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MECHANICAL PROPERTIES AND DURABILITY OF FAST-GROWING TIMBERS CULTIVATED ON DEGRADED LANDS

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Coastal dune and ex-mining lands are considered as unproductive acreages. Plantation forestry is deemed to be the most potential approach to improve the function of land. It is also the most natural technique to restore the value of the soil through phytoremediation. Considering that it has been almost two decades since the initial planting on degraded lands, mechanical and durability tests were conducted on the timbers of *Acacia mangium* and *Khaya ivorensis*. The main objective of the study was to explore the characteristics of timber grown on coastal dune and ex-mining lands. Mechanical tests of static bending, compression parallel to grain, shear parallel to grain and Janka hardness were conducted on a total of 614 green and dried timber specimens. All tests were based on BS 373 standard methods for testing of small clear specimens of timber (BSI 1957). The mechanical properties of *Acacia mangium* planted on a coastal dune site demonstrated a considerably higher value than existing records. The strength values of *Acacia mangium* and *Khaya ivorensis* from Setiu and Bidor varied from 25 to 71%, relatively. Decay ratings were classified as moderately resistant.

Keywords: Plantation forest, BRIS, tin-tailings, wood strength, degraded lands

INTRODUCTION

In the Peninsular Malaysia, coastal dune soil (also known as Beach Ridges Interspersed with Swales – BRIS) and ex-mining soil (also known as tin-tailings) formed vast tracts of unproductive ground, covering approximately 155,400 ha and 113,750 ha of the mainland respectively. These expanses are characterised as problematic soil for agriculture and are considered as degraded or waste lands (Jamilah et al. 2014, Ang et al. 2010).

Coastal dune ground consists of nutrient-poor sandy soil, originated from marine deposits. Most of the acreages lie along the shore of Kelantan, Terengganu and Pahang which experience extremely hot weather during the dry season and flooding during the wet season. The topsoil consists of 99% sand exceeding one-meter depth with poor water retention properties (Mohd Ghazali et al. 2007). Sparse shrubs, sedges and grasses dominate the vegetation community, forming a savanna-like ecosystem. The land is subjected to recurring drought during the non-monsoon months, thus, prone to wildfire (Jamilah 2006).

Tin extraction processes have adversely altered the ecological properties of land. Mining activity has transformed the microclimate, water table level, soil profiles and properties, mechanical impedance of the ground, organic community and survival rate of both plant and animal (Ang et al. 2014). The grounds are made up of washed waste products of alluvial mining comprising of sand, slime and sandy-slime tailings. In terms of fertility, the ex-mine soil is extremely deficient in almost all nutrients required by plants and has a very low water retention capacity. Slime is comparatively more fertile but it is normally water-logged (Nik Muhamad et al. 1994). The soil of ex-mine contains high concentration of potentially toxic elements (PTEs) of heavy metals. Site studies showed that ex-mining lands contain four major PTEs, namely lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg). The four PTEs were also found in fruits and fishes produced in ex-mine sites. The concentrations of PTEs in the crops were higher than the permissible levels of the national food safety standard (Ang et al. 2010).

Improving the function and value of unproductive lands has been the national priority for many years (Lim 2006). Since the 60's, tremendous attempts were made to optimise the function of denuded land for afforestation and timber production through cultivation of selected species (Mitchell 1957). The rehabilitation of degraded land with forest tree plantations is a better option. Afforestation regenerates species richness throughout the process and ultimately becomes a timber production area. Some studies found that forest trees potentially improve soil quality of degraded lands through phytoremediation (Ang et al. 2010).

Soil nutrient is evidently a major factor for the growth performance of plants. The richness of vegetation varies from site to site, very much depending on the properties of the soil (Jamilah 2006). Higher soil nutrient led to better growth and biomass production (Mohd Ghazali et al. 2007). However, the quantitative effect of soil quality on the mechanistic properties of timber is uncertain, particularly in problematic soils. If large scale projects were to commence on degraded lands, such as coastal dune and ex-mine, tangible data on the expected mechanical properties, as well as durability of the timber, is essential.

A restoration work of an ex-mining site was initiated in Bidor in 1997 through the planting of some fast-growing species (Ang et al. 2014). The aim was to transform the former tin mine area into a model of rehabilitated mixed forest stands. *A. mangium* shows good growth on sandy dunes where the water table reaches the root zone (Ang 1994). One of the initial trial sites of *A. mangium* plantation on BRIS soil was established in Tanjung Batu. Influence of site is not significant on the diameter and basal area of the trees (Amir Husni & Wan Rasidah 1994). On the contrary, a study showed that a good site with better nutrient level supports good growth on BRIS soil (Mohd Ghazali et al. 2007).

The mechanical properties and decay rating of timbers from trees grown on degraded lands have not been reported previously. Lim et al. (2011) reported on the mechanical properties of 16-year-old *A. mangium* from Ulu Sedili plantation. Mechanical properties of *Khaya ivorensis* were reported by Mohd-Jamil & Khairul (2017) based on 15-year-old samples from Bukit Hari plantation. Timber specimens of *A. mangium* and *K. ivorensis* have been tested for modulus of rupture, modulus of elasticity, compressive strength parallel to grain, shear strength parallel to grain, tensile strength and Janka hardness based on similar test methods. Hence, these studies will be the ideal comparative values for the present investigation.

This paper, in view of two decades since the early planting trials, specifically reports on the mechanical properties and fungi resistance of *A. mangium* and *K. ivorensis* timbers grown on degraded sites.

MATERIALS AND METHODS

Two exotic species of fast-growing timbers were selected as samples, *A. mangium* and *K. ivorensis.* Based on the rotation period of the national plantation scheme (Amir Husni et al. 1993), test materials were obtained from approximately 15-year-old trees. Coastal dune samples were obtained from a BRIS soil land located in Setiu, Terengganu. Ex-mining samples were obtained from a former tin-mining land in Bidor, Perak. Samples comprising of three trees of each species were randomly selected from every site. The geographical locations of Setiu and Bidor are illustrated in Figure 1.

Standard mechanical properties

Test on control sample was not conducted in the present study. However, results of earlier assessments were considered as standard properties. Mechanical properties of *Acacia mangium* were previously reported by Lim et al. (2011) based on similar tests of 16-year-old samples. Mechanical properties of *K. ivorensis* were reported by Mohd-Jamil & Khairul (2017) based on similar tests of 15-year-old samples. The samples of earlier studies were obtained from established plantation sites. Both studies were based on the same test methods of BS 373. Durability rating comparison of *A. mangium* and *K. ivorensis* with previous assessments was not carried out due to insufficient records.

Specimen preparation

For each selected tree, a log of 2 meters long was cut, approximately 30 cm from the ground. Each log was marked for green and dry specimens within the heartwood and sawn into sticks of 30 mm by 30 mm cross-section (Figure 2). All green sticks were immediately cut and planed into specimen sizes for both mechanical and fungi resistance tests. Specimens for mechanical tests of static bending, compression parallel to grain, shear parallel to grain and Janka hardness were prepared from each stick, based on a defect-clear specimen selection. The number

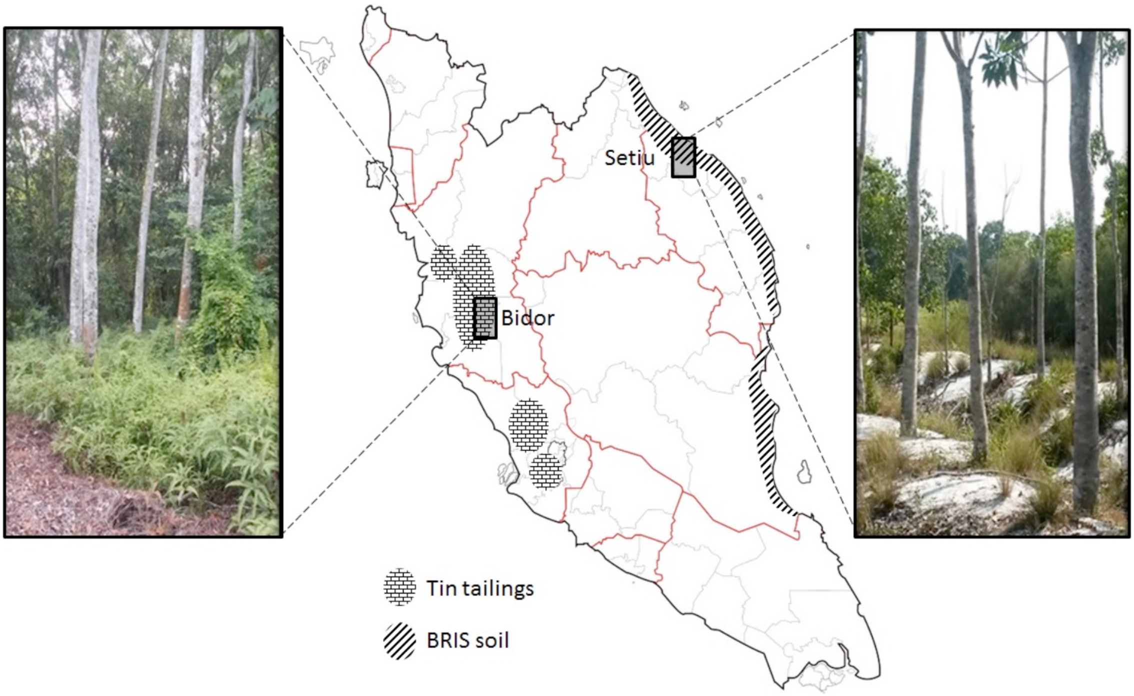

Figure 1 Major areas of BRIS soil and tin tailings of Peninsular Malaysia

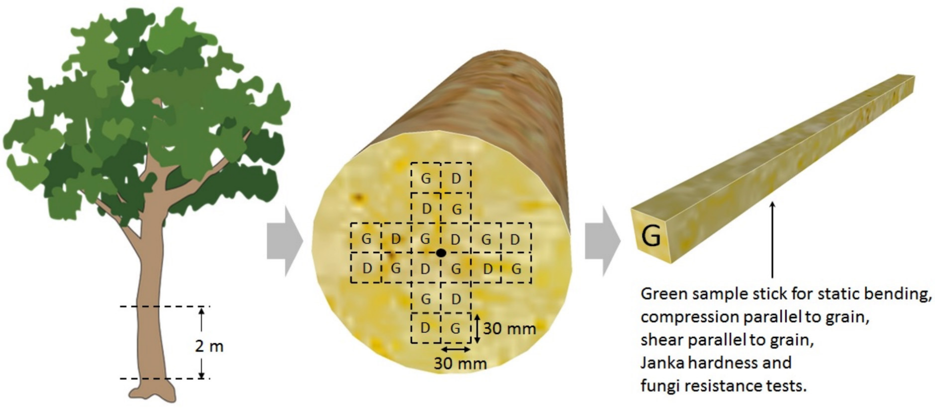

Figure 2 Cutting layout for specimen preparation (G = green, D = dry)

of specimens for each test depended on the availability of clear specimens. All mechanical tests were conducted based on BS 373 methods, to allow comparison with previous data.

For the preparation of fungi resistance test specimens, cubes of 19 mm were randomly cut from the green sticks. A total of 40 specimens were prepared from each log. All cubes were conditioned at 20 °C and 50% relative humidity to attain 20% moisture content. Fungi resistance test was conducted according to ASTM D1413 (ASTM 2007).

For dry specimens, the sticks were stacked and air-dried until a constant weight. Dried sticks were cut and planed into specimen sizes for mechanical tests of static bending, compression parallel to grain, shear parallel to grain and Janka hardness. The number of specimens for each test depended on the availability of clear specimens. Similarly, the mechanical tests were conducted based on BS 373 methods.

Static bending test

The nominal size of the specimens was 20 mm × 20 mm × 300 mm. Force was applied based on three-point loading method with a span of 280 mm. A constant loading speed was applied at 6.6 mm min^{-1}. The test arrangement is shown in Figure 3. Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated using the formulae:

$$MOE = \frac{1}{4}\frac{\Delta F}{\Delta 1}\frac{s^3}{bd^3}$$

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

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) and F_{bend} is the maximum bending load (N).

Compression parallel to grain test

The nominal size of the specimens was 20 mm × 20 mm × 60 mm. Force was applied parallel to the grain. A constant loading speed was applied at 0.6 mm min^{-1}. The test arrangement is shown in Figure 4. Compressive strength parallel to the grain was calculated using the formula:

$$\sigma_{comp} = \frac{F_{comp}}{A}$$

where F_{comp} is the maximum compressive load (N) and A is the cross-sectional area normal to the direction of load (mm^2).

Shear parallel to grain test

The nominal size of the specimens was 20 mm × 20 mm × 20 mm. Force was applied with the plane of shearing parallel to the grain. A constant loading speed was applied at 0.6 mm min^{-1}. The test arrangement is shown in Figure 5. Shear strength parallel to the grain was calculated using the formula:

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

where F is the maximum shearing load (N) and A is the area of shear (mm^2).

Janka hardness test

The test was conducted using the specimens of static bending test. A constant force of 6.35 mm min^{-1} was applied using a test jig with a semi-circular-end steel bar of 11.28 mm in diameter. The test arrangement is shown in Figure 6. The load corresponding to the penetration depth of 5.64 mm was recorded as Janka hardness value.

Specific gravity determination

The nominal size of the specimens was 20 mm × 20 mm × 60 mm. The specific gravity (SG) was calculated using the formula:

$$SG = \frac{m_{od}}{V}\frac{1}{\rho_{H_2O}}$$

where m_{od} is the oven-dried mass of the specimen (kg), V is the volume of the specimen at test (m^3) and ρ_{H2O} is the density of water (kg m^{-3}).

Fungi resistance test

The resistance of the timbers against decaying fungi was evaluated using *Coriolus versicolor* (CV) and *Gloeophyllum trabeum* (GT). Each specimen was weighed prior to sterilisation at 121°C using an autoclave for approximately one hour. The sterilised specimens were exposed to the fungi in culture bottles containing soil medium for 16 weeks (Figure 7). At the 16th week of incubation, the specimens were removed from the culture bottles. Fungal mycelia were carefully and gently brushed off from the specimens. A total of 120 specimens were tested for each timber species

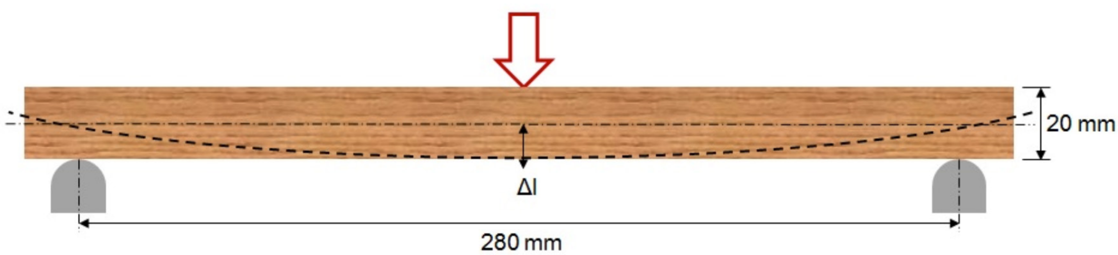

Figure 3 Arrangement for static bending test

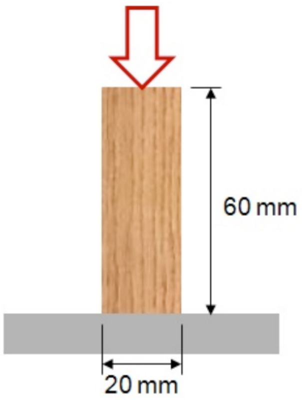

Figure 4 Arrangement for compression parallel to grain test

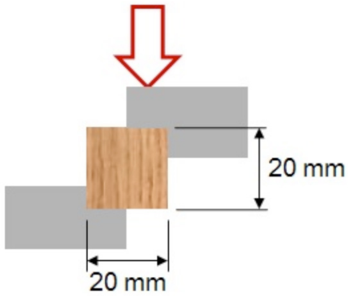

Figure 5 Arrangement for shear parallel to grain test

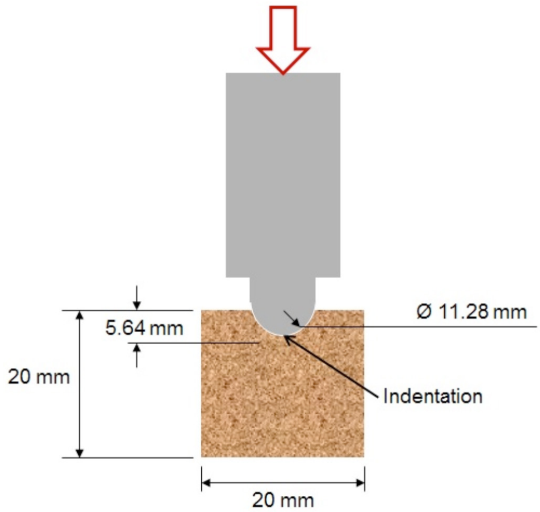

Figure 6 Arrangement for Janka hardness test

from one location. The percentage of weight losses was calculated using the formula:

$$\text{Weight loss} = \left(\frac{W_1 - W_2}{W_1}\right) \times 100\%$$

where W_1 is the weight of the conditioned specimens (g) and W_2 is weight of the specimen

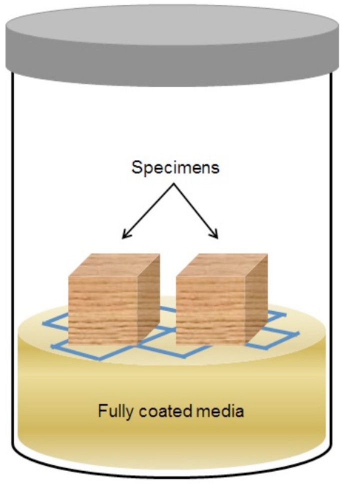

Figure 7 Arrangement of test specimens in a culture bottle

after the 16 week of incubation (g). The decay ratings based on ASTM D 1413 are presented in Table 1.

RESULTS AND DISCUSSION

Mechanical properties

The mechanical test results were presented in three conditions i.e. green, air-dried and estimated 19% moisture content. For a comparative evaluation, the properties at approximately 19% moisture condition were calculated using the Madison formula (Engku 1980). The mechanical properties of *A. mangium* and *K. ivorensis* are shown in Tables 2 and 3 respectively.

Acacia mangium

The mechanical properties of *A. mangium* from Setiu were fairly high for a fast-growing timber. The mean MOR in air-dried condition was comparable to kempas, merbatu and mertas (Lee et al. 1993). The results were higher than 20-year-old trees (Lim et al. 2011). Janka hardness of *A. mangium* from Setiu showed the highest value among all tested samples of Peninsular Malaysia.

The mechanical properties of samples from Setiu were 25 to 71% highest than Bidor. Janka hardness values showed the highest difference. Air-dried samples showed higher values than green, except for Janka hardness test of samples from Bidor. The average Janka hardness value in green condition was 21% higher than air-dried

Table 1 Decay ratings based on ASTM D1413

Decay rating	Mean weight loss (%)
Highly resistant (+++)	0–10
Resistant (++)	11–24
Moderately resistant (+)	25–44
Slightly resistant or non-resistant (-)	45 or above

Table 2 Mechanical properties of *Acacia mangium*

Site	Condition		Modulus of rupture	Modulus of elasticity	Compressive strength parallel to the grain	Shear strength parallel to the grain	Janka hardness	Moisture content	Specific gravity
			N mm^{-2}	N mm^{-2}	N mm^{-2}	N mm^{-2}	kN	%	
Bidor	Green	Average	72.5	7668	32.6	9.8	3.5	123.5	0.432
		(SD)	(4.8)	(533)	(4.7)	(1.3)	(0.5)	(20.6)	(0.026)
		n	6	6	6	10	12	6	6
	Air-dried	Average	88.5	8450	43.6	12.0	2.9	15.8	0.480
		(SD)	(6.3)	(571)	(1.5)	(1.5)	(0.4)	(0.2)	(0.030)
		n	5	5	5	10	10	5	5
	Estimated at 19% MC		82.6	8169	39.4	11.2	3.5	19.0	-
Setiu	Green	Average	91.9	10690	40.1	11.3	5.1	76.6	0.595
		(SD)	(14.2)	(1862)	(6.4)	(1.9)	(0.9)	(21.3)	(0.072)
		n	29	29	30	60	58	30	30
	Air-dried	Average	122.4	11950	57.9	16.5	5.4	14.4	0.620
		(SD)	(18.3)	(1823)	(8.6)	(2.5)	(1.6)	(0.7)	(0.082)
		n	19	19	19	38	38	19	19
	Estimated at 19% MC		108.1	11386	49.4	14.0	5.3	19.0	-

SD = standard deviation, MC = moisture content, n = number of specimen

samples. This uncommon condition has been observed in previous Janka hardness assessments of Malaysian timbers. For example, green and air-dried test results of petaling (*Ochanostachys amentacea*) were 6.59 kN and 6.36 kN, tualang (*Koompassia excelsa*) were 8.23 kN and 7.21 kN, penarahan (*Myristica gigantean*) were 4.54 kN and 4.49 kN, petai (*Parkia speciosa*) were 2.40 kN and 2.22 kN respectively, and many others, regardless of density (Lee et al. 1993). In such cases, the engineering practice was to select the green result as the representative value (MS 2001).

Based on similar testing arrangements, Lim et al. (2011) reported the mechanical properties of 16-year-old *A. mangium* from an established plantation site at Ulu Sedili. The MOR, MOE, compressive strength parallel to the grain, shear strength parallel to the grain and Janka hardness in air-dry condition (19.9% moisture content) are included in Table 4. Relatively, mechanical properties of the present samples from Bidor were generally lower than the reported values, whereas samples from Setiu were significantly higher.

Strength properties of *A. mangium* were consistent with specific gravity values. The mean specific gravity of samples from Setiu was roughly 30 to 40% higher than Bidor. The specific gravity of a 16-year-old *A. mangium* was reported in the range of 0.490 to 0.530 (Lim et al. 2011).

Khaya ivorensis

The mechanical properties of *K. ivorensis* of Bidor and Setiu samples were generally equivalent. Samples from Bidor showed slightly higher values in MOR and compression parallel to the grain tests. Mohd-Jamil & Khairul (2017) reported the mechanical properties of 15-year-old *K. ivorensis* from a hilly plantation site of Bukit Hari. Based on similar testing arrangements, the MOR, MOE,

Table 3 Mechanical properties of *Khaya ivorensis*

Site	Condition		Modulus of rupture	Modulus of elasticity	Compressive strength parallel to the grain	Shear strength parallel to the grain	Janka hardness	Moisture content	Specific gravity
			N mm^{-2}	N mm^{-2}	N mm^{-2}	N mm^{-2}	kN	%	
Bidor	Green	Average	57.0	5963	24.9	7.4	2.8	58.9	0.449
		(SD)	(9.7)	(1875)	(3.6)	(1.3)	(0.4)	(8.0)	(0.030)
		n	6	6	7	14	12	7	7
	Air-dried	Average	71.7	6626	36.0	9.9	3.8	17.1	0.445
		(SD)	(11.2)	(1467)	(4.8)	(1.6)	(2.2)	(1.2)	(0.023)
		n	5	5	5	10	10	5	5
	Estimated at 19% MC		67.9	6460	32.9	9.2	3.5	19.0	-
Setiu	Green	Average	53.3	6166	24.1	8.1	3.1	63.9	0.508
		(SD)	(8.3)	(1218)	(3.3)	(1.3)	(0.7)	(13.8)	(0.092)
		n	19	19	19	36	38	19	19
	Air-dried	Average	75.3	7608	37.1	11.8	4.0	13.9	0.523
		(SD)	(11.8)	(1626)	(3.0)	(1.8)	(0.8)	(2.4)	(0.060)
		n	13	13	13	26	26	13	13
	Estimated at 19% MC		64.2	6908	30.4	9.9	3.6	19.0	-

SD = standard deviation, MC = moisture content, n = number of specimen

Table 4 Mechanical properties of *Acacia mangium* and *Khaya ivorensis* of established plantations

Species	Site	Condition	Modulus of rupture	Modulus of elasticity	Compressive strength parallel to the grain	Shear strength parallel to the grain	Janka hardness	Moisture content	Specific gravity	Reference
			N mm^{-2}	N mm^{-2}	N mm^{-2}	N mm^{-2}	kN	%		
Acacia mangium	Ulu Sedili	Air-dried	96.6	10347	46.0	12.2	3.0	19.9	0.510	Lim et al. 2011
Khaya ivorensis	Bukit Hari	Air-dried	72.1	7872	34.1	10.7	2.8	16.8	0.458	Mohd-Jamil & Khairul 2017

compressive strength parallel to the grain, shear strength parallel to the grain and Janka hardness in air-dry condition (16.8% moisture content) are included in Table 4. In general, the mechanical properties of *K. ivorensis* samples from Bidor, Setiu and Bukit Hari were equivalent. However, Janka hardness values of the present study were considerably higher than existing data. The mean specific gravity of samples from Setiu was roughly 13 to 18% higher than Bidor. The specific gravity of a 15-year-old *K. ivorensis* was reported as 0.458 (Mohd-Jamil & Khairul 2017).

A slight deviation in the mean value will be expected in individual tests, if additional specimens were to be incorporated to the replicates. Unsatisfactory replicates were mainly due to in inavailability of defect-free specimens, and smaller logs significantly affected the sampling procedure. Nevertheless, the expected results of additional replicates were deemed to be consistent. For most properties, SD values described a similar dispersion of data between tests having small and big number of specimens. For example, based on 6 specimens, the MOR and SD of air-dried *K. ivorensis* from Bidor were 57.0 N mm^{-2} and 9.7 N mm^{-2} respectively. With a higher number of specimens (i.e. 19), the MOR and SD of air-dried *K. ivorensis* from Setiu were 53.3 N mm^{-2} and 8.3 N mm^{-2} respectively (Table 3). The statistical comparison demonstrated two samples of different populations with comparable means and SD. However, mechanical tests of appropriate replicates (for instance 40 specimens from at least 5 trees) should be conducted in future assessments.

Durability

The classification of fungi resistance of timber is subjected to the method used in testing. Comparison of rating between species is normally carried out using the same method. Based on ASTM D 1413 using *Coriolus versicolor* (CV) and *Gloeophyllum trabeum* (GT), the durability of *A. mangium* from Bidor and Setiu were both classified as moderately resistant (Table 5). In terms of weight loss, *A. mangium* from Setiu lost more weight than Bidor samples when tested against CV. On the contrary, *A. mangium* from Bidor lost more weight than Setiu samples when tested against GT.

The durability test of *K. ivorensis* against *Coriolus versicolor* (CV) and *Gloeophyllum trabeum* (GT) classified the timber from Setiu and Bidor as moderately resistant (Table 6). Samples from Bidor showed more weight loss than Setiu when tested against both CV and GT. The weight loss of *K. ivorensis* from Bidor was considerably higher when tested against GT.

In actual application, the fungi colonisation on timber is not restricted to *C. versicolor* and *G. trabeum*. Various other fungi have been associated with the rotting of *Acacia mangium* in Peninsular Malaysia e.g. *Phellinus noxius*, *Rigidoporus hypobrunneus*, *Oxyporus cf. latemarginatus* and *Tinctoporellus epimiltinus* (Lee & Noraini Sikin 1999). Thus, the decay rating obtained from laboratory test is not an absolute value of species durability. It is rather, an indicating value for comparison between different types of timbers.

The plantation plots of Setiu and Bidor were characterised by diverse ecological factors, e.g. equatorial position, climate, soil nutrients, seedling technique and silvicultural management which contributed to the inherent properties of the timbers. Thus, it is uncertain to which and how great the parameters influenced timber properties. The results obtained from the present study provided an excellent indication of the expected timber quality, cultivated on a coastal dune or ex-mining sites. The *A. mangium* timber planted on ex-mining is expected to have lower mechanical properties than standard sites. However, *A. mangium* planted on coastal dune land is expected to have higher mechanical properties. As for *K. ivorensis* planted on ex-mining or coastal dune lands, equivalent mechanical properties with the standard site is expected.

CONCLUSIONS

Mechanical tests of *A. mangium* from Setiu showed higher values than samples of 20-year-old trees. Janka hardness test of Setiu samples gave the highest value among all tests of *A. mangium* from Peninsular Malaysia. The mechanical properties of *K. ivorensis* from Setiu and Bidor were comparable to existing data. For resistance test against *C. versicolor*, the durability of *A. mangium* from Bidor and Setiu were both classified as moderately resistant. Similar rating was obtained for *K. ivorensis* from Setiu and Bidor.

Table 5 Durability class of *Acacia mangium*

Site	Average weight loss (%)		Decay rating
	Coriolus versicolor	*Gloeophyllum trabeum*	
Bidor	31.54	38.85	Moderately resistant
Setiu	34.53	35.61	Moderately resistant

Table 6 Durability class of *Khaya ivorensis*

Site	Average weight loss (%)		Decay rating
	Coriolus versicolor	*Gloeophyllum trabeum*	
Bidor	38.82	41.28	Moderately resistant
Setiu	37.28	34.81	Moderately resistant

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REFERENCES

Amir-Husni MS, Suhaimi WC, Adzmi Y & Mohd Ghazali H. 1993. Which canopy tier should be sampled to determine the fertility (nutritional) status of *Acacia mangium* on BRIS soils? *Journal of Tropical Forest Science* 6: 48–55.

Amir Husni MS & Wan Rasidah K. 1994. Growth differences, fertility status and foliar deficiency levels of six-year-old *Acacia mangium* on BRIS soils. *Journal of Tropical Forest Science* 6: 230–238.

Ang LH. 1994. Problems and prospects of afforestation on sandy tin tailings in Peninsular Malaysia. *Journal of Tropical Forest Science* 7: 87–105.

Ang LH, Tang LK, Ho WM, Hui TF & Theseira GW. 2010. Phytoremediation of Cd and Pb by four tropical timber species grown on an ex-tin mine in Peninsular Malaysia. *International Journal of Environment, Chemical, Ecological, Geological and Geophysical Engineering* 4: 70–74.

Ang LH, Ho WM & Tang LK. 2014. A model of greened ex-tin mine as a lowland biodiversity depository in Malaysia. *Journal of Wildlife and Parks* 29: 61–67.

ASTM (American Society for Testing and Materials). 2007. *D1413 Standard Test Method for Wood Preservatives by Laboratory Soil-Block Cultures. Annual Book of ASTM Standards.* ASTM, Philadelphia.

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

Engku ARC. 1980. *Basic and Grade Stresses for Some Malaysian Timbers. Trade Leaflet No. 37.* Malaysian Timber Industry Board, Kuala Lumpur.

Jamilah MS. 2006. Heath vegetation of Terengganu: neglected natural resources? Pages 1–4 in Noor Azhar MS et al. (eds) *Kustem 5th Seminar on Sustainability Science and Management*, 2–3 May 2006, Kuala Terengganu.

Jamilah MS, Nur-Faiezah AG, Siti-Kehirah A, Siti-Mariam MN & Razali MS. 2014. Woody plants on dune landscape of Terengganu, Peninsular Malaysia. *Journal of Tropical Forest Science* 26: 267–274.

Lee YH, Engku ARC & Chu YP. 1993. *The Strength Properties of Some Malaysian Timbers. Timber Trade Leaflet No. 34.* Malaysian Timber Industry Board, Kuala Lumpur.

Lee SS & Noraini Sikin Y. 1999. Fungi associated with heart rot of *Acacia mangium* trees in Peninsular Malaysia and East Kalimantan. *Journal of Tropical Forest Science* 11: 240–254.

Lim JS. 2006. *Combating Land Degradation and Promoting Sustainable Land Resource Management in Malaysia.* National Report for the Fifth Session of the Committee for the Review of the Implementation of the Convention to Combat Desertification (CRIC5). Department of Agriculture, Putrajaya.

Lim SC, Gan KS & Tan YE. 2011. *Properties of Acacia mangium Planted in Peninsular Malaysia.* Forest Research Institute Malaysia, Kepong.

Mitchell BA. 1957. Malayan tin tailings-prospects of rehabilitation. *Malayan Forester* 20: 181–186.

Mohd-Ghazali H, Wan-Rasidah K, Rosazlin A, Rozita A, Rosdi K & Abd-Rasip AG. 2007. Growth of *Acacia hybrid* (*A. mangium* x *A. auriculiformis*) on coastal sandy soil. *Journal of Tropical Forest Science* 19: 243–244.

Mohd-Jamil AW & Khairul M. 2017. Variations of mechanical properties in plantation timbers of jelutong (*Dyera costulata*) and khaya (*Khaya ivorensis*) along the radial and vertical positions. *Journal of Tropical Forest Science* 29: 114–120.

Malaysian Standards. 2001. *MS 544 Code of Practice for Structural Use of Timber: Part 2: Permissible Stress Design of Solid Timber.* Department of Standard Malaysia, Putrajaya.

Nik Muhamad M, Azizah H & Idris A. 1994. Rehabilitation of ex-tin mining land by agroforestry practice. *Journal of Tropical Forest Science* 7: 113–127.

