Journal of Tropical Forest Science 35 (Special Issue): 67–74 (2023)
https://doi.org/10.26525/jtfs2023.35S.SI.67
ISSN: 0128-1283, eISSN: 2521-9847

ASSESSMENT OF KILN DRIED *ACACIA MANGIUM* FOR PRODUCTION OF QUALITY VALUE-ADDED PRODUCTS

Zahidah Z[1, *], Sik HS[1], How SS[1], Ho WM[2], Ramzul Iklas AL[1] & Tanjong A[1]

[1]*Forest Products Division, Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia*
[2]*Forest Biotechnology Division, Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia*

**zahidah@frim.gov.my*

Submitted January 2022; accepted December 2022

The current study was aimed at exploring ways to improve the drying performance and treatment procedures of acacia timber that would boost the local timber industry through production of value–added products. In the experiment, selected mechanical properties of acacia sawn timber were determined after it was subjected to kiln drying. The mean values of modulus of rupture and modulus of elasticity of kiln dried acacia sawn were 137.48 and 13842.30 N mm^{-2} respectively, while its mean value of hardness and mean shear stress value was 5.80 kN of 17.14 N mm^{-2} respectively. Delamination and bending tests were also conducted on finger joints for truck flooring. All test pieces met the criteria for delamination of finger-joint specified in JASO M 901-85: wooden parts for cargo bed of motor trucks. The acacia finger-joint test pieces also met the criteria for Young's modulus for bending with an average bending strength value of 74 MPa. The finding indicates that *A. mangium* finger-joints produced in this study can be a potential laminating feedstock for downstream processing of value added products, such as laminated truck flooring.

Key words: Acacia timber, laminating feedstock, mechanical properties, downstream processing, value–added products

INTRODUCTION

Acacia mangium belonging to the family of Leguminosae was first introduced in Sabah, Malaysia in 1967 as a fire-break species (Nordahlia et al. 2013). It was subsequently planted in Peninsular Malaysia in 1982 to meet the increasing demand for timber. As of 2019, about 337,500 ha of *A. mangium* had been planted in Malaysia, mainly in the states of Sarawak followed by Sabah and Peninsular Malaysia (Ratnasingam et al. 2020).

Acacia mangium is classified as light hardwood timber with a density ranging between 290 and 580 kg m^3 and shrinkage of 6.4 in tangential and 2.7 in radial (Wong et al. 2002). The heartwood of the timber is light brown to golden brown in colour and may darken upon long exposure. In contrast, the sapwood is white in colour. The growth ring of *A. mangium* timber is absent or vaguely present and it has straight to shallow interlocked grain (Nordahlia et al. 2013).

Acacia mangium has been well accepted as a viable species for commercial plantation due to many of its positive characteristics: fast growing, a high survival rate and good timber quality. The logs are quite straight and easy to be processed (Lim et al. 2003). The machining properties of *A. mangium* is excellent and its surface quality has been consistently graded as good to excellent (Khairul et al. 2011). *A. mangium* timber is rated as non-durable against both fungi and insect attack and it is reported to be easily treated with preservatives (Lim et al. 2003). It is also used to manufacture furniture components, joineries and other composite panel products.

Drying plays an integral part in timber processing as it can increase the stability of timber and improve its resistance against fungal and insect attacks. Furthermore, it can enhance the physical, chemical and mechanical properties of timber as well as the efficiency of wood manufacturing processes, such as machining, gluing and finishing. There are several drying methods practised worldwide, such as air drying, kiln drying and solar drying. Each drying method will influence the drying performance of the timber, such as the duration and quality of the timber produced.

Generally, the drying of *A. mangium* is regarded as challenging by most timber producers as the timber is prone to several defects due to their inherent characteristics. Wood defects such as checks, cup and crook are generally increased after drying in *A. mangium* timber, and it is reported to be higher than other plantation species in tropical regions (Moya et al. 2008). Tenario et al (2012) reported that *A. mangium* had high incidence of collapse and splits; the separation of fibre caused by the tearing apart of wood parallel to the wood rays. He also mentioned that the defects are further compounded by the occurrence of moisture or wet pockets in the lumber. Wet pockets which tends to form in lumber from trees growing in very humid and tropical climates can influence the variability of final moisture content of the dried *A. mangium* lumber (Tenario & Moya 2011). Hence, the timber must be dried using mild drying protocol and this results in prolonged drying time with relatively high energy consumption.

Finger-joints are used extensively in the manufacture of engineered lumber, such as glue-laminated timber (glulam) and cross-laminated timber (CLT). They are reported to have a better dimensional stability and good mechanical properties compared with raw sawn timber (Vella et al. 2019). Finger joints are also usually fabricated in the form of face-cut fingers (horizontal joint) and edge-cut fingers (vertical joint) (Sim 1985). Several factors affect the successful fabrication of finger joints, such as quality of the wood, adhesive types and glue spread (How et al. 2017). Based on the density, mechanical properties and bonding properties of *A. mangium* wood, this species offers great potential as raw material for manufacture of engineered lumber (Norwahyuni et al. 2019). The introduction of finger jointing and lamination technology helps to value add the *A. mangium* timber products by finger-jointing the shorter pieces to produce longer and higher quality timber (Ong & Ting 2011).

This study was motivated by challenges faced by the local acacia timber manufacturer to produce quality acacia lumber. It specifically targets on improving the drying performance and treatment procedures to achieve this purpose. The research further assessed the quality of the kiln dried acacia timber produced which can be used in the production of laminated truck flooring and other semi-finished wooden joineries or furniture components.

MATERIAL & METHOD

Material preparation

Readily available sawn timber resources were sourced from selected timber processing mills in Sabah, Malaysia. The industrial mill usually dries the mixed sawn timber. The boards were of various lengths ranging from 600 mm up to 1800 mm with two width measurements of 50 mm and 75 mm. The thickness was fixed at 25 mm thick. The use of timber of the same thickness is important in drying as it helps to accelerate the drying time as well as minimise the moisture variation between surface and core of the timber.

Drying

Approximately 40 tonnes *A. mangium* sawn timber, each with 25 mm thickness, were dried at selected timber processing mills in Sabah using an optimised drying schedule for *A. mangium* sawn timber (Table 1).

Before commencement of the trial, sample boards were randomly selected and placed within the timber stacks for monitoring the kiln drying process. The initial moisture content of sample board was determined by cutting 25 mm-thick strip from the edge of each sample board (Figure 1). Each strip was weighed before and after drying in an oven set at 103 ± 2°C until a constant weight was achieved. The initial moisture content (MC) of each sample board was calculated using the following formula:

$$MC = \left(\frac{W_g - W_o}{W_o}\right) \times 100$$

where W_g is the weight in green condition (g) and W_o is the oven-dry weight (g) of the specimen.

The drying process was monitored periodically by weighing the sample boards at set time intervals during drying. The oven-dry weight and current moisture content (MC) of the sample board was estimated based on the following formula:

$$W_o = \frac{W_g \times 100}{MC + 100}$$

$$MC_c = \left(\frac{W_c - W_o}{W_o}\right) \times 100$$

Table 1 Moisture content based drying schedule for 30 mm-thick *Acacia mangium* sawn lumber (Sik et al. 2018)

Moisture Content (%)	DBT (°C)	WBT (°C)	RH (%)
Pre kiln drying conditioning treatment	50	50	95~
60	53	50	84
55	57	52	76
50	59	50	61
40	61	48	48
30	65	47	38
~ 18% (Case hardening relief treatment)	60	58	90~
10–12% (Equalisation)	60	51	61

DBT = dry bulb temperature, WBT = wet bulb temperature, RH = relative humidity

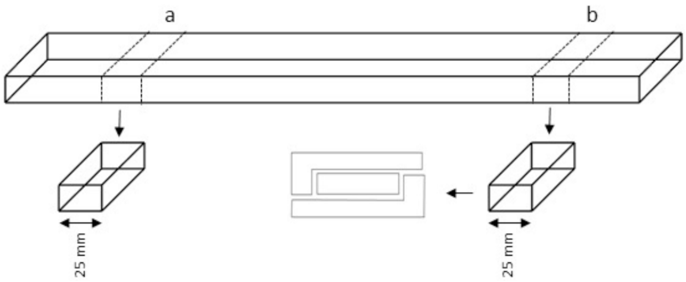

Figure 1 Sampling of sample board for determination of (a) moisture content and (b) moisture distribution. For (b), the specimen was further cut into three sections; surface 1, core and surface 2

where W_o is the oven-dry weight (kg), W_g is the weight in green condition (kg), W_c is the current weight (kg) of the sample board and MC_c is the current moisture content of the sample board.

At the end of the drying process, the moisture distribution within the core and shell of the sample board was assessed by slicing a 25 mm-thick strip into three sections of core and surface region (Figure 1).

Mechanical properties test

The kiln dried acacia timber was cut based on specific dimensions for mechanical testing in accordance with British 373 Standard.

The static bending test included Modulus of Rupture (MOR) which is a measure of maximum strength that a wood material can withstand, and Modulus of Elasticity (MOE) which is a measure of stiffness of the wood. The test was conducted by subjecting the specimens to load heads that move at a constant speed of 6.6 mm min^{-1}.

Hardness is a measure of the ability of the timber to withstand indentation force on its surface. It is a practical mechanical property used to assess the suitability of a timber species for residential and commercial flooring (Wiemann & Green 2007). In this study, the hardness test was carried out by applying a steel bar onto the test specimen with a constant force of 6.35 mm min^{-1}.

Shear strength is a measure of the ability of timber to resist internal slipping of one layer relative to another along the grain, and it is defined by the maximum load per shear plane area (Samson et al. 2021). In the current study, shear stress test was performed by applying load at a constant rate movement of 0.6mm min^{-1}.

The MOR, MOE and shear stress (t) of kiln dried *A. mangium* were calculated as per Mohd Jamil et al. (2018):

$$\text{MOR} = \frac{3}{3}\,\frac{F_{bend}{}^{3}}{bd^2}$$

$$\text{MOR} = \frac{1}{4}\,\frac{\Delta F}{\Delta 1}\,\frac{s^3}{bd^3}$$

$$t = \frac{F_{shear}}{A}$$

where, $\frac{\Delta F}{\Delta 1}$ is the slope of the graph (N mm^{-1}), s is the bending span (mm), b is the width of the specimen (mm), d is the thickness of the specimen (mm), F_{bend} is the maximum bending load (N), F is the maximum shearing load (N) and A is the area of shear, mm^2

Bonding properties of *Acacia mangium* finger joints

The kiln dried acacia sawn was blanked to a dressed size of 22 mm-thick and selected for further processing into finger-joints by joining two short pieces of sawn timber with suitable adhesive to form longer piece timber interlocking each other. Delamination test and bending test were conducted to assess the bonding performance of the fabricated acacia finger-joints sample. All test methods were carried out in accordance with JASO M 901-85: Wooden Parts for the Cargo Bed of Motor Trucks.

Delamination test

The delamination of acacia finger-joints was performed as below: The finger-joints sample of 200 mm in length with longitudinal joint at the centre were immersed in boiling water for 5 hours before being cooled down in water of ambient temperature for 1 hour. The test samples were dried at 60±3°C in the oven for 18 hours until the moisture content of the test samples was less than 18%. Upon completion of the test, 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 using the following formula:

$$\text{Delamination ratio (\%)} = \frac{\text{Total delamination length (mm)}}{\text{Total glue line (mm)}} \times 100$$

Bending test

The bending test was conducted to evaluate the stiffness and strength properties of the fabricated acacia finger-joints. The samples were tested for the centre-point bending strength and elasticity. The finger-jointed sample with dimension of 25 × 67 × 650 mm (depth × width × length) was symmetrically loaded in bending at centre-point 18 times its depth (Figure 2). The distance between the centre load point and the support was approximately 300 mm. The sample was supported with the span of approximately 600 mm. The load was applied at a constant loading-head movement adjusted so the maximum load was reached within approximately 1.5 mm min^{-1}. The bending strength (S_R) and bending modulus of elasticity (E_f) for each sample was calculated using the following formula:

$$\text{Bending strength } (S_R) = \frac{3P_{max}L}{2bd^2}$$

where, P_{max} is the maximum load borne by the test piece loaded to failure (N), L is the span of test piece (mm), b is the width of test piece (mm) and d is the depth of test piece (mm).

$$\text{Apparent Bending Modulus of Elasticity } (E_f) = \frac{PL^3}{4bd^3\Delta}$$

where, P is the increment of applied load below proportional limit (N), Δ is the increment of deflection of beam's neutral axis measured at midspan over distance L and corresponding load P (mm), L is the span of test piece (mm), b is the width of test piece (mm) and d is the depth of test piece (mm).

Matched-finger joint samples were also sent to an independent accredited laboratory of a glue supplier company for interlaboratory cross checks. The result obtained from both

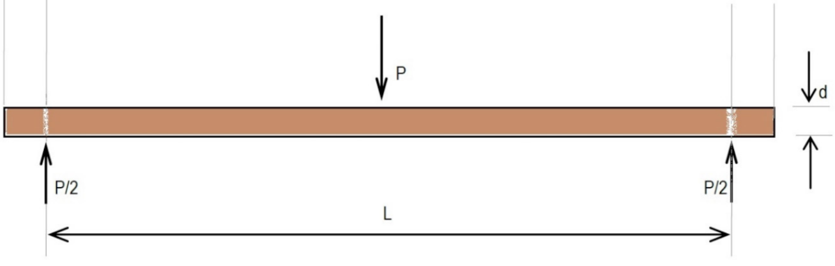

Figure 2 Arrangement for centre-point bending test of *A. mangium* finger joints

test locations complement and confirm the bonding performance of acacia finger-joints and its suitability for the production of laminated truck flooring and other semi-finished wooden joineries.

Statistical analysis

Data on mechanical and bonding properties of kiln dried *A. mangium* were subjected to one-sample t-Test using IBM SPSS software program, version 28.

RESULT & DISCUSSION

Drying

Initial moisture content

The initial moisture content (MC) of *Acacia mangium* sawn timber of 50 mm width group ranged from 20.23 to 35.86 % with a mean value of 27.30 %. The initial MC of 75 mm width *A. mangium* sawn was 102.35 % (65.82–141.20 %) (Table 2). Generally, it is common to find acacia timber with high initial MC and extremely high MC exceeding 200% has also been reported in acacia wood. The high initial MC value ranging between 110% and 184% in *A. mangium* sawn timber was also reported by Moya et al. (2008).

Drying characteristic

The drying time for 50 mm width *A. mangium* was recorded at 14 days when the timber reached the targeted moisture content (MC) of 6–8 %. Drying time for 75 mm width acacia sawn to reach the same targeted MC was about 18 days. *Acacia mangium* sawn timber was found to be able to dry uniformly throughout the timber and the variation of MC between the inner and outer layers was within permissible range of 2.0 % (Table 3).

The MC uniformity from the core towards the surface during drying is crucial in preventing or minimising the occurrence of severe case-hardening. The lack of MC uniformity has a significant impact on the manufacturing process and it will affect the quality of products manufactured. *Acacia mangium* is known for its high initial MC, presence of wet pockets and high variation in the MC. These conditions may lead to longer and irregular drying process resulting in uneven MC distribution within lumber. In this study, the protocol employed was able to dry the timber with effective moisture movement from the core towards the surface during drying, and the occurrence of wet pocket was minimised. Furthermore, drying time was reduced to about two weeks compared with conventional drying which takes about two months for 30 mm-thick sawn.

Table 2 Moisture content of *Acacia mangium* sawn timber

Width group (mm)	Initial moisture content (%)		Final moisture content (%)	
	Mean	Range	Mean	Range
50	27.23 (6.25)	20.23–35.86	5.82 (0.35)	5.40–6.33
75	102.35 (31.28)	65.82–141.20	6.57 (1.18)	5.05–7.77

Figures in parentheses are standard deviations

Table 3 Moisture distribution between surface and core section of kiln dried *Acacia mangium* sawn timber

Width group (mm)	Moisture content distribution (%)					
	Surface 1		Core		Surface 2	
	Mean	Range	Mean	Range	Mean	Range
50	5.66 (0.25)	5.37–5.95	5.92 (0.18)	5.64–6.11	5.74 (0.34)	5.21–6.06
75	6.48 (0.56)	5.83-7.35	6.82 (1.18)	5.53–8.71	6.47 (0.46)	5.89–7.17

Figures in parentheses are standard deviations

Mechanical properties

The mechanical properties of kiln dried *Acacia mangium* sawn are shown in Table 4. Static bending test results showed that the mean values of modulus of rupture (MOR) and modulus of elasticity (MOE) of kiln dried acacia sawn were 137.48 and 13842.30 N mm^{-2} respectively. The mean value for hardness of the kiln dried timber was 5.80 kN, and a mean shear stress value of 17.14 N mm^{-2} under test condition. The analysis showed the value of MOR, MOE, hardness and shear stress of all samples tested were not statistically significantly different from each other at $p>0.05$.

The mechanical properties of kiln dried *A. mangium* were compared with previously published data on air dried *A. mangium* (Table 4). The mean values of MOR, MOE and shear strength of kiln dried acacia sawn obtained in this study was higher compared with air-dried *A. mangium* samples reported by Lee et al. (1979), Mohamad Omar and Mohd. Jamil (2011) and Alik and Nungah (2014). Furthermore, the mean hardness value of kiln dried *A. mangium* obtained in this study was also increased by approximately 20 to 50 % compared with air-dried *A. mangium* (Alik & Nungah 2014, Mohamad Omar & Mohd Jamil 2011).

In this study, the kiln dried *A. mangium* was found to have better mechanical properties as compared with air-dried *A. mangium.* The finding suggested that the drying method can influence the mechanical properties of timber. Uetimane (2020) and Jacek et al. (2004) also reported that wood dried under controlled environment has better mechanical properties compared with air dried timber. Samson et al. (2021) endorsed this finding and indicated that timber dried under controlled environment, such as kiln drying and solar drying, are able to produce wood that has greater mechanical properties compared with natural drying like air-drying.

Overall, the kiln dried *A. mangium* in this study has good mechanical properties and suitable for the production of truck flooring and furniture components.

Bonding properties of *A. mangium* finger-joints

The bonding properties of finger joints sample fabricated from kiln dried *A. mangium* are shown in Table 5. The analysis showed that the value of total delamination, bending strength and Young's modulus of bending of all samples tested were not statistically significantly different from each other at $p>0.05$. The average percentage of total delamination of acacia finger-joints samples was 0.775 %. Based on the test requirements stated in JASO M 901-85, the performance of side edge boards and front end boards of the finger-jointed samples should be less than 15% and the average delamination of finger-joint should be

Table 4 Mechanical properties of *Acacia mangium* sawn timber

Condition	Modulus of rupture	Modulus of elasticity	Janka hardness	Shear strength parallel to grain
	(N mm^{-2})	(N mm^{-2})	(kN)	(N mm^{-2})
Kiln-dried [a]	137.48	13842.30	5.80	17.14
	(30.59)	(1535.59)	(1.37)	(4.16)
Air-dried [b]	95.10	11626	4.22	14.85
	(12.37)	(1184)	(0.84)	(2.75)
Air-dried [c]	111.1	10764	2.1	16.0
	(14.6)	(2226)	(0.4)	(1.6)
Air-dried [d]	103	13500	7.56	10.1
	(24.3)	(2520)	(0.5)	(1.74)

Figures in parentheses are standard deviations
a = BS 373 (1957), b = Alik & Nungah (2014), c = Mohammad Omar & Mohd Jamil (2011), d = Lee *et al* (1979)

Table 5 Bonding properties of *Acacia mangium* finger-joints

Total delamination (%)		Bending Strength (MPa)		Young's Modulus of Bending (MPa)	
Mean	Range	Mean	Range	Mean	Range
0.775 (0.951)	0–2.91	74 (12)	49.49–99.75	14,281 (1186)	10,433.32–16,296.18

As stipulated in JASO M 901-85 standard, total delamination shall not exceed 10% while bending strength and Young's modulus shall more than 60 MPa and 10,000 MPa respectively
Figures in parentheses are standard deviations

less than 10%. Thus, all *A. mangium* finger-joints sample tested in this study have met the criteria for delamination of finger-joint.

Bending strength test was carried out in order to evaluate the maximum strength capacity of the finger joints sample. The average bending strength of the acacia finger-joint samples was 74 MPa. It was comparatively higher than the value obtained from 16 and 20 year old *A. mangium* finger-joints tested under similar conditions (Ong & Ting 2011). Furthermore, the acacia finger-joints used in this study have better bending strength compared with other plantation species, such as *Khaya ivorensis* (Latifah 2018) and Kelempayan (How & Sik 2020).

Acacia finger-joint samples tested in this study has an average value of 14,281 MPa for Young's Modulus of Bending. Based on the requirements specified under "veneer cargo bed for motor trucks as stated in JASO M 901-85, the performance of side-edge boards and front end boards should be ≥ 10,000 MPa. Thus, all acacia finger-joints tested in this study met the criteria for Young's modulus of bending.

In addition, matched acacia finger joints samples sent to an independent accredited laboratory of a glue supplier company for interlaboratory cross checks also met the tests' criteria for both delamination and bending strength test under the same standard (data not shown).

The debonding or fracture of the finger joints may leads to separation of the adhered layers called delamination (How & Sik 2020). Hence, the selection of timber species with superior bonding properties is crucial in the production of finger joints. The acacia finger-joints samples tested in this study have good bonding properties as the specimens met the minimum requirement as specified in the standard. The kiln-dried *A. mangium* finger-joints is considered as capable of providing adequate bonds for lamination and suitable to be fabricated as laminated timber for production of truck flooring and other wooden products.

CONCLUSION

The drying protocol used in this study successfully dried the *Acacia mangium* timber with uniform moisture distribution between and within each sawn lumber, thus producing quality kiln dried sawn lumber suitable for downstream manufacturing of value-added products. Overall, the kiln-dried *A. mangium* has better mechanical properties compared with air-dried *A. mangium* in terms of static bending, hardness and shear stress. The fabricated *A. mangium* finger joints fulfilled the delamination requirement as specified in JASO M 901-85 standard. The acacia finger joints also met the criteria for Young's modulus with comparatively higher bending strength value in relation to other plantation species. This indicates that *A. mangium* finger-joints produced in this study can be a potential laminating feedstock for downstream processing of value added products, such as laminated truck flooring and other wooden products.

ACKNOWLEDGEMENT

The authors express their heartfelt gratitude to Ministry of Science, Technology and Innovation, Malaysia for funding this study.

REFERENCES

Alik D & Nungah L. 2014. Mechanical properties. Pp 27–37 in Alik D, Wong AHH & Ting KB. (eds.) *Proceedings of the SFC/STA Research Seminar on Basic and Working Properties of Acacia mangium Planted in Sarawak*, 11 December 2014, Kuching.

BSI (British Standards Institution). 1957. *BS 373. Methods of Testing Small Clear Specimens of Timber.* BSI, London.

How SS, Anwar UMK, Tumirah K, Hamdan H & Sik HS. 2017. Factor influencing the quality of wood adhesion-part 2: glue spreading. *Timber Technology Bulletin.* No. 78. Forest Research Institute Malaysia, Kepong.

How SS & Sik HS. 2020. Finger jointing and lamination. Pp 73–77 in Roszaini et al. (eds) *Kelempayan Wood. Properties and Uses.* FRIM Research Pamphlet No.144. Forest Research Institute Malaysia, Kepong.

Jacek B, Maciej W & Aleksandra K. 2004. The change of mechanical properties of selected wood species after drying process under various condition. *Forestry and wood Technology.* 86: 13–17.

Jaso M 901-85. 1985. *Wooden Parts for the Cargo Bed of Motor Trucks.* Japan Standard, Japan.

Khairul M, Khairul A, Teng XY et al. 2011. Sawing and machining properties. Pp 46–55 in Lim et al. (eds) *Properties of Acacia Mangium Planted in Peninsular Malaysia.* ITTO Project on Improving Utilisation and Value adding of Plantation Timbers from Sustainable Sources in Malaysia Project No. PD 306/04 (1).

Latifah J. 2018. Properties and Uses of Planted *Khaya Ivorensis* in Peninsular Malaysia. *FRIM Research Pamphlet.* No. 139. Forest Research Institute Malaysia, Kepong.

Lee YH, Engku Abdul Rahman C & Chu YP. 1979. The Strength Properties of Some Malaysian Timbers. *Malaysian Forest Service Trade Leaflet* No. 34. Malaysian Timber Industry Board, Kuala Lumpur.

Lim SC, Gan KS & Choo KT. 2003. The characteristics, properties and uses of plantation timbers-rubberwood and *Acacia mangium. Timber Technology Bulletin* No. 26. Forest Research Institute Malaysia, Kepong.

Mohd Jamil AW, Nor Azrieda AR, Roszaini K, Ang LH & Mohamad Fakhri I. 2018. Mechanical properties and durability of fast-growing timbers cultivated on degraded lands. *Journal of Tropical Forest Science.* 30: 519–527. https://doi.org/10.26525/jtfs2018.30.4.519527

Mohamad Omar MK & Mohd Jamil AW. 2011. Mechanical properties. Pp 23–45 in Lim et al. (eds) *Properties of Acacia Mangium Planted in Peninsular Malaysia.* ITTO Project on Improving Utilisation and Value adding of Plantation Timbers from Sustainable Sources in Malaysia Project No. PD 306/04 (1).

Moya R, Urena E. & Munozf. 2008. Modulation of moisture content in conventional kiln of wood from fast-growing tropical species in plantation. Paper AP-7 in *Proceedings 2008 SWST International Annual Convention.* 10–12 November 2008, Concepcion.

Nordahlia AS, Hamdan H & Anwar UMK. 2013. Wood Properties of Selected Plantation Species: *Khaya Ivorensis* (African Mahogany), *Azadirachta Excelsa* (Sentang), *Endospermum Malaccense* (Sesendok) and *Acacia Mangium. Timber Technology Bulletin* No. 51. Forest Research Institute Malaysia, Kepong.

Norwahyuni MY, Paridah MT, Seng HL, Mohammad Asim K & Redzuan MSJ. 2019. Mechanical and physical properties of Cross-Laminated Timber made from Acacia mangium wood as function of adhesive types. *Journal of Wood Science.* 65: 20. https://doi.org/10.1186/s10086-019-1799-z

Ong CB & Ting KB. 2011. Finger-jointing and lamination properties for non-structural purposes. Pp 87–99 in Lim et al. (eds) *Properties of Acacia Mangium Planted in Peninsular Malaysia.* ITTO Project on Improving Utilisation and Value adding of Plantation Timbers from Sustainable Sources in Malaysia Project No. PD 306/04 (1).

Ratnasingam J, Hazirah AL, Paramjothy N, Lim CL, Nadarajah M & Floris L. 2020. Plantation forestry in Malaysia: an evaluation of its successes and failures since the 1970. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca.* 48: 1789–1801. https://doi.org/10.15835/nbha48412167

Samson NU, Zimuzo U, Oji AN, Emmanuel AE & Boniface OU. 2021. Engineering properties of wood under different drying methods. *Global Journal of Engineering and Technology Advances.* 7: 118–124. https://doi.org/10.30574/gjeta.2021.7.3.0082

Sik HS, How SS, Ho WM & Ramzul Iklas AL. 2018. Quality throughput of *Acacia mangium* lumber from industrial kiln. *Journal of Agriculture, Forestry and Plantation.* 7: 79–82.

Sim HC.1985. An Assessment of the Strength of Finger Joints in Mersawa and Keruing. *The Malaysian Forester* 48: 187–192.

Tenorio C & Moya R. 2011. Kiln drying of *Acacia mangium* Willd Wood: Considerations of moisture content before and after drying and presence of wet pockets. *Drying Technology.* 29: 1845–1854. https://doi.org/10.1080/07373937.2011.610912

Tenorio C, Moya R & Pineda Q. 2012. Kiln drying of *Acacia Mangium* wood: colour, shrinkage, warp, split and check in dried lumber. *Journal of Tropical Forest Science.* 24: 125–139.

Uetimane E. 2020. Anatomy, drying behaviour and mechanical properties of lesser used wood species from Mozambique. PhD thesis No.66. The Swedish University of Agricultural Sciences. Uppsala.

Vella R, Michael T, Redman A, Bailleres H. 2019. Comparison of Test Method for the Determination of Delamination in Glued Laminated Timber. *BioResource.* 14: 7920–7934. DOI:10.15376/biores.14.4.7920-7934

Wiemann MC & Green DW. 2007. *Estimating Janka Hardness from Specific Gravity for Tropical and Temperate Species.* USDA Forest Service, Forest Products Lab, Madison, Wisconsin.

Wong TM, Lim SC & Chung RCK. 2002. *A Dictionary of Malaysian Timbers.* Malayan Forest Records No. 30. Forest Research Institute Malaysia. Kepong.