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Anatomical and Mechanical Properties of the Bur-Flower Tree (*Anthocephalus chinensis*)

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ABSTRACT

The anatomical and mechanical properties of wood samples from the Bur-flower tree, *Anthocephalus chinensis* were tested from two different localities and at three different ages. Anatomical features such as fiber and vessel dimensions, as well as mechanical properties were analyzed. The purpose of this research was to study wood properties and uses of *A. chinensis*. The features evaluated showed *A. chinensis* has a white to yellowish-white surface and is medium-to-coarse in texture. It has straight grain and a non-lustrous surface. The average width of vessels was 151 μm and the average fiber length was 1,700 μm. The mechanical properties evaluated showed the modulus of rupture (MOR) and modulus of elasticity (MOE) of *A. chinensis* were approximately 58 MPa and 5.5 GPa and the specific gravity was between 0.35 and 0.42. From the tested and observed results, *A. chinensis* was evaluated as a low strength and naturally durable wood.

Keywords: *Anthocephalus chinensis*, Bur-flower tree, mechanical properties, anatomical properties

INTRODUCTION

The Bur-flower tree *(Anthocephalus chinensis)* is a member of the Rubiaceae family. It is generally found in Asia (Thailand, Malaysia, Myanmar, Sri Lanka, Nepal, Bangladesh, India, Indonesia and Laos) and in some parts of Australia and Papua New Guinea (Papua New Guinea Forest Industries Association, 2006). The Bur-flower tree is a perennial plant with an average height of approximately 27 m. Its crown is round with large leaves and its branching is almost perpendicular to the trunk. The tree normally grows well in moist areas, where the average annual rainfall is approximately 1,500-5,000 mm, the average annual temperature is around 21-23°C and the height above mean sea level is approximately 1,000 m (Papua New Guinea Forest Industries Association, 2006).

The Bur-flower tree grows well in moist areas in its early growth stage, with a diameter at breast height (DBH) increment of more than 3 cm per year (Royal Forest Department, 2008). Therefore, it is very beneficial for reforestation as a pioneer species (Otsamo *et al*., 1997). The tree generally has large leaves, which may be utilized as a source of anthocyanin. This chemical component is very useful in helping to block sunlight and protect some enzymes in the leaves and enable them to work properly (Feng *et al.,* 2004; Cai *et al*., 2005).

As a pioneer species, the Bur-flower tree is suitable for reforestation due to its fast early growth and its cutting rotation of approximately

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10-20 y (Royal Forest Department, 2008). Therefore, it has been promoted as a commercial tree. It produces a large number of seedlings, which can develop into many saplings. The Bur-flower tree was promoted as a new-choice species for forest plantation establishment, although there are some discrepancies in its reported properties. Therefore, the objectives of this study were to test the wood properties and endeavor to suggest wood utilization based on the properties. This study used some anatomical and physico-mechanical properties for guidance in the use of wood sourced from the Bur-flower tree and to explain some of its silvicultural traits. This study did not cover product design and the testing of product properties.

MATERIALS AND METHODS

The experiment was set up using a completely randomized design (CRD) with 3 × 3 factorial levels, consisting of three levels of age (5, 10 and 18 y) and three levels of height above the ground (1.3, 6 and 9 m). The 10-year-old-Bur-flower trees used in this study came from a plantation at the Kasetsart University Agroforestry Research Station, located in Trat province and the 5- and 18-year-old Bur-flower trees came from plantations located in Sra Keaw province, eastern Thailand. Three trees were selected for each age replication (block). Logs 1 m long were cut from different levels up the trunk (Figure 1) and then later the logs were transversely cut into three pieces, composed of one 20-cm-thick disk and two 40-cm shorter logs (Figure 1). Wood samples for anatomical investigation were taken from the disk and samples for testing mechanical properties were taken from the 40-cm logs. Figure 2 and Table 1 show the cutting dimensions and diagram used in testing the mechanical properties. The mechanical properties (Table 1) were tested according to the ASTM D143 methods for testing small, clear specimens of timber (ASTM, 1999). For anatomical investigation, the wood samples were microtomed to provide cross, tangential and radial sections, each with a thickness of 20 μm. The

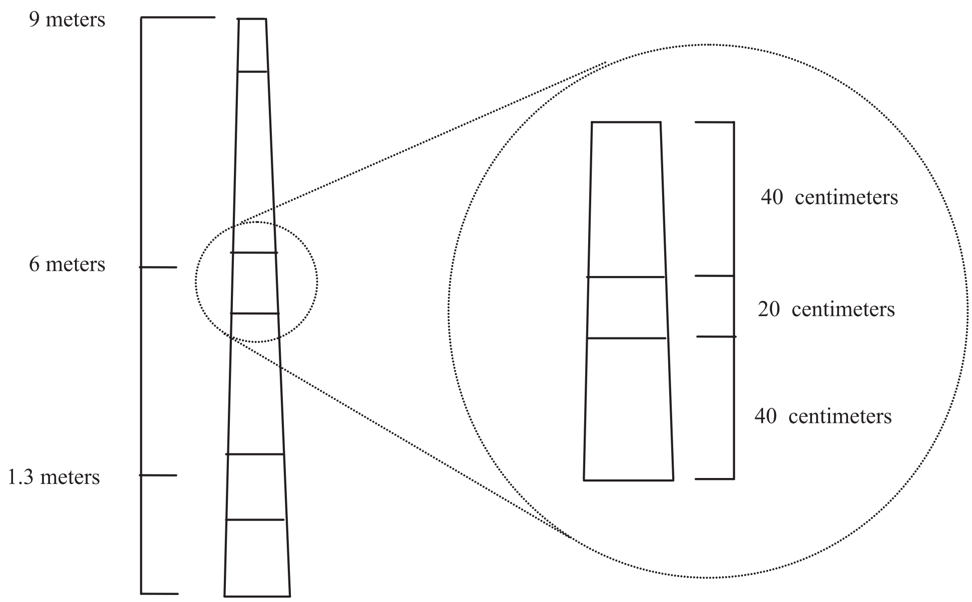

Figure 1 Diagram showing positions where 1-meter logs were cut from the trunk of *Anthocephalus chinensis* and where 20-cm-thick disk and two 40-cm logs were cut from each 1 meter log.

sections were stained with haematoxylin and safranin and mounted to provide permanent slides for microscopic observations. Microscopic structure was investigated to gain sufficient information on wood components, such as fibers, vessels and parenchyma cells. Macroscopic characteristics were viewed using a hand lens with a capability of magnifying two to three times.

Figure 2 Diagram showing the distribution of wood samples in the cross section of the log, 40 cm long, for the mechanical properties testing (Details described in Table 1).

RESULTS AND DISCUSSION

Anatomical properties

The wood color of *A. chinensis* was uniformly yellowish in the fresh condition, but uniformly whitish when dried. Dried wood was very light in weight compared to the fresh wood that had higher moisture content. The anatomical structure of the wood samples from *A. chinensis* was studied in transverse, tangential and radial sections (Figure 3). Observation of the cross section samples revealed that there were radial multiple and diffuse pores. The vessels were surrounded by a large number of longitudinal parenchyma (apotracheal parenchyma). The arrangement of the parenchyma was diffuse in aggregate and rays were homogeneous. The parenchymatous tissue had highly hygroscopic properties, since there was a large amount of starch; therefore, the wood could readily adjust to moisture content changes by evaporating or absorbing water (Balfas, 2003). The average width of a vessel cell of *A. chinensis* was 151 μm; therefore the wood was classified as medium-textured (150-200 μm) (Wheeler *et al*., 1989).

Table 1 Details of the mechanical testing of *Anthocephalus chinensis* wood samples.

Code of sample	Wood properties tested in sample	Replications	Dimensions (mm)	Remark
A	Static bending	5 (MOR & MOE)	20 × 20 × 300	-
B	Compression	5 _⊥_ & ∥ to grain	20 × 20 × 60	-
C	Shear ∥ to grain	5	20 × 20 × 20	-
D	Tension ∥ to grain	5	450 in length	could not test
E	Tension _⊥_ to grain	5	20 × 20 × 70	-
F	Hardness	5	50 × 50 × 50	-
G	Cleavage	5	20 × 20 × 45	-
H	Toughness	5	20 × 20 × 300	-
I	Nail withdrawal	5	50 × 50 × 150	-

Note:_|_ = perpendicular; || = parallel.

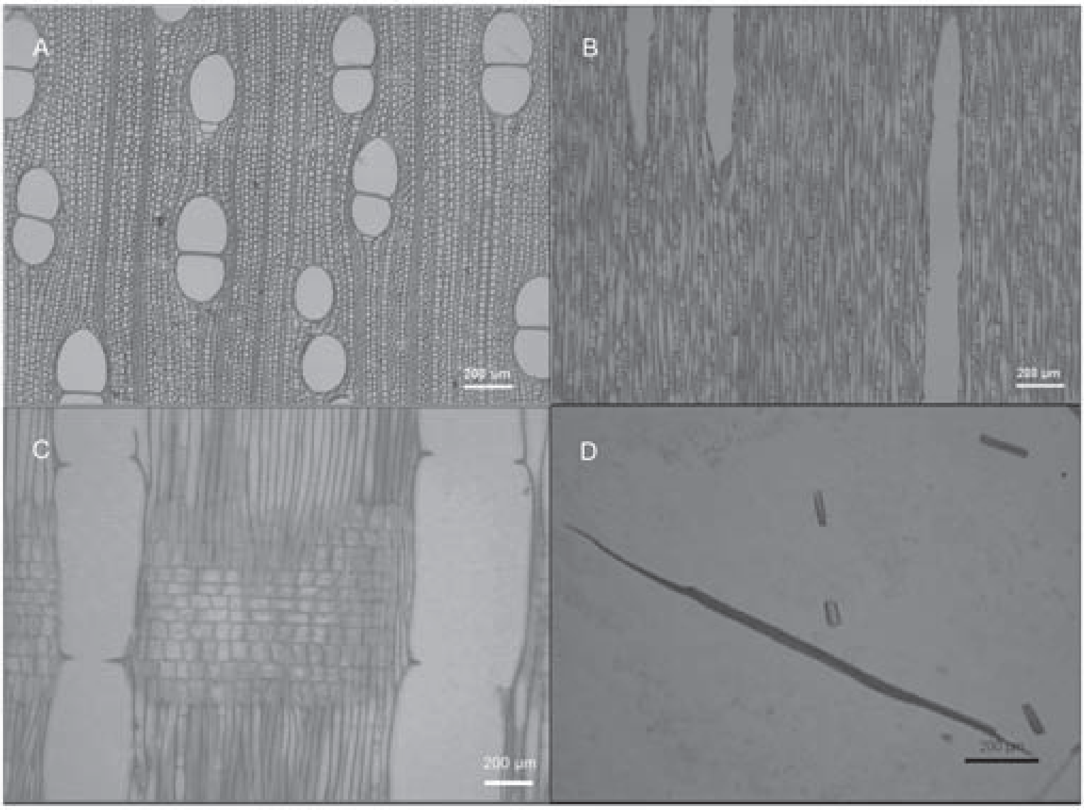

Figure 3 Anatomical characteristics of *Anthocephalus chinensis* wood (A = transverse direction, B = tangential direction, C = radial direction, D = single fiber image).

Tables 2 and 3 show the anatomical characteristics of *A. chinensis* wood compared to other fibrous materials. The average fiber length of *A. chinensis* was 1,700 µm, which was long when compared to hardwood fibers (approximately 700-1,600 µm) (Ates *et al.*, 2008). However, it was shorter than softwood (2,700-4,600 µm) (Ates *et al.*, 2008). The average fiber length of *A. chinensis* was greater than those of eucalypt (*Eucalyptus camldulensis*) and rubber wood (1,209 and 1,390 µm, respectively) (Veenin *et al.*, 2005; Erwin *et al.*, 2008). The vessel width of *A. chinensis* wood was about 151 µm, which was greater than in eucalypt (95 µm) but smaller than in rubberwood (247 µm) (Veenin *et al.*, 2005). From these results, a higher tensile strength in *A. chinensis* wood fiber could be expected, because the cell length, especially for fibers, is closely related to the axial tensile strength of wood (Tsoumis, 1991). Longer cells tend to have a higher strength. Therefore, the tensile strength in *A chinensis* wood tends to be higher than in eucalypt and rubberwood, based on the fiber length. However, the microfibril angle, which is the angle between the microfibril bundle and the cell axis, is another factor influencing tensile strength. The microfibril angle will be smaller in a longer cell and greater in a shorter one (Tsoumis, 1991). The presence of wood defects, such as knots, spiral grain and other growth abnormalities will greatly reduce the axial tensile strength (Tsoumis, 1991).

Physical and mechanical properties

Physical and mechanical description

Mechanical properties are determined by the measurement of material resistance to exterior

Table 2 Effects of age on cell characteristics of *Anthocephalus chinensis* wood samples.

Age (year)	Vessel (pore)		Ray		Fiber
	No. per 10 mm^2 (min-max)	Width (µm) mean±(std)	No. per 5 mm (min-max)	Width (µm) mean±(std)	Length (µm) mean±(std)
5	50 - 190	156.26±19.18 ^{A}	55 - 95	41.55±8.83 ^{B}	1,587.2±275 ^{A}
10	40 - 120	159.48±32.59 ^{B}	75 - 120	34.72±8.31 ^{A}	1,746.6±230 ^{B}
18	40 - 150	137.47±26.41 ^{C}	75 - 120	49.71±9.46 ^{B}	1,766.5±288 ^{B}
Average	43 - 153	151.07	68 - 112	41.99	1,700.1

Notes:
min = minimum; max = maximum; std = standard deviation.
Mean values in the same column followed by the same letter are not significantly different at the 0.05 probability level as determined by Tukey's separation procedure.

Table 3 Comparison of cell characteristics of *Anthocephalus chinensis* wood and other tree species.

Age (year)	Vessel (pore)		Ray		Fiber
	No. per 10 sq.mm (min-max)	Width (µm) mean±std	No. per 5 mm (min-max)	Width (µm) mean±std	Length (µm) mean±std
A. chinensis	43 - 153	151.07±26.06	68 - 112	41.99±8.87	1,700.1±264
E. camaldulensis[1]	140 - 180	94.50±4.42	-	-	876.7±42
H. brasilliensis[2]	-	247.33±44.08	-	43.58±6.55	1,209.0±126
T. grandis[3]	-	184.76±16.34	-	-	1,390.5±155

Notes:
min = minimum; max = maximum; std = standard deviation.
[1]Veenin *et al*. (2005), [2]Erwin *et al*. (2008), [3]Bhat *et al*. (2001).

forces, with the measurements dependent on the magnitude and the manner of loading the force, such as by bending, compressing, tensioning and shearing. Anatomical characteristics are closely related to the mechanical properties. The fiber length is positively correlated with the modulus of elasticity (MOE) and stress at proportional limit (Latif *et al*., 1990; Tsoumis, 1991). The average physical and mechanical properties of *A. chinensis* wood are presented in Tables 4 and 5. The average density, a physical property, was approximately 431 kg/m^3 at 12% moisture content. The specific gravity, another physical property, was between 0.35 and 0.42, which is considered as being in the lightweight wood category. The average modulus of rupture (MOR) and average modulus of elasticity (MOE) were 58.23 MPa and 5,518.43 MPa, respectively. The average tensile strength perpendicular to the grain, the average compressive stress perpendicular and parallel to grain, the shear stress and cleavage were 0.90, 4.44, 37.02, 14.72, and 4.12 MPa, respectively. The average hardness was 2,602.17 N. The average nail holding power was 12.92 and 13.96 N/mm in the tangential and radial direction, respectively.

Influence of age on the properties

A comparison of the mean values for MOR and MOE averaged across all heights showed that age had a positive effect on bending properties, which was likely due to the increase in specific gravity (SG) during tree growth and maturation. The average MOR was 55.4, 58.7 and 60.6 MPa for samples aged 5, 10 and 18 y, respectively. The average MOE was 5.58, 5.01 and

Table 4 Mechanical and physical properties of *Anthocphalus chinensis* wood.

Properties	Age (year)	5			10			18		
	Height (m)	1.3	6	9	1.3	6	9	1.3	6	9
1. Mechanical properties	**Unit**	Mean±Std								
1.1 Static bending										
- Modulus of rupture	MPa	61.48 ±7.00	54.47 ±5.14	50.09 ±11.85	57.82 ±10.10	59.06 ±10.02	59.30 ±8.11	61.25 ±5.92	59.53 ±4.87	61.03 ±8.00
- Modulus of elasticity	MPa	5822 ±565	5491 ±561	5435 ±716	4687 ±866	5281 ±779	5208 ±523	5921 ±910	6115 ±1123	5706 ±422
1.2 Tensile stress _l_ to grain	MPa	0.91 ±0.11	0.49 ±0.16	0.47 ±0.13	1.30 ±0.18	0.94 ±0.10	1.19 ±0.19	1.00 ±0.22	0.87 ±0.19	0.95 ±0.12
1.3 Compressive stress _l_ to grain	MPa	3.46 ±0.32	3.67 ±0.34	3.24 ±0.53	6.96 ±0.48	6.95 ±0.38	6.25 ±0.23	3.31 ±0.37	3.23 ±0.47	2.90 ±0.21
1.4 Compression stress ll to grain	MPa	41.04 ±4.86	42.23 ±7.35	42.12 ±4.67	25.85 ±3.97	32.38 ±2.22	30.90 ±4.77	38.96 ±4.18	39.51 ±5.37	40.22 ±1.83
1.5 Shearing stress ll to grain	MPa	14.74 ±1.87	14.81 ±1.16	14.91 ±0.79	14.25 ±1.86	14.32 ±1.60	12.81 ±1.11	15.70 ±1.25	16.21 ±1.45	14.76 ±1.40
1.6 Clevage	MPa	4.04 ±0.94	4.75 ±1.15	4.48 ±1.08	3.31 ±1.16	3.42 ±1.22	3.61 ±1.78	4.55 ±0.96	4.82 ±1.22	4.09 ±0.74
1.7 Hardness	N	2641 ±194	2648 ±92	2685 ±184	2342 ±152	2563 ±234	3018 ±236	2614 ±111	2599 ±165	2308 ±244
1.8 Toughness mm	N	31,692±3,948	24,970±7,384	29,274±3,019	25,970±3,103	29,236±4,434	31,062±4,068	32,939±1,949	35,405±4,426	31,125±3,493
1.9 Nail holding power										
- (Tangential)	N/mm	11.77 ±1.25	12.67 ±2.94	22.99 ±5.24	9.42 ±1.46	10.23 ±1.47	13.99±2.30	13.29 ±2.88	14.18 ±2.24	7.75 ±1.57
- (Radial)	N/mm	12.73 ±3.36	12.76 ±0.95	24.64 ±3.33	9.68 ±2.15	12.89 ±2.75	14.95±1.53	14.53 ±2.72	13.60 ±2.84	9.84 ±3.88
2. Physical properties										
2.1 Moisture content	%	11.08 ±0.39	10.95 ±0.33	11.16 ±0.33	10.45 ±0.40	11.12 ±1.07	10.63 ±0.30	11.21 ±0.65	11.18 ±0.39	11.51 ±0.86
2.2 Specific gravity	-	0.37 ±0.06	0.37 ±0.06	0.41 ±0.05	0.39 ±0.06	0.39 ±0.06	0.42 ±0.05	0.35 ±0.06	0.37 ±0.05	0.41 ±0.04
2.3 Density	kg/m^3	406 ±71	413 ±63	456 ±50	439 ±69	437 ±67	469 ±54	395 ±68	412 ±58	454 ±44

Remark: Std = standard deviation; MOR = modulus of rupture; MOE = modulus of elasticity; _l_ = perpendicular to grain; ll = parallel to grain.

Table 5 Comparison of mechanical properties of *Anthocephalus chinensis* wood and other commercial species.

Species		Moisture content	Specific gravity	Bending strength		Tension	Compression	Compression	Shear	Cleavage	Hardness	Toughness	Nail holding power		Natural durability
				MOR	MOE	⊥	⊥	‖	‖				T	R	
		(%)		-------------------	------------	------------	(MPa)	------------	------------	------------	(N)	(MPa)	------- (N/mm)	-------	(year)
A.chinensis	(mean)	11.03	0.39	58.23	5,518.43	0.90	4.44	37.02	14.72	4.12	2,602.17	-	12.92	13.96	1.5 (0.6-4.0)[3]
	(std)	±0.32	±0.02	±3.73	±433.51	±0.27	±1.73	±5.84	±0.95	±0.57	±206.06	-	±4.36	±4.40	-
H. brasiliensis[1]	(mean)	8.94	0.61	84.27	9,933.40	-	20.11	38.13	17.02	-	7,007.82	0.12	-	-	2.0 (0.5-3.8)[3]
	(std)	±0.54	±0.04	±6.05	±1,324.10	-	±3.17	±3.37	±2.44	-	±511.29	±0.02	-	-	-
E. camaldulensis[2]	(mean)	11.82	0.89	132.00	14,800.00	-	-	69.90	20.00	-	8,510.00	-	-	-	-
T. grandis[3]	(mean)	12.00	0.57	100.00	10,190.00	-	-	49.50	15.00	-	4,860.00	-	-	-	19.4 (8.4-32.6)[3]

Note: std = standard deviation; min = minimum; max = maximum; MOR = modulus of rupture; MOE = modulus of elasticity; T = tangential direction; R = radial direction.

[1] Anonymous (2007).

[2] Royal Forest Department (2008).

[3] Royal Forest Department (2004).

5.91 GPa, respectively (Table 4). ANOVA analysis showed that tree age had a significant effect on bending strength and stiffness (Table 6); the MOR and MOE values increased with age. The ten-year-old samples had the lowest compressive and shear stress parallel to the grain, with average values of 29.71 and 13.79 MPa, respectively, and also had the highest compressive and tensile stress perpendicular to the grain with average values of 6.72 and 1.14 MPa, respectively (Table 4). The results seem to indicate that there was an effect of age on compressive and tensile stress, but since the samples came from different locations, the effect of sample source seems to have dominated the influence of tree age. The ANOVA results showed that there were no significant differences between different ages based on the cleavage and hardness tests.

Influence of height on the properties

The samples taken from the trunk at different heights above the ground were not correlated to mechanical properties. In general, the bending properties are largely attributable to the effect of density or specific gravity (SG). In general, specific gravity is higher and the percentage of mature wood is greater at the bottom of the tree, and therefore it can be concluded that the bottom part should have higher bending properties than the top part. SG gradually decreases from the base to the upper part of the trunk. In the current study, the ANOVA results showed that the bending properties of the samples at various heights were not significantly different at the 0.05 level (Table 6).

Properties from different species

The mechanical properties of *A. chinensis* (average age approximately 11 y) were compared to other species, including rubberwood, eucalypt and teak wood (Table 5 and Figure 5). The bending strength of *A. chinensis* was comparable to that of rubberwood, but lower than in eucalypt and teak. Wood that has a high modulus of elasticity indicates that it is difficult to bend.

Table 6 Summary of ANOVA results for mechanical properties of *Anthocephalus chinensis* wood samples.

Properties	Factor	
	Age	Height
	-------------------- P-value --------------------	
Static bending		
- Modulus of rupture	0.1460	0.5031
- Modulus of elasticity	0.0031*	0.8824
Tensile stress _l_ to grain	0.0076*	0.4405
Compressive stress _l_ to grain	< 0.0001*	0.6413
Compression stress ll to grain	< 0.0001*	0.7630
Shearing stress ll to grain	0.0177*	0.3481
Cleavage	0.0851	0.8316
Hardness	0.5540	0.3257
Toughness		
- (Tangential)	0.0145*	0.4665
- (Radial)	0.1895	0.0957

Note: * = significant at 0.05 probability level.

The *A. chinensis* wood was easier to bend than eucalypt samples. Variation in the compression strength was comparable to that in rubberwood at similar density values. Density is the simplest means to evaluate the strength of wood without defects. When density increases, strength also increases (Tsoumis, 1991). Eucalypt with higher density tend to have a higher strength than *A. chinensis*, which has lower density. Ring-porous hardwoods, such as teak, tend to have a higher proportion of latewood, which results in a higher strength than in *A. chinensis*, although teak and *A. chinensis* have comparable densities. In general, fast-growing trees produce wood of lower strength (Tsoumis, 1991). Although eucalypts and *A. chinensis* are fast-growing trees, eucalypts have a higher density. Therefore, the mechanical properties of these two species are different. Compressive strength is usually determined by the abundance and length of parenchyma cells, including the arrangement of the vessels (Tsoumis, 1991). The vessel width of *A. chinensis* was approximately 151 μm and the fiber length of *A chinensis* was approximately 1,700 μm. *A chinensis* tends to have moderate vessel width and longer fibers than other species (Table 3).

Utilization

The selection of timber for specific uses depends on various factors and combinations applicable to the end use, such as strength, density, shrinkage, color, hardness, durability, ease of working, seasoning properties and resistance to insect attack. The recommended use in this study was based on the appearance and mechanical properties, such as transverse stress and compressive stress. The transverse stress and load indicate suitability for some applications, such as railroad ties, while the axial compressive stress indicates suitability for use in a column. The axial shear stress indicates susceptibility to splitting when nailed or screwed (Tsoumis, 1991). From the results of the current study, *A. chinensis* wood, which had low density and strength (431 kg/m^3 and 58 MPa), was unsuitable for using as decking, dowels, bridge, tool handles, sport items and other heavy construction. However based on its low density, light weight, good machining properties

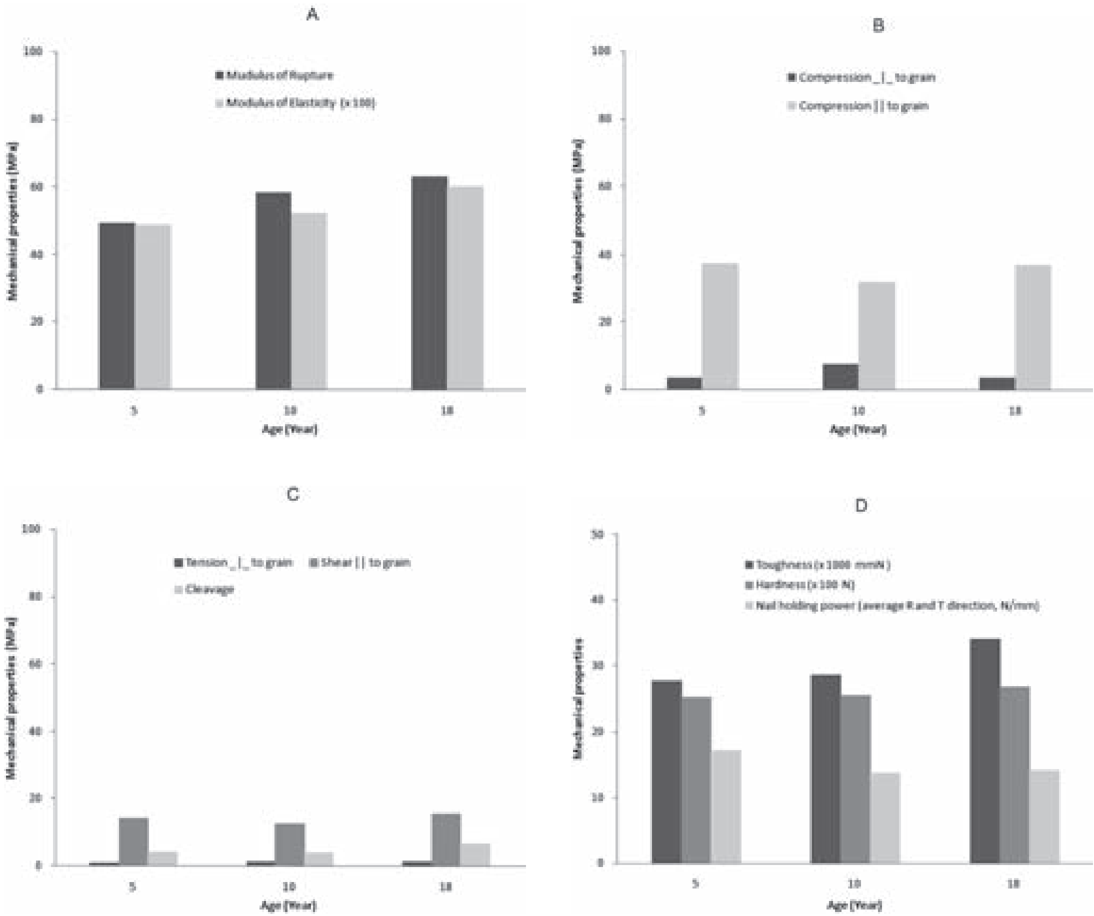

Figure 4 Mechanical properties of *Anthocephalus chinensis* wood at different ages (A = bending strength, B = compressive stress, C = tensile stress, shear stress, and cleavage, D = toughness, hardness, and nail holding power).

and good nailing properties, it can be used as blockboard and in boxes, crates and cases. The hardness of *A. chinensis* was moderately low (2,602 N), indicating resistance to abrasion and scratching. However, it might be suitable in floors, furniture and pencils. Although *A. chinensis* wood was unsuitable for heavy wood construction, it might be suitable for pallets, non-supporting struts and packaging. It has several features that make it suitable as a source of raw materials or for timber production. Moisture, density, temperature, duration of loading and defects all have an effect on the mechanical properties (Tsoumis, 1991). Defects can decrease the strength of wood, but this depends on the kind, size, and position of the defects. Attacks by fungi, insects, marine borers and through incipient decay can reduce wood strength and toughness. From the test results, *A. chinensis* wood has low natural durability; it requires wood preservation treatment before use.

CONCLUSION

Wood from the Bur-flower tree (*Anthocephalus chinensis*) can be classified as a light wood having a moderately smooth surface.

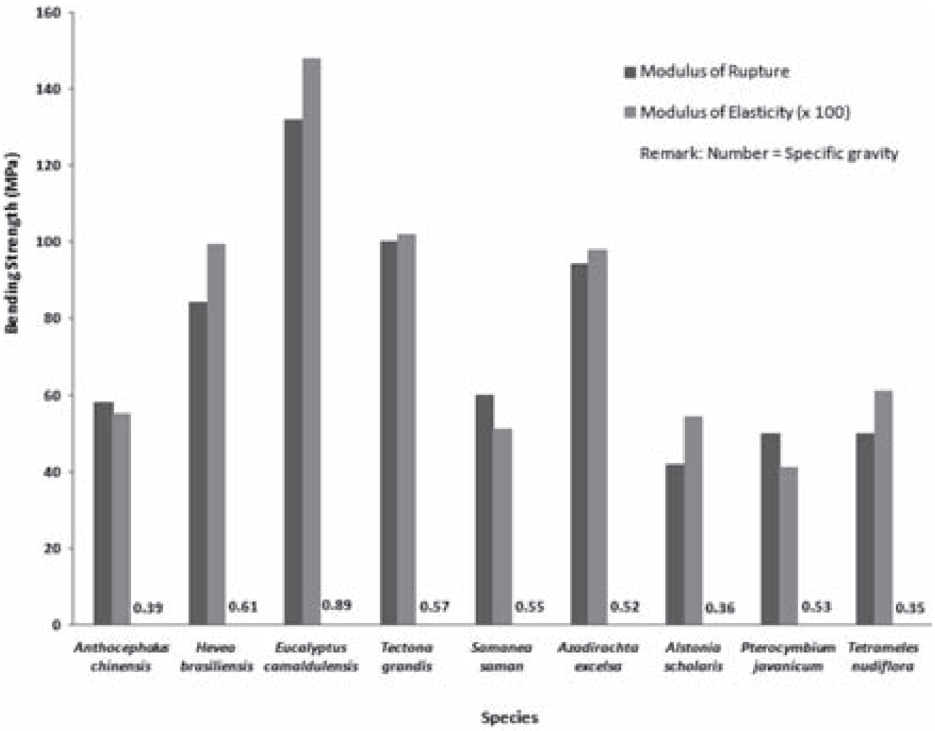

Figure 5 Comparison of mechanical properties of *Anthocephalus chinensis* wood with other species.

Tree age had a positive effect on bending properties, but the effect of the height in the trunk from which samples were taken for bending strength testing was barely noticeable. *A. chinensis* has a white to yellowish-white surface and is medium-to-coarse in texture. It has straight grain and a non-lustrous surface. The average width of vessels was 151 μm and the average fiber length was 1,700 μm. The mechanical properties evaluated showed the MOR and MOE of *A. chinensis* was approximately 58 MPa and 5.5 GPa, respectively, and the specific gravity was between 0.35 and 0.42. The low density and strength of the *A. chinensis* wood samples meant that it was unsuitable for using as decking, dowels, bridge, tool handles, sports items and other heavy construction. However, based on its low density, light weight and good machining and nailing properties, it can be used as blockboard and in boxes, crates, and cases. The hardness of *A. chinensis* was moderately low (2,602 N), which indicates resistance to abrasion and scratching. However, it might be suitable in floors, furniture and pencils. Although *A. chinensis* wood was unsuitable for heavy wood construction, it might be suitable for pallets, non-supporting struts and packaging. *A. chinensis* was evaluated as a low strength wood and because of its low natural durability, it requires wood preservation treatment before use.

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