SURVEY OF WOOD STRENGTH PROPERTIES OF URBAN TREES IN SINGAPORE USING THE FRACTOMETER II

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Received February 2009

GANESAN SK & ABDUL HAMID M. 2010. Survey of wood strength properties of urban trees in Singapore using the Fractometer II. The Fractometer II, a portable field-based wood testing device, was used to assess the radial bending strength, fracture angle and longitudinal compression strength of freshly cored wood samples from the lower trunk of 25 urban tree species in Singapore. Tables of standard values for the future use of this device for the species tested are presented. For radial bending strength and fracture angle, the data showed interspecific variation. *Paraserianthes falcataria* (Leguminosae), a species noted for snapping, had radial bending strength that was significantly lower than all the species tested. *Swietenia macrophylla* (Meliaceae) had high fracture angle and radial bending strength. The use of the Fractometer II and the results of this survey in tree risk assessment are discussed.

Keywords: Fracture angle, radial bending strength, longitudinal compression strength, tropical trees, tree risk assessment

GANESAN SK & ABDUL HAMID M. 2010. Penggunaan Fraktometer II untuk mengkaji ciri kekuatan kayu pokok hutan bandar di Singapura. Fraktometer II merupakan alat mudah alih yang diguna untuk menguji kayu di lapangan. Kami menggunakan alat ini untuk mengukur kekuatan lentur jejari, sudut patah dan kekuatan pemampatan ira selari bagi sampel empulur kayu yang baru sahaja diambil daripada bahagian bawah batang 25 spesies pokok hutan bandar di Singapura. Jadual nilai standard bagi kegunaan alat ini pada masa hadapan disertakan dalam kertas kerja ini. Bagi nilai kekuatan lentur jejari serta sudut patah, data menunjukkan variasi antara spesies. *Paraserianthes falcataria* (Leguminosae), spesies yang mudah menyentap, mempunyai kekuatan lentur jejari yang lebih rendah secara signifikan berbanding dengan semua spesies lain. *Swietenia macrophylla* (Meliaceae) mempunyai nilai sudut patah serta kekuatan lentur jejari yang besar. Kegunaan Fraktometer II dan keputusan yang diperoleh daripada tinjauan ini dalam penilaian risiko pokok dibincangkan.

INTRODUCTION

Wood strength is reduced by decay. Therefore, one of the aims of tree risk assessment is to detect decay and then determine its extent and severity on the tree. For mapping out the extent of decay, several instruments are available. These include micro-drills and tomography. In cases where the extent of decay is very high or very low, this information is sufficient to recommend options for action. However, there may be situations where it is uncertain whether the weakening due to the decay has exceeded an acceptable threshold. In such situations it would be useful to have an assessment of the quality of the wood remaining. The Fractometer, a portable field-based wood testing device developed by Instrumenta Mechanik Labor (IML) and Forschungszentrum Karlsruhe, has been designed for this. This device measures the elasticity and fracture strength of wood (Mattheck *et al.* 1995). In addition to the fracture angle and radial bending strength, the Fractometer II measures longitudinal compression strength for a wood sample (Mattheck *et al.* 1995). The longitudinal compression strength is the resistance that the trunk opposes to a failure by applying axial stress. The fracture angle indicates whether the wood sample undergoes a brittle or non-brittle fracture while the radial bending strength is the resistance which the tree opposes to a failure by perpendicular stress.

A limitation on the use of the Fractometer II is that the breaking strengths expected of sound wood need to be known (Lonsdale 1999). The application of results of a Fractometer II measurement requires comparison to known standards and to decay-free samples taken from

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the same tree (Mattheck *et al.* 1994). Application of the Fractometer II for tropical trees in Singapore is limited by the lack of comparative standard results and familiarity in using the equipment. The research described in this paper addresses these issues. However, in utilising known standards, there is the limitation in the use of the Fractometer II in that the breaking strength does not only vary between tree species, but that there is variation within species and within individual trees (Lonsdale 1999).

Within individual trees, wood properties are known to vary radially (Niklas 1997). Wood samples from higher up in the tree may also exhibit different strength properties (Niklas 1997). However, since the aim of this project was to generate tables of standard values to aid in the use of the Fractometer II, within tree variation was not investigated.

MATERIALS AND METHODS

A total of 25 tree species were sampled for radial bending strength, fracture angle and longitudinal compressive strength. Samples were taken from trees along roadsides, in parks and vacant lands in Singapore. Twenty-four species were selected on the basis of their importance as street trees in Singapore. In addition, *Paraserianthes falcataria* was included in the survey on account of its reputation among local arborists for high rates of failure as wild sown trees even though it is not planted as a street tree in Singapore.

A 300-mm Suunto increment borer was used to extract the wood samples. Care was taken to select trees that were healthy, with no perceptible lean ranging from a circumference of 0.9 to 1.1 m measured at 1.0 m above the ground. Core samples from each tree were extracted at a height of 1.0 to 1.1 m. Cores were 5 mm wide and ranged from 15 to 30 cm in length. When the core was extracted from the tree, the entire core was inserted into the Fractometer II. Readings for radial bending fracture strength and fracture angle were taken at 15 mm intervals along the core. For each species, this was repeated on 10 different trees. The sample size of 10 trees per species was chosen because this was what was possible given the constraints of manpower. Trees above 0.9 m in girth were chosen since in the Singapore context, this is the category of urban trees that is likely to have significant impact when they fail.

For longitudinal compressive strength, the 15-mm core remnant from fracture moment and fracture angle test was cut to 5-mm lengths using a sharp blade and a template. Readings on the longitudinal compressive strength were taken at the first failure or kinking of the fibres. For each species, this was repeated on five different trees. Data for radial bending strength and the fracture angle were then subjected to an F-test to investigate whether there was any significant interspecific variation. Results were then ranked using the Duncan's multiple range analysis.

RESULTS

Results for radial bending strength and fracture angle could not be obtained for *Erythrophleum guineense* because the increment borer was not able to penetrate trees of this species. Fractometer readings for radial bending strength and fracture angle were thus obtained from 24 species. In the case of longitudinal compression strength, results of 22 species are presented. For the two species not measured, *Khaya senegalensis* and *Cassia fistula*, the point where the wood fibres kinked was not apparent.

Before applying statistical tests, results were tested to determine whether the data points had a normal distribution. Results were plotted as cumulative frequency distributions (Figures 1, 2 and 3). The plots for radial bending strength and fracture angle adhered to the S-shaped curve expected of a normal distribution (Figures 1 and 2). Data for longitudinal compressive force was skewed to the right (Figure 3) indicating that the data were not normally distributed.

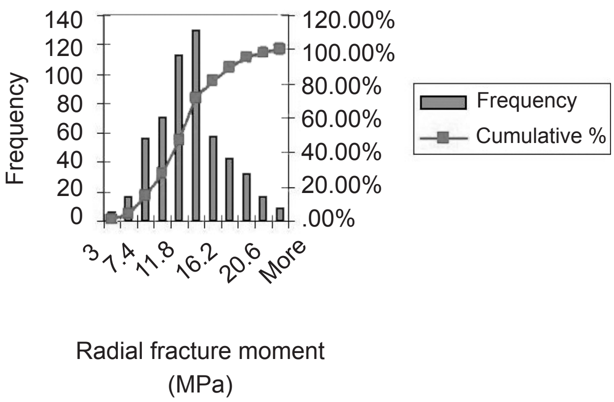

Figure 1 Cumulative frequency distribution for radial bending strength

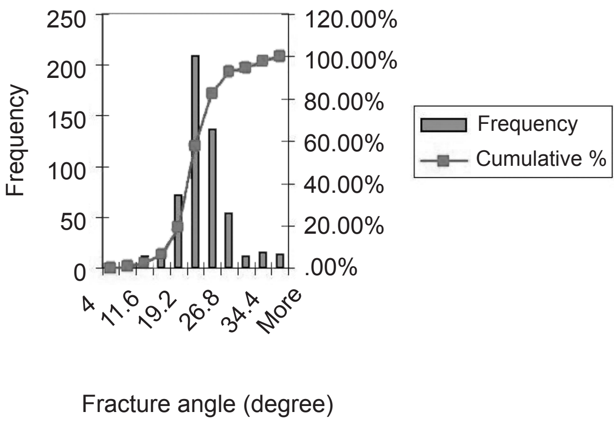

Figure 2 Cumulative frequency distribution for fracture angle

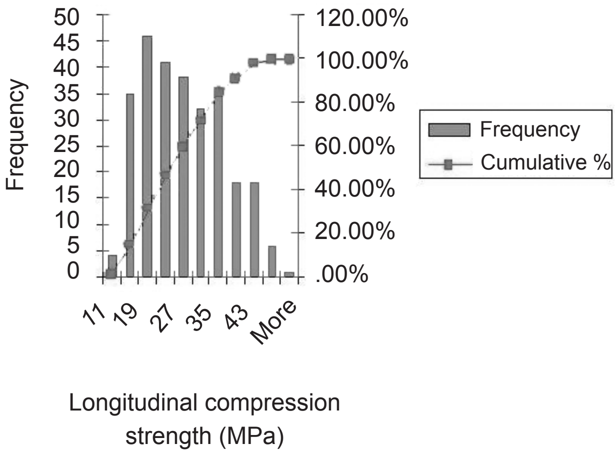

Figure 3 Cumulative frequency distribution for longitudinal compressive force

Radial bending strength

The radial bending strength measurements were variable and ranged from 5 to 10 MPa for *P. falcataria* and from 5 to 25 MPa for *Delonix regia* (Table 1). On the basis that data for the radial fracture moment were normally distributed, an F-test was carried out to investigate intraspecific variation. Results of this test are given in Table 2.

Since the F value was greater than the F critical value, we rejected the null hypothesis that there was no significant variation between species. A Duncan's multiple range analysis was then carried out. From the Duncan's test, *P. falcataria* showed low radial bending strength that was significantly lower than the rest of the species tested (Table 3).

Arfeuillea arborescens, *Swietenia macrophylla* and *Tamarindus indica* formed a homogenous subset that had significantly higher radial bending strength than the other species tested.

Fracture angle

The fracture angles were more variable than the radial bending strength values. In *Syzygium grande* (Myrtaceae) the values ranged from 4° to 42° whereas for *P. falcataria* it ranged from 19° to 25° (Table 4). On the basis that the data for the fracture angle were normally distributed, an F-test was carried out to investigate intraspecific variation. Results of this test are shown in Table 5.

Since the F value was higher than the F critical, the null hypothesis that there was no significant difference in fracture moment between the species tested was thus rejected. A Duncan's multiple range analysis was then carried out (Table 6). From the Duncan's test, *Pterocarpus indicus* and *Peltophorum pterocarpum* had the lowest fracture angle at 16.32° and 16.86° respectively. *Terminalia cattapa* and *S. macrophylla* had the highest fracture angles at 29.18° and 30.93° respectively.

Longitudinal compression strength

The frequency distribution of the longitudinal compression strength data was skewed to the right, meaning that the data were not normally distributed. As such, no further statistical tests were carried out. Only the range of longitudinal compression strength results is presented (Table 7).

DISCUSSION

The Fractometer II provides measurements on the wood strength values from a living tree. However, wood strength is just one component in the overall risk assessment of a tree. Where there is decay, its extent in the tree is much more important than the wood strength value in risk assessment. However, results obtained in this study can be used in the following manner.

When the tree has a trunk decay, the residual wall thickness has been determined and found to be marginally sufficient. To make a decision, information on the quality of the wood in the residual wall is required. A core is extracted from the residual wall and a Fractometer test is carried out to give radial bending strength and fracture

Table 1 Radial bending strength data of 24 tree species sampled in this survey

Species	Fracture moment (MPa)				
	Average	Standard deviation	Variance	Minimum	Maximum
Paraserianthes falcataria	7.30	1.44	2.08	5	10
Syzygium grande	9.28	4.64	21.55	3	20
Tabebuia rosea	9.71	4.36	19.02	3	17
Cerbera odollum	9.84	2.18	4.74	5	13
Samanea saman	10.44	2.76	7.64	3	16
Couroupita guianensis	10.84	2.53	6.38	3	15
Alstonia sp.	11.08	2.31	5.34	7	16
Adenanthera pavonina	11.76	3.46	11.96	6	20
Terminalia cattapa	12.05	3.99	15.89	5	24
Cinnamomum iners	12.36	4.24	17.98	5	22
Delonix regia	12.54	5.80	33.68	5	25
Callerya atropurpurea	12.79	5.15	26.52	5	23
Mangifera indica	13.06	2.41	5.80	9	18
Cassia fistula	13.32	2.72	7.39	9	18
Peltophorum pterocarpum	13.33	2.70	7.30	8	22
Pterocarpus indicus	13.42	2.13	4.53	10	18
Andira inermis	13.58	3.28	10.78	7	23
Lagerstroemia speciosa	13.74	3.35	11.22	5	20
Khaya senegalensis	14.28	2.70	7.31	10	20
Khaya grandifoliola	14.60	4.39	19.25	11	30
Acacia auriculiformis	14.98	3.90	15.24	9	23
Tamarindus indica	16.46	4.40	19.40	7	28
Swietenia macrophylla	16.66	3.76	14.11	10	27
Arfeuillea arborescens	18.22	3.60	12.95	10	29

Table 2 F-test for radial bending strength

	ANOVA					
Source of variation	SS	df	MS	F	P-value	F critical
Between groups	6302.724	23	274.0315	21.31134	4.85E-72	1.539327
Within groups	13810.01	1074	12.85848			
Total	20112.74	1097				

angles. These results are then compared with the range of values obtained for this particular species in the table that has been generated. E.g. we sample a *Samanea saman* (Leguminosae) and obtain a fracture moment of 12 MPa and a fracture angle of 25°. Both these values are greater than the mean values on the standard table; therefore, we can conclude that the wood quality is sufficient.

The second aim of this study was to gain experience in the use of the Fractometer II. We found that with practice, we could confidently obtain readings for fracture moment and fracture angles. In the case of longitudinal compressive strength, we found difficulty in trying to determine the first point of failure when there is kinking of wood fibres. However, this point was clarified with subsequent discussions

Table 3 Duncan's multiple range test for radial bending strength (MPa)

Species	n	Subset for alpha = 0.05												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Paraserianthes falcataria	25	7.300												
Syzygium grande	50		9.280											
Tabebuia rosea	50		9.710	9.710										
Cerbera odollum	50		9.840	9.840										
Samanea saman	50		10.440	10.440	10.440									
Couroupita guianensis	50		10.840	10.840	10.840	10.840								
Alstonia sp.	50			11.080	11.080	11.080	11.080							
Adenanthera pavonina	46				11.761	11.761	11.761	11.761						
Terminalia cattapa	30				12.050	12.050	12.050	12.050	12.050					
Cinnamomum iners	50					12.370	12.370	12.370	12.370					
Delonix regia	50					12.540	12.540	12.540	12.540	12.540				
Callerya atropurpurea	47						12.787	12.787	12.787	12.787				
Mangifera indica	50							13.060	13.060	13.060	13.060			
Cassia fistula	25							13.320	13.320	13.320	13.320	13.320		
Peltophorum pterocarpum	50							13.350	13.350	13.350	13.350	13.350		
Pterocarpus indicus	50							13.420	13.420	13.420	13.420	13.420		
Andira inermis	50								13.580	13.580	13.580	13.580		
Lagerstroemia speciosa	50								13.620	13.620	13.620	13.620		
Khaya senegalensis	50									14.280	14.280	14.280		
Khaya grandifoliola	25										14.600	14.600		
Acacia auriculiformis	50											14.980	14.980	
Tamarindus indica	50												16.460	16.460
Swietenia macrophylla	50													16.660
Arfeuillea arborescens	50													18.020
Significance		1.000	0.071	0.116	0.062	0.053	0.052	0.070	0.091	0.056	0.091	0.067	0.055	0.055

Table 4 Fracture angle data of the 24 tree species sampled in this survey

Species	Fracture angle (°)				
	Average	Standard deviation	Variance	Minimum	Maximum
Pterocarpus indicus	16.32	1.77	3.12	12	20
Peltophorum pterocarpum	16.86	5.15	26.57	6	25
Adenanthera pavonina	18.96	2.68	7.20	14	26
Khaya senegalensis	19.34	6.81	46.35	9	28
Tabebuia rosea	20.00	4.43	19.59	2	25
Lagerstroemia speciosa	20.72	3.43	11.80	14	27
Paraserianthes falcataria	20.92	1.55	2.41	19	25
Callerya atropurpurea	21.11	3.68	13.58	15	30
Khaya grandifoliola	21.40	3.01	9.08	18	30
Alstonia sp.	21.42	3.71	13.76	15	29
Acacia auriculiformis	21.72	3.52	12.37	15	31
Cassia fistula	21.72	4.19	17.54	10	30
Tamarindus indica	22.40	2.05	4.20	15	27
Cinnamomum iners	22.50	1.98	3.93	19	27
Mangifera indica	22.84	2.98	8.87	20	34
Samanea saman	23.06	2.45	6.02	19	30
Arfeuillea arborescens	23.32	3.94	15.49	16	30
Delonix regia	23.66	2.22	4.92	18	28
Couroupita guianensis	23.92	2.58	6.65	20	31
Syzygium grande	24.66	13.74	188.76	4	42
Cerbera odollum	24.76	2.65	7.04	20	31
Andira inermis	25.96	6.49	42.12	15	40
Swietenia macrophylla	29.18	7.76	60.15	16	40
Terminalia cattapa	30.93	5.50	30.27	15	36

Table 5 F-test for fracture angle

	ANOVA					
Source of variation	SS	df	MS	F	P-value	F critical
Between groups	11038.36	23	479.9289	19.77462	6.03E-67	1.539327
Within groups	26065.92	1074	24.26995			
Total	37104.29	1097				

with CG Mattheck (personal communication) in which the first point of failure for wood samples tested was clearly established.

The study also provided an opportunity to investigate interspecific variation in the radial fracture moment, fracture angle and longitudinal compressive strength of tropical trees in Singapore. Results showed that *P. falcataria* had low radial bending strength that was significantly lower than the rest of the species tested. This tree has a reputation among local arborists in Singapore for being prone to snapping. The data for *Paraserianthes falcataria* in this study was 5–10 MPa. This is equivalent to 19–38 Fractometer units, which is comparable with salix (15–20), poplar (15–20) and birch (30–40) in Bethge *et al.* (1996). The difference is that *P. falcataria* can reach very large sizes. The combination of weak wood and a large tree can lead to high rates of failure. Indeed, *P. falcataria* is long reputed to be prone to failure. Corner (1952) reported that wood of this tree is inherently weak and recommended it not to be planted as a roadside tree. This concurs

Table 6 Duncan's multiple range test for fracture angle (in degrees)

Species	n	Subset for alpha = 0.05											
		1	2	3	4	5	6	7	8	9	10	11	12
Pterocarpus indicus	50	16.320											
Peltophorum pterocarpum	50	16.860	16.860										
Adenanthera pavonina	46		18.739	18.739									
Khaya senegalensis	50			19.340	19.340								
Tabebuia rosea	50			20.000	20.000	20.000							
Lagerstroemia speciosa	50			20.720	20.720	20.720	20.720						
Paraserianthes falcataria	25			20.920	20.920	20.920	20.920	20.920					
Callerya atropurpurea	47				21.106	21.106	21.106	21.106					
Khaya grandifoliola	25				21.400	21.400	21.400	21.400	21.400				
Alstonia sp.	50				21.420	21.420	21.420	21.420	21.420				
Acacia auriculiformis	50				21.720	21.720	21.720	21.720	21.720	21.720			
Cassia fistula	25					22.000	22.000	22.000	22.000	22.000			
Tamarindus indica	50					22.400	22.400	22.400	22.400	22.400	22.400		
Cinnamomum iners	50						22.500	22.500	22.500	22.500	22.500		
Mangifera indica	50						22.840	22.840	22.840	22.840	22.840		
Samanea saman	50						23.060	23.060	23.060	23.060	23.060		
Arfeuillea arborescens	50							23.320	23.320	23.320	23.320		
Delonix regia	50								23.660	23.660	23.660	23.660	
Couroupita guianensis	50									23.920	23.920	23.920	
Syzygium grande	50										24.660	24.660	
Cerbera odollum	50										24.760	24.760	
Andira inermis	50											25.960	
Swietenia macrophylla	50												29.180
Terminalia cattapa	30												30.933
Significance		0.611	0.076	0.066	0.055	0.055	0.067	0.060	0.075	0.081	0.060	0.052	0.098

Table 7 Longitudinal compression strength data of 22 tree species surveyed

Species	Longitudinal compression strength (MPa)
Alstonia sp.	12–19
Cerbera odollum	11–21
Couroupita guianensis	13–21
Samanea saman	10–26
Paraserianthes falcataria	18–27
Mangifera indica	15–26
Cinnamomum iners	18–31
Andira inermis	12–40
Delonix regia	20–35
Khaya grandifoliola	22–29
Lagerstroemia speciosa	19–34
Syzygium grande	13–34
Tamarindus indica	19–40
Peltophorum pterocarpum	18–42
Terminalia cattapa	21–37
Tabebuia rosea	24–40
Callerya atropurpurea	25–37
Swietenia macrophylla	27–40
Adenanthera pavonina	28–39
Arfeuillea arborescens	30–46
Acacia auriculiformis	33–51
Pterocarpus indicus	37–52

with results by Addison and Henderson (1953). Our study provides quantitative evidence that *P. falcataria* should not be planted as a roadside tree. *Arfeuillea arborescens* (Sapindaceae), *S. macrophylla* (Meliaceae) and *T. indica* (Leguminosae) formed a homogenous subset that had significantly higher radial fracture moment than the other species tested.

The fracture angle measures the elasticity of the wood sample. *Pterocarpus indicus* and *P. pterocarpum* had the lowest fracture angle at 16.32° and 16.86° respectively. *Terminalia cattapa* (Combretaceae) and *S. macrophylla* (Meliaceae) had the highest fracture angles at 29.18° and 30.93° respectively.

According to Mattheck and Breloer (1994), the breaking resistance of wood is best represented by the fracture moment and the energy that is expended to break the wood sample. This energy is a function of the fracture moment and the fracture angle. In this study, *S macrophylla* had the highest results in both the fracture angle and fracture moment. *Tabebuia rosea* (Bignoniaceae) had relatively low results for fracture angle and fracture moment.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the participation of the following Singapore arborists in this project: TK Chew, CS Voon, K Khoo, E Kang and S Mohd Naem.

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