Physical and mechanical properties of plantation-grown *Acacia auriculiformis* of three different ages

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Summary

We assessed the physical and mechanical properties of timber of plantation-grown 8-, 12- and 13-y-old trees of *Acacia auriculiformis* A.Cunn. ex Benth. from Sirsi, Karnataka, India. The timber of the 13-y-old trees was dense, very strong, moderately tough, stable in service and hard, and it compared favourably with teak in several properties. The results suggest that it can be used for tool handles, oars, paddles, packing cases, ammunition boxes, etc. It was also found suitable for the rural construction industry where timbers of small diameter can be used. If trees are allowed to grow older to attain greater size the range of potential uses will increase.

Keywords: plantations; wood properties; shrinkage; mechanical properties; modulus of elasticity; *Acacia auriculiformis*

Introduction

Acacia auriculiformis A.Cunn. ex Benth. is native to savannas of Papua New Guinea, islands of Torres Strait and northern Australia. In natural stands it is a vigorous tree, reaching a height of 30 m with a trunk up to 60 cm in diameter. Because of its ability to grow on very poor soil and in areas with an extended dry season, it has been introduced into countries such as India, Indonesia, Malaysia, Tanzania and Nigeria.

Acacia auriculiformis was introduced into India about three or four decades ago. In 1990, provenances with straight boles from Papua New Guinea and northern Queensland were planted in the Uttar Kannad and Dharwad districts of Karnataka, India, and their performance was considered good (Rai 1995). The species has also been grown as an avenue tree in other parts of India, viz. Tamil Nadu, Bihar, Orissa and West Bengal, and in fuelwood plantations in Dharwad and other areas of Karnataka. The trees are useful for shade, for ornament, for screening boundaries and for windbreaks, as well as for agroforestry and for mitigating soil erosion. The tree produces a considerable amount of litter from branches and dead leaves that can be gathered for fuel. It is one of the species recommended for firewood farming in degraded lands (Chaturvedi 1985) because of its excellent quality as firewood. The wood burns without smoke or sparks and has a calorific value of 4800–4900 cal kg^{-1} (20.1–20.5 MJ kg^{-1}) (Anon. 1980). The timber also provides a good pulp yield (Guha and Pant 1966).

Recently this species has become popular among both public and private-sector planters[1]. As the planting has been a pioneering effort, there is not much scientific information available about the tree's performance in this region. Information on growth rate and wood properties — which is helpful in evaluating its potential for various end-uses — is essential for informed investment in extensive plantation programs. An understanding of the wood properties and their variation with age (Rao *et al.* 2004) provides a basis for assessing opportunities for value-added uses.

Comments on properties and processing of wood of *A. auriculiformis* have been provided by Rajan *et al.* (1979), Ananthnarayana *et al.* (1987), Kumar *et al.* (1987) and Shukla *et al.* (1990). Keating and Bolza (1982) provided some details of wood characteristics. Kazmi *et al.* (1990) discussed the properties of the wood for the purpose of identification. Verghese *et al.* (1999) reported limited quantitative information pertaining to fibre and vessel morphology in 15-y-old trees from Maharashtra. Rao *et al.* (2004, 2007) described anatomical variation in 8–13-y-old trees.

Because of the lack of systematic information on physical and mechanical properties in relation to tree age, we have investigated those properties. In this paper, we present information on the physical and mechanical properties of wood from trees 8, 12 and 13 y old, and compare them with published values for teak.

Material and methods

Sampling

Five logs each of 8-, 12- and 13-y-old plantation-grown *A. auriculiformis* were procured from Sirsi, Uttar Kannad (Karnataka) to provide wood for evaluation of the physical and mechanical properties of the species. The stands from which the logs were obtained were grown from a single unspecified seed source and in the same locality. Table 1 shows the details of

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[1] Rao, R.V., Rao, K.S., Shukla, S.R., Kothiyal Vimal, Kumar, P., Sudheendra, R., Chandrashekhar, M.N., Jayakumar, M.N., Malkhede, S.K, Madhav Ambadi, Mohamed Amanulla, B.K. and Sathishchandra, K.M. (2005) Evaluation of physical and mechanical properties of *Acacia auriculiformis* × *A. mangium* hybrid, *A. mangium* × *A. auriculiformis* hybrid, *A. auriculiformis* (Spring Vale provenance and local) and *A. mangium*. Report to The Mysore Papermills Ltd, Bhadravathi, Karnataka, India, 37 pp. (unpublished).

Table 1. Environmental factors at Sirsi, Uttar Kannada (Karnataka, India) near the *Acacia auriculiformis* study site

Factor	Value
Latitude	14.96°N
Longitude	74.72°E
Altitude	600 m asl
Maximum daily temperature	23–28°C
Annual rainfall	2500 mm
Soil type	Deep, clayey soil on laterite plateau
Drainage	Good (well drained)

environmental factors at the stands. Average, minimum and maximum girths and average length of logs from each age group of trees are given in Table 2.

All the logs were marked and numbered on the top end and sawn directly into full-length scantling of 6.25 cm × 6.25 cm cross-section to obtain the maximum number of test specimens from each log. One or two scantlings were obtained per log. Each scantling was halved along the radius of the log to provide samples for green and air-dry testing based on IS: 2455 (Anon. 1974).

Measurement of properties

Small clear specimens were tested, in both green and air-dry states, for the following physical and mechanical properties using the procedure given in IS: 1708 (Anon. 1986).

Physical properties

(i) *Moisture content*. Moisture content was measured using test specimens of 2 cm × 2 cm × 2.5 cm on the basis of oven-dry weight as per the standard procedure. The numbers of specimens taken to determine moisture content in the green and air-dry states were 525 and 580 respectively.

(ii) *Density and specific gravity*. Density (colloquially 'weight' or 'heaviness') in both the green and air-dry condition was calculated from the weight of specimens in the green condition and their volume in the green condition, and similarly the air-dry weight and air-dry volume (adjusted to 12% EMC) respectively. Specific gravity was estimated from volume at test (green or air dry) and oven-dry weight using the standard mercury displacement method. Specific gravity based on green volume is referred to here as standard specific gravity. The numbers of specimens taken to determine both density and specific gravity in green and air-dry states were 531 and 578 respectively.

(iii) *Shrinkage*. For the measurement of shrinkage, true radial, tangential, longitudinal and volumetric samples were prepared. The specimen size for volumetric shrinkage was 2 cm × 2 cm × 6 cm, while for radial, tangential and longitudinal shrinkage the specimen size was 2 cm × 2 cm × 5 cm. Specimens were weighed in the green condition to 0.001 g accuracy and their length was measured to 0.002 cm accuracy using Mitutoyo digital screw gauge calipers of 0.001 cm accuracy. Specimens were allowed to air dry, and periodically weighed and lengths measured until no further loss of weight was observed. The specimens were then oven dried and the dimensions measured. The numbers of specimens taken to determine radial, tangential, longitudinal and volumetric shrinkage from the green to an oven-dry state were 164, 160, 151 and 162 respectively.

Mechanical properties

The mechanical testing was conducted on a computer-controlled Universal Timber Testing Machine (UTM) as described below:

(i) *Static bending strength*. The size of specimens was 2 cm × 2 cm × 30 cm with a span length of 28 cm. The loading was applied at a constant rate of 1.0 mm min^{-1} on the tangential surface of the sample. The numbers of specimens used in green and air-dry states were 159 and 162 respectively. Three different static bending strength parameters, fibre stress at elastic limit (*FS at LP* in MPa), modulus of rupture (*MOR* in MPa) and modulus of elasticity (*MOE* in MPa) were computed using the equations:

$$FS\ at\ LP = 3 \times P \times l\,/\,2 \times b \times h^2 \qquad \text{(a)},$$

$$MOR = 3 \times P_{\max} \times l\,/\,2 \times b \times h^2 \qquad \text{(b)},$$

$$MOE = P \times l^3\,/\,4 \times D \times b \times h^3 \qquad \text{(c)},$$

where P = load at the limit of proportionality (kN); $P_{\max}$ = maximum load (kN), l = span of the test specimen (mm), b = breadth of the test specimen (mm), h = depth of the test specimen (mm) and D = deflection at the limit of proportionality (mm).

(ii) *Compressive strength parallel to grain*. The size of specimens was 2 cm × 2 cm × 8 cm in length, and the rate of loading was 0.6 mm min^{-1}. The numbers of specimens used in green and air-dry conditions were 124 and 156 respectively. The compressive strength parallel to the grain (maximum crushing stress, *MCS*) was calculated by the equation:

$$\sigma_{\text{cpl}} = P_{\max}/A\ ,$$

where σ_{cpl} = *MCS* (MPa), $P_{\max}$ = maximum crushing load at

Table 2. Length and girth of five logs in each age group

Tree/log no.	Age (y)	Average available length of log (m)	Girth (diameter) at breast height (cm)		
			Mean	Minimum	Maximum
T1–T5	8	4.55	38.2 (12.2)	32 (10.2)	42 (13.4)
T6–T10	12	4.55	42.8 (13.6)	36 (11.5)	44 (14.0)
T11–T15	13	4.24	50.8 (16.2)	46 (14.6)	53 (16.9)

break point (kN) and A = area of cross section of the specimen on which force was applied (mm^2).

(iii) *Compressive strength perpendicular to grain*. The size of specimens was 2 cm × 2 cm × 10 cm. Load was applied at the 2 cm × 2 cm cross-section on the tangential surface at a rate of 0.6 mm min^{-1}. The numbers of specimens used in green and air-dry conditions were 117 and 147 respectively. The compressive strength perpendicular to the grain (compressive stress at limit of proportionality — *CS at LP* in MPa) was calculated by the equation:

$$CS\ at\ LP = P/A\ ,$$

where P = load at the limit of proportionality (kN) and A = area of cross-section of specimen on which force was applied (mm^2).

(iv) *Hardness under static indentation*. The size of specimens was 5 cm × 5 cm × 5 cm. Load (kN) required to penetrate into the specimen a steel bar with an hemispherical end or a steel ball of 1.128 cm diameter to a depth of 0.564 cm was recorded. Measurements were made at the centre of the radial, tangential and end faces; no splitting or chipping occurred. The rate of loading was kept constant at 6 mm min^{-1}. The numbers of specimens used in green and air-dry conditions were 125 and 115 respectively.

(v) *Shear strength parallel to grain*. The size of specimens was 5 cm × 5 cm × 6 cm. The specimens were notched at one end to produce shear failure in an area of 5 cm × 5 cm in the radial or tangential plane. The numbers of specimens used in green and air-dry conditions were 50 and 36 respectively. The shear strength parallel to the grain in radial and tangential planes (maximum shearing stress — *MSS* in MPa) was calculated by the equation:

$$MSS = P_{max}/A\ ,$$

where P_{max} = maximum load required for shearing the area (kN) and A = shearing area of the specimen on which force was applied (mm^2).

(vi) *Tensile strength perpendicular to grain*. The size of specimens was 5 cm × 5 cm × 6 cm. The specimens were notched on the two surfaces perpendicular to the grain so as to produce a failure on an area of 5 cm × 2 cm. The numbers of specimens used in green and air-dry conditions were 21 and 26 respectively. The tensile strength perpendicular to the grain in radial and tangential planes (*TS* in MPa) was calculated by the equation:

$$TS = P_{max}/A\ ,$$

where P_{max} = maximum load required for failure perpendicular to grain (kN) and A = area of the specimen on which force was applied (mm^2).

(vii) *Nail- and screw-holding power*. Nails of 50 mm length and 2.50 mm shank diameter and screws of 50 mm length and 8 gauge were used for testing. The size of the specimens was 5 cm × 5 cm × 15 cm. The numbers of specimens used in green and air-dry conditions were 31 (in total from trees of all three ages) and 19 (from 13-y-old trees only) respectively. Nails and screws were driven in for 25 mm at right-angles to the surface of specimens. Two nails or screws were driven on each of the radial and tangential surfaces and one on each end. The maximum load required (kN) to pull out the nails or screws was recorded for radial, tangential and end surfaces. The average values of radial and tangential surfaces were named 'side values'.

Statistical design and analysis

The three stands from which each of which five logs were obtained were aged 8, 12 and 13 y respectively. Although the stands were growing near each other in an apparently-uniform environment, the effects of tree age on the sample logs are inevitably confounded with unquantified effects of the stand environments. Although in discussion in this paper we attribute differences between the three sets of sample logs to the effects of stand age, it is important to recognise that stand effects are due to both stand age and stand environment: the field design does not permit these factors to be separated. The comparison with teak has similar constraints.

Results and discussion

General properties and description of wood

Average thickness of the bark for the entire tree was measured as 4.2 mm, 4.8 mm and 5.4 mm for the 8-, 12- and 13-y age classes respectively. The sapwood and heartwood were distinct. The heartwood, which is yellowish-brown in colour, occupied on average 76–85% of the area of each cross-section. The wood is moderately hard and moderately dense, with shallowly interlocked grain and medium texture. Fine lines of parenchyma simulate the presence of growth rings; the actual growth rings are indistinct. Wood structure is diffuse porous. Axial parenchyma is paratracheal, vasicentric and also diffuse-in-aggregate. Rays are very fine and closely spaced.

Physical and mechanical properties

Air-dry values were adjusted to a sample moisture content of 12% using the method of Sekhar and Rajput (1968) where relevant.

Average values of the physical and mechanical properties as determined in green and air-dry conditions are presented in Table 3 for 8-, 12- and 13-y-old trees, along with the corresponding values for 'standard teak', *Tectona grandis* (Sekhar and Rawat 1966), for the purpose of comparison.

Average standard specific gravity was highest in 13-y-old trees (0.62) followed by 12-y (0.60) and 8-y-old trees (0.57) as shown in Figure 1. In other studies, 14-y-old trees from Mudigere, Karnataka, had an average specific gravity of 0.72 (air-dry) (Kumar *et al.* 1987), whereas 9-y-old trees from Gaya, Bihar, had a specific gravity of 0.62 (Shukla *et al.* 1990). Verghese *et al.* (1999) reported that specific gravity was 0.59 for 15-y-old plantations from Wada, Maharashtra. Keating and Bolza (1982) reported that the specific gravity of timber obtained from Indonesia was 0.58–0.64. Mohd Noor Mahat (1999) reported variation in specific gravity (0.53–0.61) of different provenances tested in Malaysia. Thus specific gravity appears to be widely influenced by age, environmental factors and seed origin.

Longitudinal shrinkage was lowest in the 8-y-old trees and volumetric shrinkage was highest in the 13-y-old trees (Table 2).

Table 3. Average physical and mechanical properties of *Acacia auriculiformis* of 8-, 12- and 13-y-old trees and *Tectona grandis* (teak) in green and air-dry condition

Properties	*Acacia auriculiformis*									*Tectona grandis*		
	8 y			12 y			13 y					
	Green	Air-dry	I.F.	Green	Air-dry	I.F.	Green	Air-dry	I.F.	Green	Air-dry	I.F.
MC (%)	54	12	—	48	12	—	44	12	—	76	12	—
Density# (kg m^{-3})	875	665	—	869	711	—	883	729	—	1056	672	—
Specific gravity	0.570	0.590	—	0.603	0.616	—	0.625	0.645	—	0.596	0.604	—
Longitudinal shrinkage (%)	0.53	—	—	0.61	—	—	0.61	—	—	—	—	—
Radial shrinkage (%)	2.66	—	—	2.66	—	—	2.64	—	—	2.30	—	—
Tangential shrinkage (%)	5.34	—	—	5.06	—	—	5.43	—	—	4.80	—	—
Volumetric shrinkage (%)	7.84	—	—	7.35	—	—	8.22	—	—	6.80	—	—
Static bending												
FS at LP (MPa)	48.6	61.1	26	57.5	66.1	15	63.1	72.7	15	49.9	63.9	28
MOR (MPa)	73.9	99.7	35	87.8	100.7	15	91.6	106.6	16	82.5	94.1	14
MOE (GPa)	8.9	9.8	11	10.8	11.4	6	10.9	13.0	19	10.8	11.7	9
Compression parallel to grain: max. stress (*MCS*) (MPa)	32	12	(61)	36	45	25	37	50	34	41	52	28
Compression perpendicular to grain: compression stress at *LP* (*CS at LP*) (MPa)	6.6	9.6	45	7.1	10.1	41	7.9	11.0	39	8.4	9.9	17
Hardness (static indentation)												
Radial (kN)	3.6	3.7	4	3.2	3.6	13	3.6	4.8	31	5.5	4.9	(10)
Tangential (kN)	3.7	3.8	1.6	3.4	4.0	18	3.7	4.9	32	5.4	5.1	(5)
End (kN)	3.6	3.6	0.3	3.1	3.2	2.6	3.9	4.0	3	4.8	4.8	(0.4)
Shearing stress parallel to grain (*MSS*)												
Radial (MPa)	5.0	8.2	64	6.1	—		6.8	6.9	2.4	8.8	9.5	8
Tangential (MPa)	6.7	9.1	35	6.8	—		7.7	9.0	17	9.8	10.6	8
Tensile stress perpendicular to grain (*TS*)												
Radial (MPa)	3.2	3.1	(4)	2.6	1.3	(42)	2.7	1.2	(55)	6.7	5.6	(16)
Tangential (MPa)	3.5	4.1	17	2.9	1.9	(36)	3.8	2.0	(47)	7.9	6.5	(18)
Nail-holding power												
Side (kN)	0.92	*—	—	0.81	*—	—	0.96	0.62	(35)	1.25	—	—
End (kN)	0.34	*—	—	0.54	*—	—	0.71	0.52	(27)	0.89	—	—
Screw-holding power												
Side (kN)	2.49	*—	—	2.70	*—	—	3.02	2.99	(1.0)	3.25	—	—
End (kN)	1.31	*—	—	1.57	*—	—	1.69	2.37	40	2.32	—	—

FS at LP = Fibre stress at limit of proportionality
MOR = Modulus of rupture
MOE = Modulus of elasticity
MSS = Maximum shearing stress
I.F. = Improvement factor (%)
Numbers in brackets indicate negative values
#Colloquially density may be referred to as 'weight' or 'heaviness'
*Insufficient samples were available to obtain these figures directly. Estimates used in the preparation of Table 4 were calculated using the method of Rajput *et al.* (1991).

Radial and tangential shrinkage were more or less age-independent. Figure 1 shows the variation of modulus of rupture (*MOR*), modulus of elasticity (*MOE*) and maximum crushing stress (*MCS*) parallel to the grain in the green and air-dry state for all the tree ages. *MOR*, *MOE* and *MCS* increased with tree age from 8 to 13 y. Improvement factors (I.F.), indicating the percentage increase in the observed values of various mechanical properties from the green to air-dry state, were also calculated and are listed in Table 3. Air-dry values for most mechanical properties were substantially higher than the corresponding green values except for MCS (of 8-y-old trees), tension perpendicular to grain, and nail-holding powers. Hardness and tension values determined in radial, tangential and end directions and tension perpendicular to the grain appear to be independent of age, whereas the shear values were found to be age related, being highest for the 13-y-old specimens. Nail-holding power was age-related only in end grain, whereas screw-holding power was age-related for all the directions studied and highest in the 13-y-old trees.

A comparison with teak using suitability indices

The data obtained on testing the samples in green and air-dry conditions were used to calculate 'suitability' indices, assigning a value of 100 to teak as a reference. From Table 4, it can be seen that the suitability of even 8-y-old acacia in 'strength as a beam'

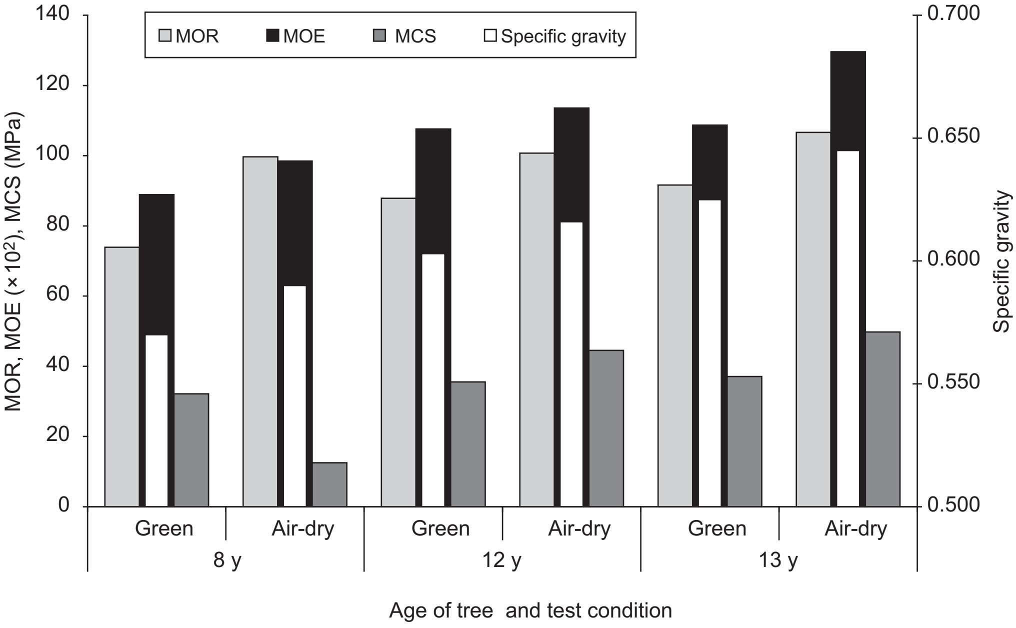

Figure 1. Specific gravity, modulus of rupture (*MOR*), modulus of elasticity (*MOE*) and maximum crushing stress parallel to grain (*MCS*) in plantation-grown *Acacia auriculiformis* 8-, 12- and 13-y-old in green and air-dry condition

Table 4. Suitability of various properties of green *Acacia auriculiformis* wood from trees of three different ages (8, 12 and 13 y) compared with *Tectona grandis* (teak) from 14 locations rated as 100. Both green and air-dry data have been taken into account in preparing this table.

Property	Suitability index value		
	8 y	12 y	13 y
Strength as a beam	104	116	123
Stiffness as a beam	91	104	109
Suitability as a post	71	90	95
Shock-resisting ability	89#	95#	100#
Retention of shape	85	89	83
Shear	72	62	79
Surface hardness	85	84	97
Splitting coefficient	57	37	44
Nail-holding power	77#	85#	64
Screw-holding power	73#	81#	82
Density (colloquially 'weight')	99	106	109

Figures based on data computed from a strength — specific gravity relationship using the method described by Rajput *et al.* (1991)

is better than teak. The suitability as a post was found to be 95 for 13-y-old trees, an improvement over 8- and 12-y-old trees. The shock-resistance ability of the 12- and 13-y-old trees was comparable to that of teak. Retention of shape was best (89) in 12-y-old trees. The 13-y-old trees had the highest comparative rating for shear (79) of three age classes. Surface hardness values were 97 and 85 in 13- and 8-y-old trees respectively. The 12-y-old trees were less refractory than those of other ages. Samples of requisite dimensions were not available for testing the nail- and screw-holding powers of air-dry samples from 8- and 12-y-old trees due to the small girth of those trees, so values were computed from a strength–specific gravity relationship (Rajput *et al.* 1991). While nail-holding power was found to be independent of age, the screw-holding power was better for 12- and 13-y-old trees than for 8-y-old trees. In terms of density, 8-y-old trees are similar to standard teak. The suitability indices presented by Kumar *et al.* (1987) for 14-y-old trees differ from the results of this trial.

Safe working stresses and a comparison with teak

Safe working stresses were determined for the acacia wood when used in internal, external and wet conditions (using standard discount factors, as a safety measure), and results are presented in Table 5 along with standard teak values for comparison. The stresses are those relevant in load-bearing situations in the three different conditions. This information is important for using timber from trees of different species, different ages and different girth classes, assuming that the material is available in the required sizes. On comparing the safe working stresses of *A. auriculiformis* of different ages with the corresponding values for teak in the table, it is seen that the extreme fibre stresses in beams of 12- and 13-y-old trees are higher than those of teak in all three conditions. Other safe working stresses like shear along the grain, horizontal shear in beams, maximum compressive stress parallel to the grain and compressive stress perpendicular to the grain for the 13-y-old trees are comparable with values for teak.

It is customary in studies of the wood properties of a species to compare the data for the timber with the available published information and to group the species with others having similar properties (Sekhar and Gulati 1972). In this study, the data may be used to compare the timber from trees of different ages with that of other species. Thus the timber of 8-y-old *A. auriculiformis* was dense (as in *Acer* spp., *Tectona grandis*, *Acacia leucophloea*), strong (as in *Acacia arabica*, *Anogeissus pendula*), not tough (as in *Dalbergia sissoo*, *Adina cardifolia*, *Chlorophora excelsa*), and stable in service and moderately hard (as in *Bridelia retusa*, *Morus serrata*, *Schima wallichi*). Timber of 12-y-old trees was dense, very strong, not tough, stable and moderately hard. Similarly 13-y-old *A. auriculiformis* was dense, very strong, moderately tough (as in *Acrocarpus fraxinifolius*, *Canarium bengalense*), stable and hard.

Suitability for different end uses

Indices of suitability for different uses were calculated (Sekhar and Gulati 1972) for *A. auriculiformis* of all three ages. The timber is well suited for tool handles, oars and paddles, as the relevant values are comparable to those of teak or better. The figures indicating suitability for construction purposes are very encouraging, and trees of greater size can be used for this purpose: the larger trees are required because recovery after sawing will be greater and costs of milling will be correspondingly reduced. The suitability figures relevant to furniture and ammunition boxes are encouraging, and are independent of age. Similarly, the suitability figures suggest the potential use of the wood for light packing cases. The data on nail and screw-holding should be used cautiously: it was found that pre-boring would minimise problems of splitting, and for most of the uses mentioned above it is important that the timber should not split when nailed or screwed. Preliminary studies on natural durability by Nagaveni and Anathapadmanabha (1991) showed that the wood of the species was highly resistant and can safely be used in decay-prone environments. Turnery articles, furniture, handicrafts and artifacts were made to confirm the multi-purpose nature of the species.

Conclusion

Investigations of physical and mechanical properties of plantation-grown *A. auriculiformis* of three different ages (8, 12 and 13 y) from Sirsi, Karnataka, indicate that the wood can be used for tool handles in workshops, factories and the agricultural sector; oars and paddles; light packing cases; ammunition boxes; etc. It can also satisfy the requirements of the rural construction industry where timbers of small diameter can be used. If the trees are allowed to grow to greater age and size, the wood will have an expanded range of applications. Processing technologies like seasoning and preservation have to be studied to maximise opportunities for value-adding and improving sapwood durability.

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Table 5. Safe working stresses of 8-, 12- and 13-y-old *Acacia auriculiformis* compared with values for *Tectona grandis* (teak)

Strength property	Location											
	Inside				Outside				Wet			
	8 y	12 y	13 y	Teak	8 y	12 y	13 y	Teak	8 y	12 y	13 y	Teak
Extreme fibre stress in beams (MPa)	14.7	17.6	18.3	16.5	12.3	14.6	15.3	13.7	9.9	11.7	12.2	11.0
Shear along grain (MPa)	0.92	1.01	1.13	1.46	0.92	1.01	1.13	1.46	0.92	1.13	1.13	1.46
Horizontal shear in beams (MPa)	0.64	0.71	0.79	1.02	0.64	0.71	0.79	1.02	0.64	0.71	0.79	1.02
Maximum compressive stress parallel to grain (MPa)	8.05	7.8	9.3	10.2	7.2	7.9	8.2	9.0	5.8	6.5	6.7	7.4
Compressive stress perpendicular to grain (MPa)	3.8	4.1	4.5	4.8	3.0	3.2	3.5	3.7	2.4	2.6	2.9	3.0

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