechanical Properties of *Acacia mangium* Cement Bonded Board. M.Sc. Project Report, Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.

KHOO, K. C., MOHD NOR, M. Y. & LEE, T. W. 1991. Some compensatory forest plantation species for paper pulp. Pp 764–773 in Sheikh Ali Abod et al. (Eds) *Recent Developments in Tree Plantations of Humid/Subhumid Tropics of Asia. Proc. of Regional Symposium,* June 5–9 1989, University Pertanian Malaysia, Serdang, Malaysia.

PEH, T. B., KHOO, K. C. & LEE, T. W. 1982. Sulphate pulping of *Acacia mangium* and *Cleistopholis glanca* from Sabah. *Malaysian Forester* 45(3): 404–418.

RAHIM, S., CHEW, L. T., KHOZIRAH, S. & ZAKARIA, M. A. 1991. Cement bonded particleboard from *Acacia mangium.* A preliminary study. *J. Trop. For. Sci.* 2(4): 267–273.

TACHI, M., TANGE, J., NAGADOMI, W. Y., SUZUKI, TERASHIMA, N. & YASUDA, S. 1989. Manufacture of wood cement boards IV. Cement hardening inhibitory components of Malaysian fast-growing tree *Acacia mangium. Mokuzai Gakkaishi* 35(8): 731–735.

WISE, MURPHY & D'ADDICO. 1946. Holocellulose in Wood. *Paper Trade Journal 122 # 2:* 35.

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