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GRADE STRESSES AND STRENGTH GROUP OF PLANTATION TIMBER: *ACACIA MANGIUM*

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INTRODUCTION

The national forest plantation programme emphasises on the development of eight selected tropical species and *Acacia mangium* is one of them. *Acacia mangium* trees have been planted in Peninsular Malaysia since 1982 through the Compensatory Forest Plantation Project (Ani & Lim 1993). The plantation records in Peninsular Malaysia have reached over 30 years of development since the first local trial. The endeavor was initially planned to be a large-scale industrial programme with a planting rotation of 15 to 20 years. Continuous properties assessments have been carried out ever since the first timber processing from locally grown trees to ensure the utmost utilisation of the material. Although the inherent characteristics of the timber might have been influenced by diverse ecological factors – climate, soil, silviculture, etc., research outputs have delivered an excellent indication of the expected timber quality. The mechanical properties of *Acacia mangium* timber showed comparable values with some indigenous medium hardwoods. In terms of resistance against fungi, the timber of *Acacia mangium* is classified as moderately resistant. Most likely, products made of solid timber of *Acacia mangium* will set out a new chain of demand and supply in the forest plantation business. Besides, a much greater waste-to-wealth outcome is expected from small diameter logs. This article provides a comprehensive calculation of grade stresses and strength grouping arrangement of *Acacia mangium* planted in Peninsular Malaysia. Through this compilation, engineers and designers can make a fair judgement of the mechanical properties of *Acacia mangium*.

TEST SPECIMENS AND METHOD OF TESTING

Logs of *Acacia mangium* were obtained from Ulu Sedili, Johor for 16-y-old sampling and from Kemasul, Pahang for 20-y-old sampling. A total of 6 logs with a nominal length of 2.5 m were selected from each sample batch. All logs were subsequently sawn into sticks of 60 mm × 60 mm cross-section at the Log Processing Workshop, Forest Research Institute Malaysia. Half of the sticks were immediately processed into specimen sizes at the Machining and Prototyping Unit, Forest Research Institute Malaysia for green condition tests. The other half was stacked and air-dried under shed before being processed into specimen sizes for air-dry condition tests. The mechanical assessment was conducted based on BS 373 (1957) standard methods for 2 cm specimens. Mechanical tests of static bending, compression parallel to the grain, shear parallel to the grain, compression perpendicular to the grain, Janka hardness and specific gravity were conducted on both green and air-dried specimens.

MECHANICAL PROPERTIES

The mechanical properties of *Acacia mangium* timber were reported by Mohamad Omar & Mohd-Jamil (2011). Test results of two sample batches i.e. 16-y-old and 20-y-old are shown in Table 1.

Table 1 The mechanical properties of *Acacia mangium* (mean ultimate values)

Species	Condition of specimens	Moisture content	Specific gravity	Modulus of rupture	Modulus of elasticity	Compressive strength parallel to the grain	Compressive strength perpendicular to the grain at 2.54 mm deformation	Shear strength parallel to the grain	Janka hardness
		(%)		(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	kN
Acacia mangium 16-y-old of Ulu Sedili	Green	116.7	0.50	79.5	9307	35.9	5.4	8.2	3.1
		(22.9)	(0.07)	(15.2)	(2149)	(8.3)	(0.8)	(1.9)	(0.7)
	Air-dry	19.9	0.51	96.6	10347	46.0	6.4	12.2	3.0
		(10.7)	(0.09)	(19.6)	(1670)	(7.4)	(1.3)	(2.1)	(0.7)
Acacia mangium 20-y-old of Kemasul	Green	94.5	0.56	102.5	10838	43.4	7.2	11.3	3.4
		(18.3)	(0.06)	(15.2)	(1814)	(8.0)	(1.7)	(1.9)	(0.5)
	Air-dry	15.8	0.58	111.1	10764	52.9	8.9	16.0	2.1
		(2.3)	(0.05)	(14.6)	(2226)	(7.9)	(1.0)	(1.6)	(0.4)

Note: The figures (in brackets) are the standard deviation values

Table 2 Basic and grade stresses of *Acacia mangium* (N mm^{-2})

Species		Bending				Tension				Compression parallel				Compression perpendicular				Shear				Modulus of elasticity	
		Basic	Sel	Sta	Com	Basic	Sel	Sta	Com	Basic	Sel	Sta	Com	Basic	Sel	Sta	Com	Basic	Sel	Sta	Com	Mean	Min
Acacia mangium 16-y-old	G	17.6	14.1	11.1	8.8	10.6	8.5	6.7	5.3	11.0	8.8	6.9	5.5	3.1	2.6	2.5	2.3	1.5	1.1	0.8	0.7	9300	4300
	D	22.1	17.7	13.9	11.1	13.3	10.6	8.3	6.7	14.7	11.8	9.3	7.4	3.8	3.2	3.0	2.9	2.4	1.7	1.3	1.1	10500	4900
Acacia mangium 20-y-old	G	26.8	21.4	16.9	13.4	16.1	12.8	10.1	8.0	16.5	13.2	10.4	8.3	3.4	2.9	2.7	2.5	2.7	2.0	1.5	1.2	10800	6600
	D	28.2	22.6	17.8	14.1	16.9	13.6	10.7	8.5	18.8	15.0	11.8	9.4	3.9	3.3	3.1	2.9	3.4	2.4	1.9	1.5	10800	6600

Green (G); Dry (D); Select grade (Sel); Standard grade (Sta); Common grade (Com).

Table 3 Strength Group (SG) classification of Malaysian timbers

SG1	SG2	SG3	SG4	SG5	SG6	SG7
Naturally Durable						
Balau	Belian	Bekak	Giam	Teak		
Bitis	Mata Ulat	Delek	Malabera	Tembusu		
Chengal	Kekatong	Keranji	Merbau			
Penaga			Resak			
Requiring Treatment						
	Dedaru	Balau, Red	Berangan	*Acacia mangium* (20-y-old)	Bayur	*Acacia mangium* (16-y-old)
	Kempas	Kelat	Dedali	Alan Bunga	Damar Minyak	Ara
	Merbatu	Kembang Semangkok	Derum	Babai	Durian	Batai
	Mertas	Kulim	Kapur	Balek Angin Bopeng	Jelutong	Geronggang
		Pauh Kijang	Kasai	Bintangor	Jongkong	Laran
		Penyau	Keruntum	Brazil Nut	Kasah	Pelajau
		Perah	Mempening	Gerutu	Machang	Pulai
		Petaling	Meransi	Kedondong	Medang	Sesendok
		Ranggu	Meranti Bakau	Keledang	Melantai	Terentang
		Ru	Merawan	Keruing	Meranti, Light Red	
		Surian Batu	Merpauh	Ketapang	Meranti, Yellow	
		Tualang	Nyalin	Kungkur	Mersawa	
			Perupok	Melunak	Sengkurat	
			Punah	Mempisang	Terap	
			Rengas	Mengkulang		
			Simpoh	Meranti, Dark Red		
				Meranti, White		
				Nyatoh		
				Penarahan		
				Petai		
				Ramin		
				Rubberwood		
				Sengkuang		
				Sepetir		
				Tetebu		

Source: MS 544 2001

BASIC AND GRADE STRESSES

The derivation of basic and grade stresses for green and dry conditions of 16-y-old and 20-y-old *Acacia mangium* was based on the formulae reported by Chu et al. (1997). For demonstration, the derivation of basic and grade stresses of 16-y-old Acacia mangium is shown in the Appendix. The basic and grade stresses of *Acacia mangium* timber are presented in Table 2. The basic and grade stresses derived from *Acacia mangium* timber were compared with the working stresses of the respective strength group (SG) classification of Malaysian timbers for the lowest values (Chu et al. 1997). Referring to Table 2, all basic and grade stresses of 20-y-old *Acacia mangium* were higher than SG5 but the modulus of elasticity values were lower than SG4. In the same way, all grade stresses of 16-y-old *Acacia mangium* were higher than SG7 but the modulus of elasticity values were lower than SG6. Thus, based on the comparative stresses for green and dry conditions, 20-y-old and 16-y-old *Acacia mangium* are categorised in SG5 and SG7 respectively (Table 3).

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APPENDIX

Calculation of green basic and grade stresses of *Acacia mangium* (16-y-old)

It has been a practice in Malaysia to estimate for 99% confidence limit, i.e. allowing only 1% error (alpha level, α = 0.01). Therefore, the critical value is taken as $t_{0.99}$ = 2.33.

(a) Bending (modulus of rupture)

$$\text{Green basic stress} = \frac{\text{Mean ultimate stress} - 2.33 \times \text{Standard deviation}}{\text{Factor of safety}}$$

$$= \frac{79.5 - 2.33 \times 15.2}{2.5}$$

$$= \underline{\underline{17.6}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.80 \times 17.6 = \underline{\underline{14.1}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.63 \times 17.6 = \underline{\underline{11.1}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.50 \times 17.6 = \underline{\underline{8.8}} \quad \text{N mm}^{-2}$$

(b) Tension parallel to the grain

$$\text{Grade stresses} = \text{Bending grade stresses} \times 60\%$$

$$\text{Select grade stress} = 14.1 \times 0.6 = \underline{\underline{8.5}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 11.1 \times 0.6 = \underline{\underline{6.7}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 8.8 \times 0.6 = \underline{\underline{5.3}} \quad \text{N mm}^{-2}$$

(c) Compression parallel to the grain

$$\text{Green basic stress} = \frac{\text{Mean ultimate stress} - 2.33 \times \text{Standard deviation}}{\text{Factor of safety}}$$

$$= \frac{35.9 - 2.33 \times 8.3}{1.5}$$

$$= \underline{\underline{11.0}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.80 \times 11.0 = \underline{\underline{8.8}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.63 \times 11.0 = \underline{\underline{6.9}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.50 \times 11.0 = \underline{\underline{5.5}} \quad \text{N mm}^{-2}$$

(d) Compression perpendicular to the grain

$$\text{Green basic stress} = \frac{\text{Mean ultimate stress} - 1.64 \times \text{Standard deviation}}{\text{Factor of safety}}$$

$$= \frac{5.4 - 1.64 \times 0.8}{1.3}$$

$$= \underline{\underline{3.1}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.85 \times 3.1 = \underline{\underline{2.6}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.80 \times 3.1 = \underline{\underline{2.5}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.75 \times 3.1 = \underline{\underline{2.3}} \quad \text{N mm}^{-2}$$

(e) Shear parallel to the grain

$$\text{Green basic stress} = \frac{\text{Mean ultimate stress} - 2.33 \times \text{Standard deviation}}{\text{Factor of safety}}$$

$$= \frac{8.2 - 2.33 \times 1.9}{2.5}$$

$$= \underline{\underline{1.5}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.72 \times 1.5 = \underline{\underline{1.1}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.56 \times 1.5 = \underline{\underline{0.8}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.45 \times 1.5 = \underline{\underline{0.7}} \quad \text{N mm}^{-2}$$

(f) Modulus of elasticity

$$\text{Green mean modulus of elasticity} = \frac{\text{Modulus of elasticity}}{\text{Factor of safety}}$$
$$= \frac{9307}{1.0}$$
$$\approx \underline{\underline{9300}} \quad \text{N mm}^{-2}$$

$$\text{Green minimum modulus of elasticity} = \frac{\text{Modulus of elasticity - } 2.33 \times \text{Standard deviation}}{\text{Factor of safety}}$$
$$= \frac{9307 - 2.33 \times 2149}{1.0}$$
$$\approx \underline{\underline{4300}} \quad \text{N mm}^{-2}$$

Calculation of dry basic and grade stresses of *Acacia mangium* (16-y-old)

(a) Bending (modulus of rupture)

Based on Madison formula:

$$\log(\text{Stress at 19\% MC}) = \log(\text{Green stress}) + \frac{(\text{FSP} - \text{Max. air dry MC})}{(\text{FSP} - \text{MC of air dry test})} \times \log\left(\frac{\text{Air dry stress}}{\text{Green stress}}\right)$$
$$= \log(79.5) + \frac{25-19}{25-19.9} \times \log\left(\frac{96.6}{79.5}\right)$$
$$= 2.000$$

$$\text{Stress at 19\% MC} = 100.0 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$
$$= \frac{100.0}{79.5} \times 17.6$$
$$= \underline{\underline{22.1}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.80 \times 22.1 = \underline{\underline{17.7}} \quad \text{N mm}^{-2}$$
$$\text{Standard grade stress} = 0.63 \times 22.1 = \underline{\underline{13.9}} \quad \text{N mm}^{-2}$$
$$\text{Common grade stress} = 0.50 \times 22.1 = \underline{\underline{11.1}} \quad \text{N mm}^{-2}$$

(b) Tension parallel to the grain

$$\text{Grade stresses} = \text{Bending grade stresses} \times 60\%$$
$$\text{Select grade stress} = 17.7 \times 0.6 = \underline{\underline{10.6}} \quad \text{N mm}^{-2}$$
$$\text{Standard grade stress} = 13.9 \times 0.6 = \underline{\underline{8.3}} \quad \text{N mm}^{-2}$$
$$\text{Common grade stress} = 11.1 \times 0.6 = \underline{\underline{6.7}} \quad \text{N mm}^{-2}$$

(c) Compression parallel to the grain

$$\log(\text{Stress at 19\% MC}) = \log(\text{Green stress}) + \frac{(\text{FSP} - \text{Max. air dry MC})}{(\text{FSP} - \text{MC of air dry test})} \times \log\left(\frac{\text{Air dry stress}}{\text{Green stress}}\right)$$

$$= \log(35.9) + \frac{25-19}{25-19.9} \times \log\left(\frac{46.0}{35.9}\right)$$
$$= 1.682$$

$$\text{Stress at 19\% MC} = 48.1 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$
$$= \frac{48.1}{35.9} \times 11.0$$
$$= \underline{\underline{14.7}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.80 \times 14.7 = \underline{\underline{11.8}} \quad \text{N mm}^{-2}$$
$$\text{Standard grade stress} = 0.63 \times 14.7 = \underline{\underline{9.3}} \quad \text{N mm}^{-2}$$
$$\text{Common grade stress} = 0.50 \times 14.7 = \underline{\underline{7.4}} \quad \text{N mm}^{-2}$$

(d) Compression perpendicular to the grain

$$\log(\text{Stress at 19\% MC}) = \log(\text{Green stress}) + \frac{(\text{FSP} - \text{Max. air dry MC})}{(\text{FSP} - \text{MC of air dry test})} \times \log\left(\frac{\text{Air dry stress}}{\text{Green stress}}\right)$$

$$= \log(5.4) + \frac{25-19}{25-19.9} \times \log\left(\frac{6.4}{5.4}\right)$$
$$= 0.819$$

$$\text{Stress at 19\% MC} = 6.6 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$
$$= \frac{6.6}{5.4} \times 3.1$$
$$= \underline{\underline{3.8}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.85 \times 3.8 = \underline{\underline{3.2}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.80 \times 3.8 = \underline{\underline{3.0}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.75 \times 3.8 = \underline{\underline{2.9}} \quad \text{N mm}^{-2}$$

(e) Shear parallel to the grain

$$\log(\text{Stress at 19\% MC}) = \log(\text{Green stress}) + \frac{(\text{FSP} - \text{Max. air dry MC})}{(\text{FSP} - \text{MC of air dry test})} \times \log\left(\frac{\text{Air dry stress}}{\text{Green stress}}\right)$$

$$= \log(8.2) + \frac{25-19}{25-19.9} \times \log\left(\frac{12.2}{8.2}\right)$$
$$= 1.117$$

$$\text{Stress at 19\% MC} = 13.1 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$
$$= \frac{13.1}{8.2} \times 1.5$$
$$= \underline{\underline{2.4}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.72 \times 2.4 = \underline{\underline{1.7}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.56 \times 2.4 = \underline{\underline{1.3}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.45 \times 2.4 = \underline{\underline{1.1}} \quad \text{N mm}^{-2}$$

(f) Modulus of elasticity

$$\log(\text{Stress at 19\% MC}) = \log(\text{Green stress}) + \frac{(\text{FSP} - \text{Max. air dry MC})}{(\text{FSP} - \text{MC of air dry test})} \times \log\left(\frac{\text{Air dry stress}}{\text{Green stress}}\right)$$

$$\log(\text{Dry mean modulus of elasticity @ 19\% MC}) = \log(9307) + \frac{25-19}{25-19.9} \times \log\left(\frac{10347}{9307}\right)$$

$$= 4.023 \quad \text{N mm}^{-2}$$

$$\text{Dry mean modulus of elasticity} = 10544 \quad \text{N mm}^{-2}$$
$$\approx \underline{\underline{10500}} \quad \text{N mm}^{-2}$$

$$\text{Dry min. modulus of elasticity} = \frac{\text{Dry mean modulus of elasicity}}{\text{Green } \textit{mean} \text{ modulus of elasticity}} \times \text{Green min. modulus of elasticity}$$
$$= \frac{10500}{9300} \times 4300$$
$$= 4855 \quad \text{N mm}^{-2}$$
$$\approx \underline{\underline{4900}} \quad \text{N mm}^{-2}$$

Tree of *Acacia mangium* is one of the prime species in the national plantation forestry programme. The programme was initiated with a vision to offset the shortage of sawn timbers and to level with the current deficit of industry revenue. A continuous acquisition of the physical and mechanical data is carried out to ensure the utmost utilisation of plantation timber outputs. This article provides a comprehensive derivation of timber grade stresses and strength grouping procedure of *Acacia mangium* planted in Peninsular Malaysia.

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