Strength Assessment of Malaysian Timbers in Structural Size

Mohd Jamil Abdul Wahab, Mohd Zamin Jumaat and Mohamad Omar Mohamad Khaidzir

Abstract In Malaysian timber engineering practice, mechanical tests on timbers were conducted based on small clear timber specimens. Throughout the world, the practice of structural size timber assessment has been long-established. Stress values obtained from structural size timber are more accurate for allocating value in structural design. Preliminary testing works have been initiated to establish the mechanical properties of Malaysian timbers in structural form. Some commercial timbers were tested using structural size bending method. Results indicated that bending strength of structural size specimen is lower compared to small planks.

Keywords Bending · Modulus · Strength · Elasticity · Tropical

1 Introduction

The formal mechanical testing of Malaysian timbers started circa 1920s. Original documents of the experimental results date back to year 1929 still exist and are being kept in Timber Engineering Laboratory of Forest Research Institute Malaysia (FRIM). The method of testing was similar to BS 373:1957 and ASTM D143–52 [1]. The timbers were tested based on small clear specimen method in green and fully air-dried condition. Lee et al. [2] have compiled the mechanical test results of some commercial Malaysian timbers in Timber Trade Leaflet No. 34. However, several properties have not been estimated and some have been

M. J. A. Wahab (✉) · M. O. M. Khaidzir
Timber Engineering Laboratory, Forest Research Institute Malaysia, FRIM, Kepong, Malaysia
e-mail: mohdjamil@frim.gov.my

M. Z. Jumaat
Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia

R. Hassan et al. (eds.), *InCIEC 2013*, DOI: 10.1007/978-981-4585-02-6_2,

inadequately estimated, partly because the assessments were based on a small quantity of material and partly because there is variation in mechanical properties even in the same log. So far, in Malaysian timber engineering practice, mechanical tests on timber were conducted based on small clear timber specimens.

These data are the basis for strength groups (SG) of Malaysian timbers which refer to as SG1 to SG7. Besides, the values became the foundation of Malaysian Standard Code of Practice on Structural Use of Timber [3]. From a scientist point of view, stresses obtained from small clear specimen's method may have been technically convenient for the determination of timber's mechanical properties. However, the method cannot provide accurate values for structural engineering applications due to the great variations in biological materials. Structural engineers and designers need accurate and reliable values concerning the structural performance of timber in its' definite size.

Practically, timbers of structural sizes are very seldom free from defects. In fact, the load may be applied for an indefinite period instead of a few minutes. Unlike homogeneous materials, the result of timber defects on strength has been fairly established and recognized in the basic testing rules. Fully as significant as the presence of the defects are their size, number, and location in the piece [4]. Defects will have their greatest effect at points of maximum stress.

Stress values obtained from structural size timber are more accurate for allocating value in structural design since the risk of stress ratio is eliminated. Besides, the values will reflect more on the actual strength of the timber in use. Throughout the world, the practice of structural size timber assessment has been long-established. The formal stress grading system in the United States started since 1902 with tests on both small and structural size timbers [5]. The arrangement for structural timber test varies in different parts of the world. In Australia and North America, the measurement of deflection is at the middle point between supports, often referred as global measurement. Whereas in Europe, the measurement is over a gauge length between two loading points, usually referred as local measurement [6]. Although there are several dissimilarities on the testing set up, but the test pieces are in structural sizes.

Small specimen methods for mechanical testing of timber have resulted with incomparable values, hence totally unjustifiable conclusions. Local and global timber practitioners start inquiring on what are the stresses of Malaysian timbers in their structural form. The following sections of this paper will discuss on the stresses of some commercial timber tested in structural size.

2 Research Methodology

The assessment focuses on the determination of bending strength and modulus of elasticity in structural size timber planks. Evaluation of stresses is made by comparing the results with small specimen values. Timber samples were selected from several commercial timber groups. Each sample was cut into standard

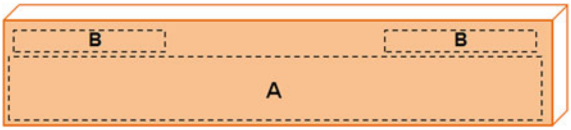

Fig. 1 Cutting pattern and nominal dimension of test specimens; *A* structural size specimen (50 × 150 × 3,050 mm) and *B* small clear specimen of 2 inches standard (50 × 50 × 762 mm)

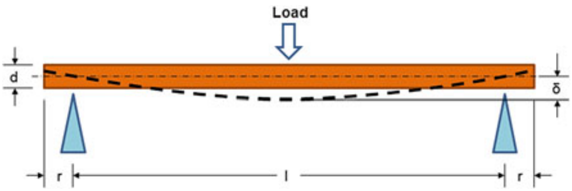

Fig. 2 Small clear timber specimen bending test arrangement; *l* bending span (711 mm), *r* overhang (25 mm), *d* specimen thickness (50 mm) and *δ* bending deflection (mm)

dimensions for structural size specimen and small clear specimen. Figure 1 illustrates the cutting pattern of the specimens.

2.1 Small Clear Specimen Method

Load was applied at the middle of the plank. The test arrangement is shown in Fig. 2. This particular configuration is referred as 'three-point bending' or 'centre-point bending'. The bending strength is presented as bending modulus of rupture (MOR) which is the corresponding stress in the timber at a point of failure. The MOR in three-point bending was calculated based on the equation below

$$MOR = \frac{3P_{\max} l}{2bd^2} \quad (1)$$

where P_{max} is the maximum applied load (N), l is the bending span (mm), b is the width of the specimen (mm) and d is the depth of the specimen (mm).

Load–deflection graphs were recorded automatically through Trapezium 2 software. Loads corresponding to increments of deflection were recorded. The modulus of elasticity (MOE) in three-point bending was calculated using the following equation

$$MOE = \frac{\Delta P l^3}{4\Delta\delta b d^3} \quad (2)$$

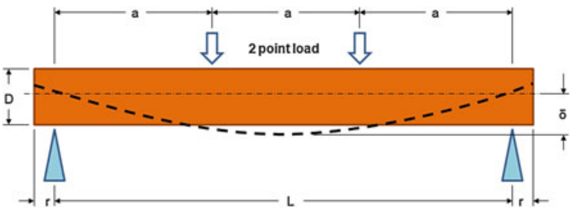

Fig. 3 Arrangement for structural size bending test; *L* bending span (18 × D mm), *r* overhang (≥D/2 mm), *D* specimen thickness (mm), *a* distance between a loading point and the nearest support (L/3 mm) and δ bending deflection (mm)

where ΔP is the increment of load below the limit of proportionality (N), l is the bending span (mm), $\Delta\delta$ is the increment of deflection corresponding the load (mm), b is the width of the specimen (mm) and d is the depth of the specimen (mm).

2.2 Structural Size Timber Method

Test configuration for specimen in structural sizes is referred to as 'four-point bending'. Arrangement for four-point bending test is illustrated in Fig. 3. The test piece was symmetrically loaded at two points over a span of 18 times the thickness (D). The test piece was simply supported on each side with an overhang of not less than half the thickness of the specimen. The distance between the two loading points was equal to the distance between one loading point and the nearest support. Small steel plates were inserted between the piece and the loading points to minimize the local indentation. Load was applied at constant loading-head movement adjusted so that the maximum load is reached within 5 ± 2 min.

Before testing, a critical section was determined in each piece of timber. The critical section was positioned at the centre of the mid span, between the inner load points. The tension edge of the piece was selected at random. The corresponding MOE in four-point bending was calculated from the following equation

$$MOE_{structural} = \frac{\Delta F(L^3 - 3La^2 + 2a^3)}{4\Delta\delta BD^3} \quad (3)$$

where L is the bending span (mm), a is the distance between a loading point and the nearest support (mm), B is the width of the plank (mm), D is the thickness of the plank (mm), ΔF is the increment of load (N) and $\Delta\delta$ is the increment of deformation corresponding to ΔF (mm).

Structural size bending strength was determined by bending the timber specimens to failure. The MOR in four-point bending was calculated from the following equation

$$MOR_{structural} = \frac{F_{\max} a}{2W} \tag{4}$$

where F_{max} is the maximum load (N), a is the distance between an inner load point and the nearest support (mm) and W is the section modulus (mm^3).

3 Results and Discussion

3.1 Stress Analyses

To date, four sample groups of Malaysian hardwood were tested. However, due to limited project funding and timber availability, the number of specimens was not the same. The analysis is more likely to demonstrate the effect of plank's dimension on the strength and stiffness. Readers should bear in mind that the current strength and stiffness values of Malaysian timbers are based on small plank assessments, thus the results will explain the actuality in mechanical properties of structural timber. Test pieces from each sample were tested for both structural size and small planks. Initially, a sample of 33 planks of mixed hardwoods was tested in three different sizes each. The results are shown in Table 1. The moisture content (MC) of the test pieces was also calculated.

Generally, the bending strength of structural size planks is lower compared to the smaller one. The difference is apparent even between small planks of 2 cm and 2 in. Smaller plank resulted with less influence of defects, such as knots and cross grain. At the same time, it was impractical to totally avoid defect from structural size plank. Defective planks were previously proven to affect the strength of timber. On the other hand, the MOE value is higher for larger planks. However the differences are less significant than the MOR values.

To determine whether the result is the same regardless of density, three specific groups of timber were evaluated. Penaga, kulim and sesendok are timbers in SG1, SG3 and SG7 respectively. Samples of 40 penaga, 90 kulim and 33 sesendok were tested for small and structural size method. Table 2 shows the respective average results of MOR and MOE. For each sample, the results indicated that MOR of structural size specimen is lower compared to small planks. However, the differences were uneven and did not compare well for a fixed ratio. The distributions of structural data are scattered. Then again, structural size MOE values are higher compared to small planks. Thus these patterns are similar for all timber despite the consequences of the SG. The MOR and MOE comparisons of the three timber groups between two different plank sizes are shown in Figs. 4, 5 and 6.

Defects and wood grain deviation reduce the strength distinctly. For tropical timber, the deviation is difficult to distinguish. In actual visual grading practice, even the grain angle is not easy to be determined [7]. In fact, a clear and straight-grained plank may be expected to demonstrate slight variability in mechanical

Table 1 Average MOR and MOE values of mixed hardwood planks of three different sizes

Structural size (50 × 100 × 2,030 mm)		Small clear (50 × 50 × 760 mm)		Small clear (20 × 20 × 300 mm)		MC at test (%)
MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	
78.1 (20.8)[a]	16,074 (2,730)	96.6 (25.5)	14,198 (3,014)	117.1 (30.5)	14,677 (3,226)	20–30

[a] Standard deviation values (in brackets)

Table 2 Average MOR and MOE values of penaga, kulim and sesendok

Timber name	Structural size (50 × 150 × 3,000 mm)		Small clear (50 × 50 × 760 mm)		Average MC at test (%)
	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)	
Penaga	108 (14.9)	18,331 (1,625)	144 (14.9)	17,315 (1,712)	16.2
Kulim	75 (11.8)	13,736 (1,821)	94 (14.8)	12,805 (2,105)	21.0
Sesendok	43 (9.5)	8,454 (1,525)	53 (6.8)	6,925 (1,274)	18.0

[a] Standard deviation values (in brackets)

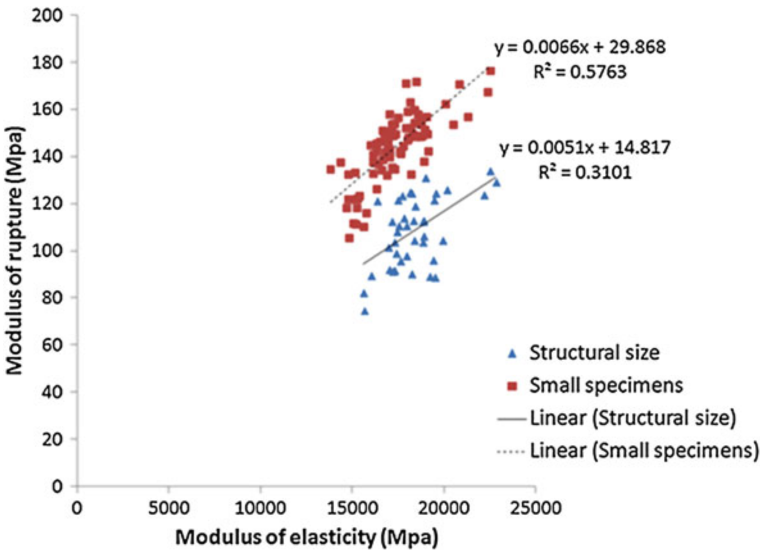

Fig. 4 Distribution of MOR and MOE results of penaga timber between structural and small planks

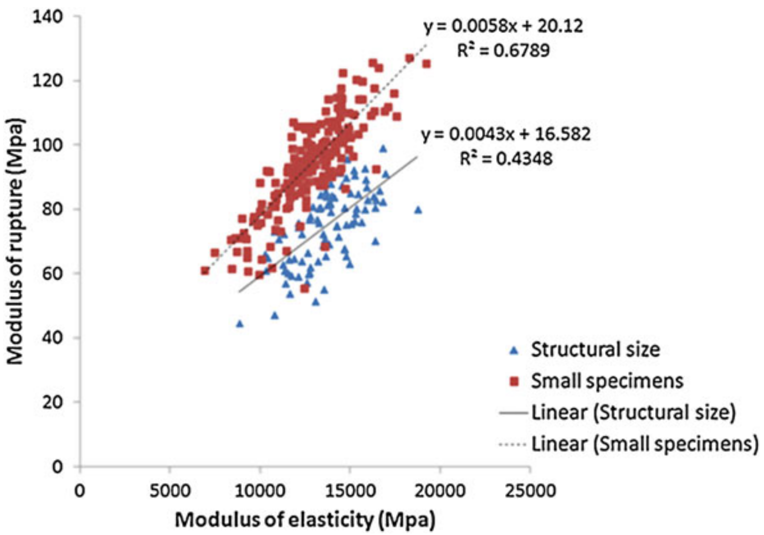

Fig. 5 Distribution of MOR and MOE results of kulim timber between structural and small planks

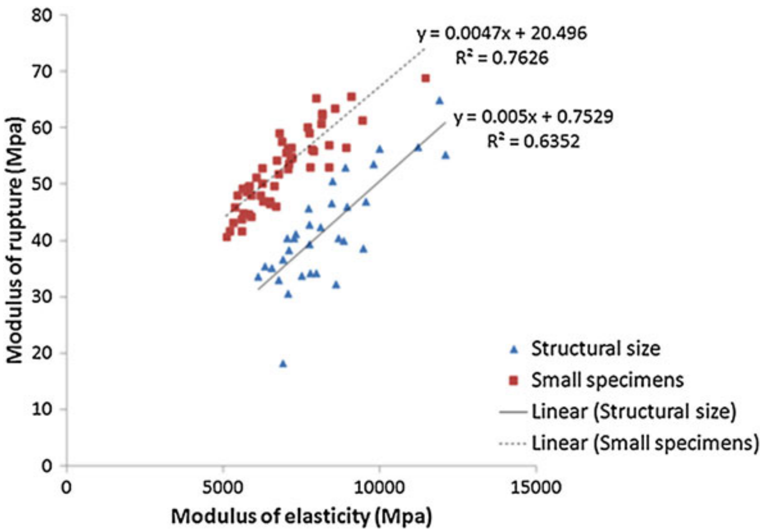

Fig. 6 Distribution of MOR and MOE results of sesendok timber between structural and small planks

Fig. 7 The crossed-gain failure of structural size test piece was noticeable

properties along the length [8]. Ironically, even when all factors known to influence the strength of timber have been considered, the strength value will still differ 10–15 % than another [9] (Fig. 7).

A number of factors have to be considered in testing large size timbers. Defects will have their greatest effect when at points of maximum stress. In a beam tested under centre loading, the maximum stress in bending occurs at the centre. Defects would have their maximum effect at the centre of the length on the bottom face and also on the lower edges of the vertical faces of the beam. If the defects were located toward the neutral axis and toward the ends, their effect would diminish.

Under third-point load, defects would have the maximum effect in the lower surface and edges anywhere between the loads.

The bearings at the load points require special attention in order to prevent indentation or premature compression failure both along and across the grain. This is taken care of by distributing the load through bearing plates and curved blocks. Another major source of error in edgewise large size bending will be linked to the initial twist of the timber piece. Twisted plank resulted in buckling during test. However, it was observed that buckling error can be eliminated by placing thin plate in gap between twisted plank and support. Vertical roller supports on both side of the test piece will improve the assistance.

It is, certainly, well known that the MC in timber has a tremendous effect on the strength of timber pieces. Above 25 % MC, the strength of timber does not alter, but as timber dries its strength increases. The exact MC below which there is an increase of strength is known as the "fibre saturation point" and it is not the same for every species [9]. In structural sizes, however, the development of defects tends to offset any increase in fibre strength that may take place as a result of a reduction in MC. Furthermore, tropical hardwood timbers, even after air seasoning for 1–2 years, are only partially dry. The outer shell may be somewhat near an air-dried condition, but the moisture content increases from this point to a practically green condition at the centre. This unequal distribution of moisture content causes a progressive failure and appears to be one of the large factors that prevent so called air-dried timbers from showing any higher strength than green timbers. After many years of seasoning, structural timbers will assume a more nearly uniform moisture content throughout, and, with the exception of additional weakening due to defects, would be expected to increase in strength.

In other words, it is highly essential that none of the details, such as average moisture content, moisture distribution, and size, number, and location of defects, be overlooked or slighted in any way if results of any significant value are to be obtained. Careful analysis should also be made of the data to see that none of the factors that affect the strength of structural timbers have been overlooked or misinterpreted.

3.2 Recent Research and Development

One very important and pertinent issue in the marketplace is the extension of the CE mark to cover timber destined for structural use. The letters "CE" are the abbreviation of French phrase "Conformité Europééne" which literally means "European Conformity". CE-marking is a manufacturer's declaration that the product complies with the essential requirements of health, safety and environmental protection legislation. All timbers for any structural use in Europe (EU-25 plus Iceland, Liechtenstein, Norway and Switzerland), regardless of origin, had to be marked CE as referred in the European standard EN 14081 and classified according to mechanical criterion in structural form. Unfortunately, the assessment of this strength prerequisite has not been carried out for most tropical species, including Malaysian timber species.

A national committee on strength grouping of timber has been discussing concerning the drawbacks for the execution of structural size assessment. The laboratories involve should be concerned on the capacity of staff and facility available. Testing structural size heavy hardwoods timbers anticipates the laboratory to be equipped with a principal testing machine not less than 300 kN of loading capacity. Generally, staff responsible for conducting the tests should possess a high level of understanding of the theory and procedure of the structural size test indicated by their qualification and experience. The governmental organizations such as Malaysian Timber Industrial Board (MTIB) and Malaysian Timber Council (MTC) should be aware of the high expenses needed to procure the samples required to execute the test. Millions of Ringgit has to be invested to fund the testing of over hundred of marketable timber species in large sizes. With more than 3,000 species of Malaysian timbers, it is almost impossible to conduct the structural size test for each species. Eventually the amount of tested planks plus remnants which are not reusable for structural application is just like creating extra damages to the timber businesses. Not to overlook the risk of unavailable timber species owing to the statistics of what is still available in the forests. Above and beyond, the time frame to accomplish the assessment would be unpredictable.

It appeared that in structural form timber does not perform as well as it turns out in small specimens. Nevertheless, these deceptive values have been referred for timber construction practice for decades went before. Thus preliminary testing works have been initiated to establish the relationship between small timber specimen and structural size properties that leads to the more precise mechanical strength values. A compliment should be given to University of Malaya for funding the groundwork project in structural size testing of Malaysian timbers which started at the end of 2009. Current project on structural size timber testing of Malaysian timber is being sponsored by Ministry of Science and Technology of Malaysian Government.

Strength and stiffness values of timber planks of different dimensions should be measured with extra concern compared to homogeneous materials. Solely use of strength values obtained from small plank test for classification and design of timber structures is not practically ideal. From these considerations it appears that for a better mechanical criterion of timber planks, testing method that measures as closely as possible in-service performance is required. Although the intended values may not be very accurate due to the characteristic of biological material, but is nonetheless necessary to be performed.

4 Conclusion

In general, the experimental results indicated that bending strength of larger plank is lower compared to the smaller one. In term of modulus of elasticity, larger plank is generally exhibits higher value compared to small plank. For academic comparison, test method using small specimens still remains valid in characterising the mechanical properties of timber. However, by itself, the test specimen is not representative of actual plank being used in the construction practice. Unfortunately, this method became the basis for the structural stresses of Malaysian timbers for many years. Tests on timber of structural size give more precise and reliable values concerning the actual service condition of timber in construction. However, the drawback of cost and duration of time needed to execute large plank assessment of Malaysian timbers is extremely immeasurable.

Acknowledgments We are indebted to Che Muhammad Farid and Syarmiza Anuar for assisting in the mechanical testing work. The research was financed by the Institute of Research Management and Monitoring, University of Malaya and currently funded by Ministry of Science, Technology and Innovation Malaysia for the structural size timber assessment in Forest Research Institute Malaysia.

References

1. C. Engku Abdul Rahman, Basic and grade stresses for some Malaysian timbers. Malayan Forester **34**, 131–134 (1971)
2. H. Lee Yew, C. Engku Abdul Rahman, P. Chu Yue, The strength properties of some Malaysian timbers. Timber Trade Leaflet No. 34. Forest Department: Kuala Lumpur (1993)
3. MS 544, Code of practice for structural use of timber: Part 2—Permissible stress design of solid timber, Department of Standard Malaysia (First revision) (2001)
4. B. Madsen, H. Andrew Buchanan, Size effects in timber explained by a modified weakest link theory. Can. J Civil Eng. **13**(2), 218–232 (1986)
5. W.L. Galligan, D.W. Green, Structural lumber: an overview of research needs. Am. Soc. Civil Eng 3–27 (1984)
6. L. Bostrom, Determination of the modulus of elasticity in bending of structural timber—comparison of two methods. Eur. J. Wood Wood Prod. **57**(2), 145–149 (1999)
7. R. Geert, J.W. Van de Kuilen, Comparison of methods of strength classification of tropical hardwood timber, in *Proceedings of the Eleventh World Conference on Timber Engineering*, 20–24 June 2010, Riva Del Garda
8. D.S. Gromala, Determination of modulus of rigidity by ASTM D-198 flexural methods. J. Test. Eval. **13**(5), 352–355 (1985)
9. A.V. Thomas, Some notes on timber testing. Malayan Forester **1**, 56–59 (1931)