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GRADE STRESSES AND STRENGTH GROUP OF 15-YEAR-OLD *TAMARINDUS INDICA*

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INTRODUCTION

The tree of *Tamarindus indica* (locally known as asam jawa or celagi) is a moderate to large monotypic genus with a potential to grow up to 24 m in height and over 1 m in diameter. *Tamarindus indica* is believed to be indigenous to tropical Africa (Diallo et al. 2007). It grows wild over the continent mostly in Sudan, Cameroon, Nigeria, Zambia and Tanzania. The species was introduced to Malaysia in the distant past for various food and medicinal uses. Today, the trees of *Tamarindus indica* are widely found throughout the country (Figure 1). In foreign nations such as in Africa and India, the timber of *Tamarindus indica* is highly valued for furniture, panelling, wheels, axles, gears for mills, planking for sides of boats, tool handles, rice pounders, mortars and pestles (Bhadoriya et al. 2011). With the trade restriction of ramin (*Gonystylus* spp.) and escalated market price of rubberwood (*Hevea brasiliensis*), the readily available *Tamarindus indica* is a potential alternative for light-coloured timber. The Janka hardness value of *Tamarindus indica* is fairly high indicating suitability for high foot-traffic flooring such as for offices, showrooms, indoor sport arenas and restaurants. This article provides a comprehensive calculation of grade stresses and strength grouping arrangement of *Tamarindus indica* planted in Peninsular Malaysia. Through this compilation, engineers and designers can make a fair judgement of the mechanical properties of *Tamarindus indica*.

Figure 1 A mature tree of *Tamarindus indica* in Chuping, Perlis

TEST SPECIMENS AND METHOD OF TESTING

An 'extra test' of mechanical properties assessment of *Tamarindus indica* was conducted in which the test material was obtained from one tree. The tree was planted for landscaping in a housing area in Serendah, Selangor. The age of the tree was approximately 15-year-old. A log of 1.5 meters long was cut at 50 cm from above the ground. The bottom and top diameters measured 22.3 cm and 20.5 cm respectively. The log was sawn into sticks of 30 mm × 30 mm and one stick of 60 mm × 60 mm at the Log Processing Workshop, Forest Research Institute Malaysia. Half of the sticks were subsequently processed into test 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 until a constant weight was attained before being processed into specimen sizes for air-dry condition tests. The sticks were cut and planed into specimen sizes for static bending, compression parallel to the grain, compression perpendicular to the grain, shear, Janka hardness and specific gravity tests. The mechanical tests were conducted based on BS 373 (1957) standard methods for 2 cm specimens using a universal testing machine at the Wood Composite Testing Laboratory, Forest Research Institute Malaysia.

MECHANICAL PROPERTIES

The mechanical properties of timber of 15-year-old *Tamarindus indica* were reported by Mohd-Jamil et al. (2020) as shown in Table 1. Since the tested samples were based on a juvenile tree, mechanical properties of higher values are expected from samples of matured trees.

In general, air-dry samples should demonstrate higher mechanical properties as compared to green samples. However, the previous study of 15-year-old *Tamarindus indica* showed that the mean MOE values in green and air-dry conditions were 8530 and 8476 N mm^{-2}, while the mean values of compressive strength parallel to grain were 43.1 and 42.4 N mm^{-2} respectively.

Similarly, opposing values have been observed in previous mechanical properties assessments of other species. For example, the mean bending MOE values of 20-year-old *Acacia mangium* in green and air-dry conditions were 10838 and 10764 N mm^{-2} respectively (Mohamad Omar & Mohd-Jamil 2011), and *Acacia auriculiformis* were 13900 and 13500 N mm^{-2} (Lee et al. 1993).

Besides, conflicting values were also observed in other modes of testing regardless of age or density, and the following are some of the examples. The green and air-dry values of compression perpendicular to the grain test of chengal (*Neobalanocarpus heimii*) were 12.21 and 12.00 N mm^{-2} respectively. The green and air-dry values of shear parallel to the grain test of damar minyak (*Agathis dammara*) were 8.1 and 6.9 N mm^{-2}, and tembusu (*Fagraea fragrans*) 8.1 and 6.9 N mm^{-2} respectively. The green and air-dry values of Janka hardness of petaling (*Ochanostachys amentacea*) were 6.59 and 6.36 kN, tualang (*Koompassia excelsa*) 8.23 and 7.21 kN, and penarahan (*Myristica gigantean*) 4.54 and 4.49 kN respectively (Lee et al. 1993).

In such cases, the engineering practice is to select the green result as the representative value. For example, the mean green value of compression perpendicular to the grain test of chengal (*Neobalanocarpus heimii*) is higher than air-dry. Thus the green stresses are used as both green and air-dry grade stresses (MS 2001).

BASIC AND GRADE STRESSES

The derivation of basic and grade stresses for green and dry conditions of 15-y-old *Tamarindus indica* was based on the formulae reported by Chu et al. (1997). The mathematical calculation of basic and grade stresses of 15-y-old *Tamarindus indica* is shown in the Appendix. The basic and grade stresses of *Tamarindus indica* timber are presented in Table 2. The calculated basic and grade stresses were compared with the basic and grade 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 15-y-old *Tamarindus indica* were higher than SG7 but the minimum modulus of elasticity values were lower than SG6. Thus, based on the comparative stresses for green and dry conditions, 15-y-old *Tamarindus indica* is categorised under SG7 (Table 3).

CONCLUSIONS

The basic and grade stresses of 15-y-old *Tamarindus indica* in green and dry conditions were derived using the formulae reported by Chu et al. (1997). Based on the comparative stresses in green and dry conditions as specified in The Strength Groups of Malaysian timbers, 15-y-old *Tamarindus indica* is categorised under Strength Group (SG) 7. However, since the values are based on samples of a juvenile tree, mechanical properties of higher values and a higher strength group are expected from samples of matured trees.

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Table 1 The mechanical properties of 15-year-old *Tamarindus indica* (mean ultimate values)

Species	Condition of specimens	Moisture content	Specific gravity	Modulus of rupture	Modulus of elasticity	Compressive strength parallel to the grain	Compressive stress perpendicular to the grain at 2.54 mm deformation	Compressive stress perpendicular to the grain at the limit of proportionality	Shear strength parallel to the grain	Janka hardness
		(%)		(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	(N mm^{-2})	N
Tamarindus indica 15-y-old of Serendah	Green	58.4	0.684	79.9	8530	43.1	8.2	6.2	13.1	n.a.
		(5.7)	(0.017)	(15.5)	(1712)	(5.3)	(0.5)	(0.3)	(1.9)	n.a.
	Air-dry	18.0	0.691	95.3	8476	42.4	11.1	9.4	15.6	4747
		(0.4)	(0.021)	(12.4)	(907)	(3.7)	(0.9)	(1.1)	(1.4)	(350)

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

Table 2 Basic and grade stresses of 15-year-old *Tamarindus indica* (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
Tamarindus indica 15-y-old	G	17.5	14.0	11.0	8.8	10.5	8.4	6.6	5.3	20.5	16.4	12.9	10.3	4.4	3.7	3.5	3.3	3.5	2.5	2.0	1.6	8500	4500
	D	20.3	16.2	12.8	10.2	12.2	9.7	7.7	6.1	20.5	16.4	12.9	10.3	6.3	5.4	5.0	4.7	4.1	3.0	2.3	1.8	8500	4500

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	Asam jawa (15-y-old)
	Mertas	Kulim	Kapur	Balek Angin Bopeng	Jelutong	Batai
		Pauh Kijang	Kasai	Bintangor	Jongkong	Geronggang
		Penyau	Keruntum	Brazil Nut	Kasah	Laran
		Perah	Mempening	Gerutu	Machang	Pelajau
		Petaling	Meransi	Kedondong	Medang	Pulai
		Ranggu	Meranti Bakau	Keledang	Melantai	Sesendok
		Ru	Merawan	Keruing	Meranti, Light Red	Terentang
		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: Mohd-Jamil 2018

Appendix

Calculation of green basic and grade stresses of *Tamarindus indica* (15-y-old)

Based on calculation method published in Trade Leaflet No. 37 (Engku 1980):

It has been a practice in Malaysia to estimate for 99% confidence limit, i.e. allowing only 1% error (alpha level, $\alpha = 0.01$), except for compression perpendicular to the grain where the confidence limit is 95%. Therefore, the critical value is taken as $t_{0.99} = 2.33$, and $t_{0.95} = 1.64$ for compression perpendicular to grain (Chu et al. 1997).

(a) Bending (modulus of rupture)

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

$$= \frac{79.9 - 2.33 \times 15.5}{2.5}$$

$$= \underline{\underline{17.5}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Select grade stress} = 0.80 \times 17.5 = \underline{\underline{14.0}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Standard grade stress} = 0.63 \times 17.5 = \underline{\underline{11.0}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Common grade stress} = 0.50 \times 17.5 = \underline{\underline{8.8}} \quad \mathrm{N\,mm^{-2}}$$

(b) Tension parallel to the grain

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

$$\text{Select grade stress} = 14.0 \times 0.6 = \underline{\underline{8.4}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Standard grade stress} = 11.0 \times 0.6 = \underline{\underline{6.6}} \quad \mathrm{N\,mm^{-2}}$$

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

(c) Compression parallel to the grain

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

$$= \frac{43.1 - 2.33 \times 5.3}{1.5}$$

$$= \underline{\underline{20.5}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Select grade stress} = 0.80 \times 20.5 = \underline{\underline{16.4}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Standard grade stress} = 0.63 \times 20.5 = \underline{\underline{12.9}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Common grade stress} = 0.50 \times 20.5 = \underline{\underline{10.3}} \quad \mathrm{N\,mm^{-2}}$$

(d) Compression perpendicular to the grain

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

$$= \frac{6.2 - 1.64 \times 0.3}{1.3}$$

$$= \underline{\underline{4.4}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Select grade stress} = 0.85 \times 4.4 = \underline{\underline{3.7}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Standard grade stress} = 0.80 \times 4.4 = \underline{\underline{3.5}} \quad \mathrm{N\,mm^{-2}}$$

$$\text{Common grade stress} = 0.75 \times 4.4 = \underline{\underline{3.3}} \quad \mathrm{N\,mm^{-2}}$$

(e) Shear parallel to the grain

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

$$= \frac{13.1 - 2.33 \times 1.9}{2.5}$$

$$= \underline{\underline{3.5}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.72 \times 3.5 = \underline{\underline{2.5}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.56 \times 3.5 = \underline{\underline{2.0}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.45 \times 3.5 = \underline{\underline{1.6}} \quad \text{N mm}^{-2}$$

(f) Modulus of elasticity

$$\text{Green mean modulus of elasticity} = \frac{\text{Modulus of elasticity}}{\text{Factor of safety}}$$

$$= \frac{8530}{1.0}$$

$$\approx \underline{\underline{8500}} \quad \text{N mm}^{-2}$$

$$\text{Green minimum modulus of elasticity} = \frac{\text{Modulus of elasticity} - 2.33 \times \text{Standard deviation}}{\text{Factor of safety}}$$

$$= \frac{8530 - 2.33 \times 1712}{1.0}$$

$$\approx \underline{\underline{4500}} \quad \text{N mm}^{-2}$$

Calculation of dry basic and grade stresses of *Tamarindus indica* (15-y-old)

(a) Bending (modulus of rupture)

Based on Madison formula:

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

$$= \log(79.9) + \frac{25-19}{25-18.0} \times \log\left(\frac{95.3}{79.9}\right)$$

$$= 1.968$$

$$\text{Stress at 19\% MC} = 92.9 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$

$$= \frac{92.9}{79.9} \times 17.5$$

$$= \underline{\underline{20.3}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.80 \times 20.3 = \underline{\underline{16.2}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.63 \times 20.3 = \underline{\underline{12.8}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.50 \times 20.3 = \underline{\underline{10.2}} \quad \text{N mm}^{-2}$$

(b) Tension parallel to the grain

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

$$\text{Select grade stress} = 16.2 \times 0.6 = \underline{\underline{9.7}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 12.8 \times 0.6 = \underline{\underline{7.7}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 10.2 \times 0.6 = \underline{\underline{6.1}} \quad \text{N mm}^{-2}$$

(c) Compression parallel to the grain

Based on MS 544: 2001,

if,

$$\text{Dry mean ultimate stress} < \text{Green mean ultimate stress}$$

then assumed,

$$\text{Dry mean ultimate stress} = \text{Green mean ultimate stress}$$

$$\text{Dry mean compressive strength parallel to grain} < \text{Green mean compressive strength parallel to grain}$$

$$42.4 < 43.1$$

Hence,

$$\text{Green basic stress} = \underline{\underline{20.5}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.80 \times 20.5 = \underline{\underline{16.4}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.63 \times 20.5 = \underline{\underline{12.9}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.50 \times 20.5 = \underline{\underline{10.3}} \quad \text{N mm}^{-2}$$

(d) Compression perpendicular to the grain

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

$$= \log(6.2) + \frac{25-19}{25-18.0} \times \log(\frac{9.4}{6.2})$$

$$= 0.947$$

$$\text{Stress at 19\% MC} = 8.9 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$

$$= \frac{8.9}{6.2} \times 4.4$$

$$= \underline{\underline{6.3}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.85 \times 6.3 = \underline{\underline{5.4}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.80 \times 6.3 = \underline{\underline{5.0}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.75 \times 6.3 = \underline{\underline{4.7}} \quad \text{N mm}^{-2}$$

(e) Shear parallel to the grain

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

$$= \log(13.1) + \frac{25-19}{25-18.0} \times \log(\frac{15.6}{13.1})$$

$$= 1.182$$

$$\text{Stress at 19\% MC} = 15.2 \quad \text{N mm}^{-2}$$

$$\text{Dry basic stress} = \frac{\text{Stress at 19\% MC}}{\text{Green stress}} \times \text{Green basic stress}$$

$$= \frac{15.2}{13.1} \times 3.5$$

$$= \underline{\underline{4.1}} \quad \text{N mm}^{-2}$$

$$\text{Select grade stress} = 0.72 \times 4.1 = \underline{\underline{3.0}} \quad \text{N mm}^{-2}$$

$$\text{Standard grade stress} = 0.56 \times 4.1 = \underline{\underline{2.3}} \quad \text{N mm}^{-2}$$

$$\text{Common grade stress} = 0.45 \times 4.1 = \underline{\underline{1.8}} \quad \text{N mm}^{-2}$$

(f) Modulus of elasticity

Based on MS 544: 2001,
if,

$$\text{Dry mean ultimate stress} < \text{Green mean ultimate stress}$$

then assumed,

$$\text{Dry mean ultimate stress} = \text{Green mean ultimate stress}$$

$$\text{Dry mean modulus of elasticity} < \text{Green mean modulus of elasticity}$$

$$8476 < 8530$$

Hence,

$$\text{Dry mean modulus of elasticity} = \text{Green mean modulus of elasticity}$$

$$= \underline{\underline{8500}} \quad \text{N/mm}^2$$

$$\text{Dry minimum modulus of elasticity} = \text{Green minimum modulus of elasticity}$$

$$= \underline{\underline{4500}} \quad \text{N/mm}^2$$

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Tamarindus indica was introduced to Malaysia in the distant past for various food and medicinal uses. Today, the trees of *Tamarindus indica* are widely found throughout the country. With the trade restriction of ramin (*Gonystylus* spp.) and the escalated market price of rubberwood (*Hevea brasiliensis*), the readily available *Tamarindus indica* is a potential alternative for light-coloured timber. The timber of *Tamarindus indica* can be used for general components of buildings where loadings are not severe. The Janka hardness of *Tamarindus indica* was fairly high indicating suitability for flooring. This article provides a comprehensive derivation of timber grade stresses and strength grouping procedure of *Tamarindus indica* planted in Peninsular Malaysia. Through this compilation, engineers and designers can make a fair judgement of the mechanical properties of *Tamarindus indica.*

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