RELATIONSHIP BETWEEN MECHANICAL PROPERTIES OF STRUCTURAL SIZE AND SMALL CLEAR SPECIMENS OF TIMBER

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MOHD JAMIL AW, MOHD ZAMIN J & MOHAMAD OMAR MK. 2013. Relationship between mechanical properties of structural size and small clear specimens of timber. The trend towards European marking for structural timber requires testing of some mechanical properties in structural sizes. However, this strength prerequisite has not been carried out for most tropical species, including Malaysian timbers. Existing strength data of Malaysian timbers are based on mechanical tests of small clear specimens. Groundwork testing was conducted on some selected commercial species to detect potential strength correlation between structural size and small clear specimens. Bending test for mixed hardwood species was conducted on structural size and small clear specimens. Weak correlation was observed between the bending strength of small clear and structural size specimens. Modulus of elasticity relationship was found to be consistent even for unconditioned and ungraded specimens.

Keywords: Bending strength, local modulus of elasticity, correlation

MOHD JAMIL AW, MOHD ZAMIN J & MOHAMAD OMAR MK. 2013. Hubungan antara ciri mekanik spesimen kayu bersaiz struktur dan bersaiz kecil tanpa kecacatan. Usaha ke arah mendapatkan penandaan Eropah untuk kayu struktur memerlukan ujian beberapa ciri mekanik dalam saiz struktur. Bagaimanapun, keperluan ini masih belum dilaksanakan untuk kebanyakan spesies kayu tropika, termasuklah kayu Malaysia. Data kekuatan kayu Malaysia yang sedia ada adalah berdasarkan ujian mekanik spesimen bersaiz kecil tanpa kecacatan. Ujian awalan dijalankan ke atas beberapa kayu komersial terpilih untuk mengkaji hubungan antara kekuatan kayu bersaiz struktur dengan kayu kecil tanpa kecacatan. Ujian lenturan terhadap pelbagai spesies kayu keras dijalankan ke atas spesimen bersaiz struktur dan bersaiz kecil tanpa kecacatan. Hubungan yang lemah diperhatikan antara kekuatan lentur spesimen bersaiz kecil tanpa kecacatan dengan spesimen bersaiz struktur. Hubungan modulus kekenyalan adalah konsisten walaupun untuk spesimen yang belum dikeringkan dan belum digred.

INTRODUCTION

To date, timber strength data in Malaysia are derived from standard mechanical tests on small clear specimens. The procedures are similar to BS 373 (1957) for 2-inch specimens and ASTM D143 (1952) (Engku 1971). Small clear specimen is defined as specimen with no visible deviation from the length of the specimen. For tropical timber, this is hard to distinguish. In practice, even the grain angle deviation is not easy to determine (Geert & van de Kuilen 2010). Thus it is practical to assume that for Malaysian timbers, the tested specimens are the corresponding small clear specimens. Therefore, timber strength data were obtained using small clear timber specimens measuring 2 inches (Lee et al. 1993).

The European Conformity (CE) marking of structural timber requires testing based on EN 408 (2003) which specifies laboratory method for the determination of some physical and mechanical properties of timber in structural sizes. Strength values that determine the corresponding European strength classes for timber are expressed as characteristic values. These values are derived from the results of structural size specimen tests (Geert & van de Kuilen 2010, Hugh 2010). There are only two means to achieve the goal: (1) to conduct destructive structural size test or (2)

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to manipulate the existing small clear data so that it is equivalent to properties obtained from structural size test. In a reference document of the European Standard, EN 384 (2004), a clause mentioned that an alternative method for determining characteristic values of structural size specimen is through correlation with existing data of small clear specimens (Lanvin et al. 2009).

Several discussions at the national level have been held regarding the possible setback and risk of structural size timber testing if the assessment is to be executed. The laboratories appointed to conduct the assessment should be concerned about the capacity of staff and facilities available. Governmental organisations such as Malaysian Timber Industrial Board (MTIB) and Malaysian Timber Council (MTC) should be aware of the high expenses needed to procure samples for testing. Millions of ringgit have to be invested to fund the testing of marketable timber species in large sizes. With more than 3000 Malaysian species, it is almost impossible to conduct structural size test for each species (Wong 1982). Eventually, the amount of specimens tested and remnants from samples which are not reusable for structural application create more damages to the timber business.

A study was conducted to derive a linear function for all structural tropical hardwood species over the range of strength classes D40 to D70. The assessment used the existing structural size data of 12 species included in EN 338 (2009) and corresponding small clear data that fulfilled the requirements of EN 384. The function derived from the study was y = 0.35x where y was 90% of the characteristic bending strength of full size specimens and x was the bending strength of small clear specimens (Lanvin et al. 2009). Regression plots between the global modulus of elasticity (MOE) were studied for the full size and small non-clear specimens of cumaru *(Dypterix odarata)*. Both sizes showed good correlation between the global MOE and bending strength. The ratio between slopes of the two regression lines was 0.0092/0.0061 = 0.66; it is considered as the size effect between small and full size specimens (Geert & van de Kuden 2010). Another study on bending test of six *Dryobalanops* species from Sarawak showed that bending strength of small clear and full size specimens were correlated at $r^2 = 0.56$ in green condition and slightly lower at $r^2 = 0.55$ in air-dried condition. The bending strength relationships of green and air-dried specimens of small clear to full size are y[structural] = 0.66x + 49.2 and y[structural] = 0.60x + 78.7 respectively (Alik & Badarul 2006).

This paper focuses on the relationship between structural size and small clear timber specimens in bending test for mixed species tropical hardwood. The outcome should reduce the uncertainty in the development of the correlation factor and will assist the CE marking of Malaysian timbers.

MATERIALS AND METHODS

A total of 75 planks of mixed hardwood species, unconditioned and ungraded, were cut into structural size and small clear specimens. Mixed hardwood with density ranging from 400 to 900 kg m^{-3} were processed into two nominal sizes, 50 mm × 50 mm and 50 mm × 100 mm cross-sections. The bending strength of small clear timber specimen presented as modulus of rupture (MOR) in three-point bending was calculated based on the equation below.

$$\text{Bending MOR} = \frac{3PL}{2bd^2}$$

where P = applied load (N), L = span (mm), b = width (mm) of the specimen, d = depth (mm) of the specimen.

Modulus of elasticity in three-point bending was calculated using the equation below.

$$\text{Bending MOE} = \frac{1}{4} \times \frac{P'L^3}{\Delta' bd^3}$$

where P' = applied load at the limit of proportionality (N), L = span (mm), Δ = deflection at the limit of proportionality (mm), b = width (mm) of the specimen and d = depth (mm) of the specimen.

Test set up for measuring local MOE in structural size bending is illustrated in Figure 1. The test piece was symmetrically loaded at two points over a span of 18 times the depth. The deflection was measured within the gauge length on one side of the specimen. Small steel plates were inserted between specimens and loading points to minimise the local indentation. The tension edge of the piece was selected at random (Hugh 2010).

The local MOE in four-point bending was calculated from the equation below.

$$MOE_f = \frac{a l_1^2 \Delta F}{16 I \Delta w}$$

where a = distance (mm) between a loading point and the nearest support, l_1 = gauge length (mm), I = second moment of area (mm^4), ΔF = increment of load (N) and Δw = increment of deformation (mm) corresponding to ΔF.

The deflection for global MOE was measured within the two supports taken simultaneously. The global MOE in four-point bending was calculated from the equation below.

$$MOE_{f,\ global} = \frac{l^3 \Delta F}{b h^3 \Delta w}\left(\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right)$$

where l = bending span (mm), b = width (mm) of the specimen and h = depth (mm) of the specimen.

Bending strength was determined by bending the specimens to failure through similar arrangement of loading points. The MOR in four-point bending was calculated from the equation below.

$$MOR_f = \frac{F_{max}\, a}{2W}$$

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

RESULTS AND DISCUSSION

In general, the ultimate bending strength of full size specimen was lower than that of small clear one. However, the differences were uneven and did not compare well to fit a straight relationship. The two measurements were linearly correlated to a degree of $r^2 = 0.40$ (Figure 2). Three-point bending method gave less influence of injurious defects such as knots and cross-grains and did not bring horizontal shear into play as did four-point bending method. Structural size bending, which is the four-point bending method, approximates more to actual bending condition. For this reason, strength tests made by the three-point loading method gave considerably higher results than the four-point method (Newlin 1930).

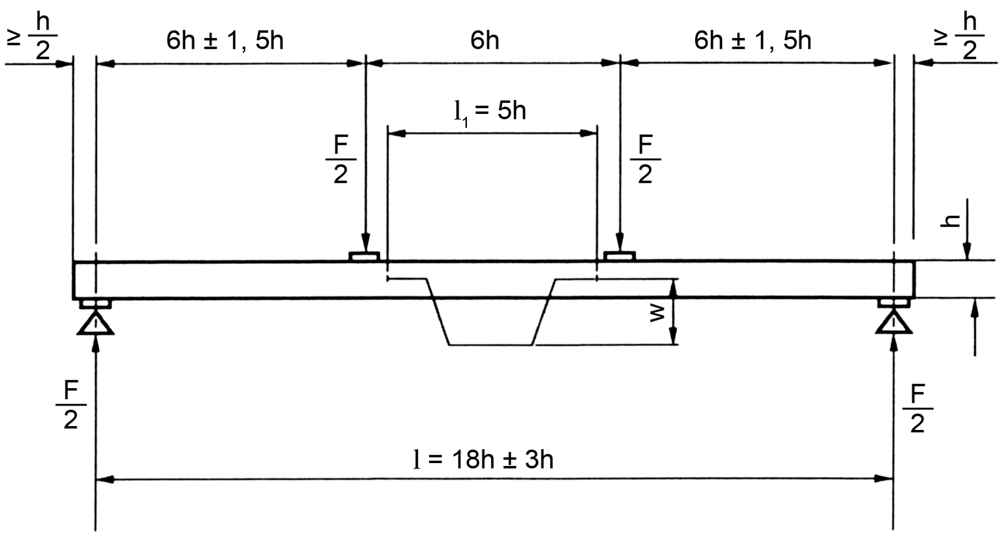

Figure 1 Test arrangement for measuring local modulus of elasticity in bending (EN 408: 2003); F = load, h = depth of specimen, l = bending span, l_1 = gauge length, w = deformation

Exponential, logarithmic, power and polynomial correlations were also presented using the same data. Figure 2 shows that a better r^2 is obtained for linear correlation compared with exponential, logarithmic and power correlations (Figure 3a, b and c). However, Figure 3d demonstrated that polynomial function best fit the correlation compared with the rest. An algebraic analysis was performed based on the polynomial function:

$$f(x) = -0.0013x^2 + 0.7493x + 16.416$$

$$\frac{df(x)}{dx} = -0.0026x + 0.7493$$

At slopes = 0;

$$\frac{df(x)}{dx} = 0$$

$x = 288$ MPa

Hence;

$f(288) = 124$ MPa

$f(350) = 119$ MPa

$f(400) = 108$ MPa

Since the graph consisted of a single variable which was MOR and since the sizes were fixed, the relationship was unlikely to obtain reduced values. The polynomial correlation would only be reasonable if the effective ranges and limits for the function were established. However, this is also impractical since the correlation is meant to determine unknown strength values. Besides, the trend showed that the difference of stresses was neither increasing nor decreasing, thus the relationship was more possible to be linear rather than polynomial. The differences are better illustrated in Figure 4. One parameter, structural MOR, was sorted to an ascending plot. Even though the square plotting was jagged, virtually a straight line could be observed parallel to the triangle data points. The dashed line was a real-time trend line plotted using Microsoft Excel. A linear correlation between structural and small clear specimen MOR was clearly observed.

A study on bending strength of *Dryobalanops* species showed that small clear specimens and full size structural specimens were correlated at $r^2 = 0.56$ in green condition. The reason for the slightly better relationship was possibly due to the smaller density range of 630–820 kg m^{-3}. Based on the density, the timber could be classified as medium heavy hardwood. The results showed that generally MOR of small size specimens was higher than that of structural size planks with linear relationship of y[structural] = 0.66x + 49.2. Defect present in the structural size specimens could be the major factor affecting the correlation (Alik & Badorul 2006).

Therefore, based on the abysmal correlation in Figure 2, it could be understood that the strength ratio of small and structural size specimens was greatly influenced by the

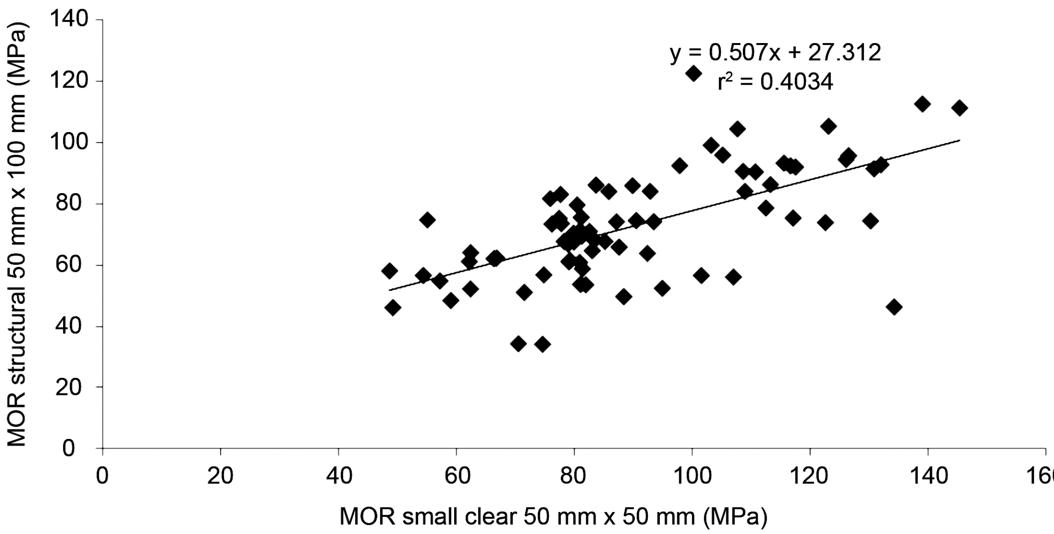

Figure 2 Linear correlation of MOR between structural size and small clear specimens of mixed hardwoods; MOR = modulus of rupture

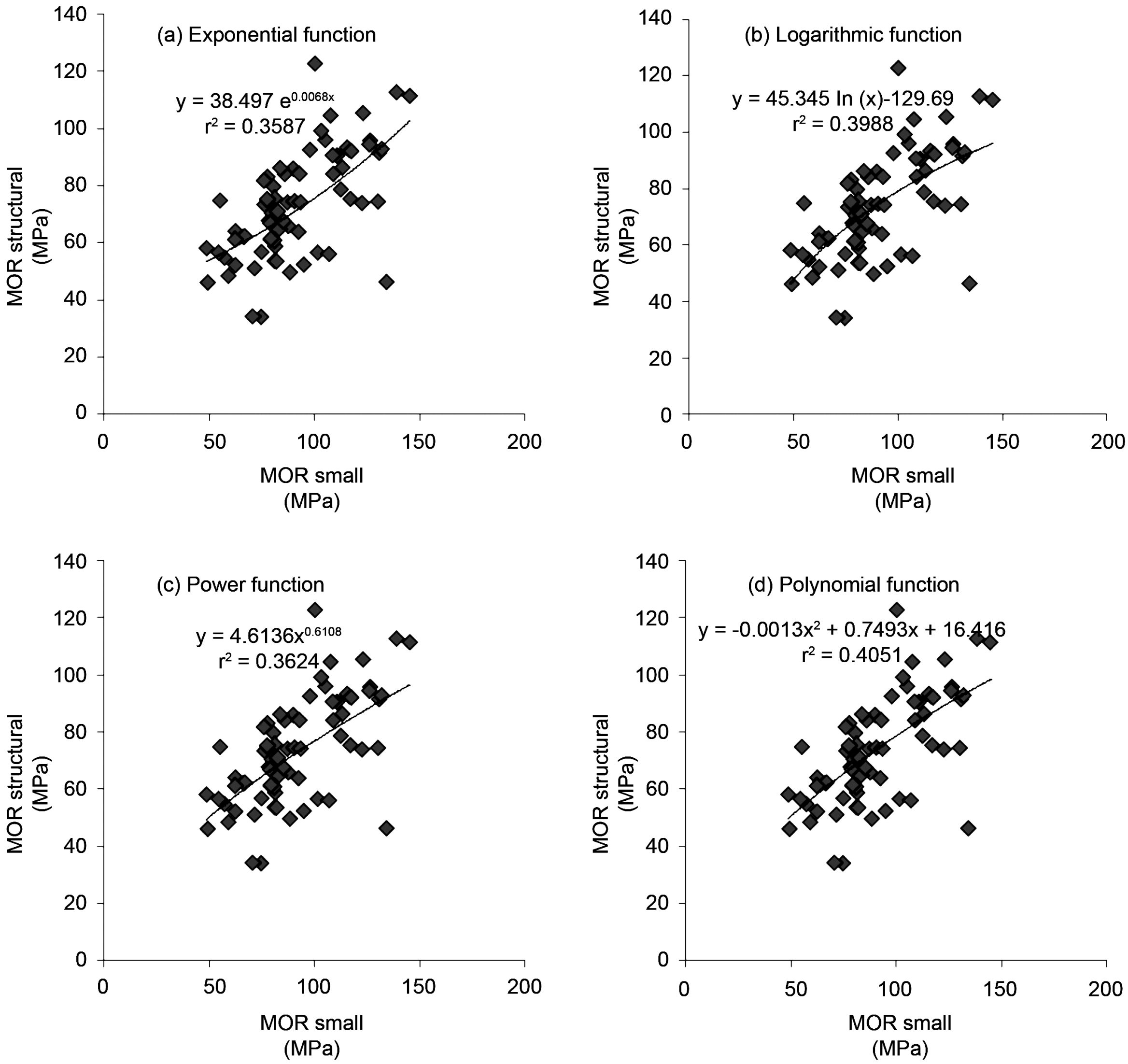

Figure 3 Exponential, logarithmic, power and polynomial analyses for correlation of MOR between structural size and small specimens of mixed hardwood; MOR = modulus of rupture

quality of the timber. Defects such as knots and distorted grain were previously proven to affect the strength of timber (Desch & Dinwoodie 1996). It was suggested that the test material be graded before test for the data to be useful for correlation analysis. The test values of the rejects should not be included in the calculation of characteristic values, but they should demonstrate that the grading rules successfully exclude the weak material (Hugh 2010).

A single species of keruing of almost similar density was extracted from the population and plotted for structural size and small clear MOR correlation. Better results (Figure 5) were observed. Although proper grading procedures were not performed, visual inspection during the test showed that specimens of keruing contained minor defects. Oven-dried densities of specimens were measured in the range of 600–800 kg m^{-3}. Thus, better MOR correlation between structural and small clear specimens was observed in the sample of a similar density timber and with less defects. The two parameters were correlated at $r^2 = 0.72$.

Nevertheless, even when every precaution has been taken to avoid all factors known to

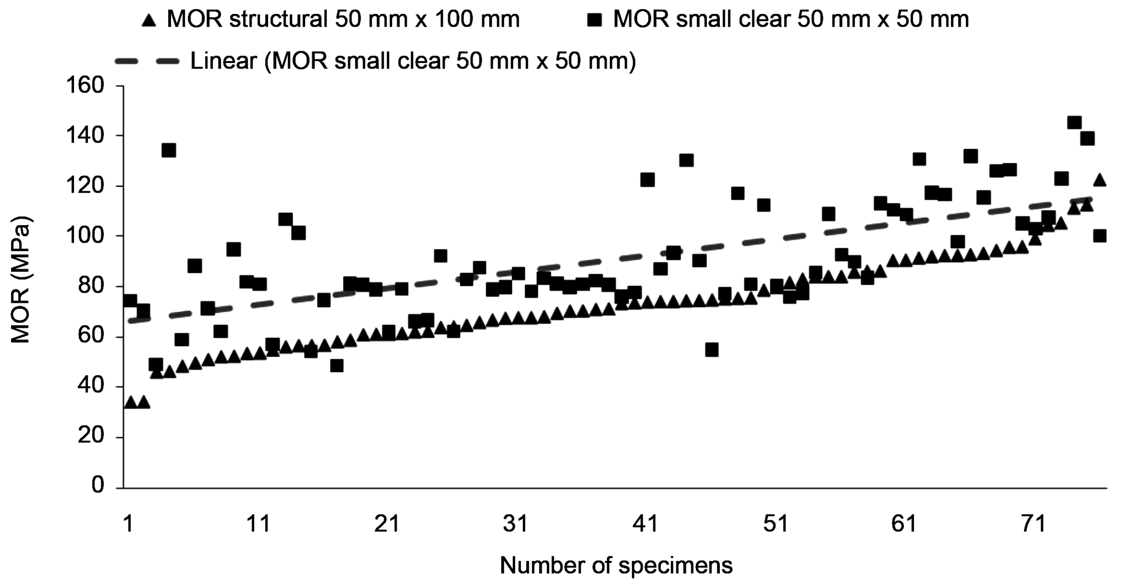

Figure 4 Bending strength values of structural size and small clear specimens of mixed hardwoods sorted in the ascending parameter; MOR = modulus of rupture

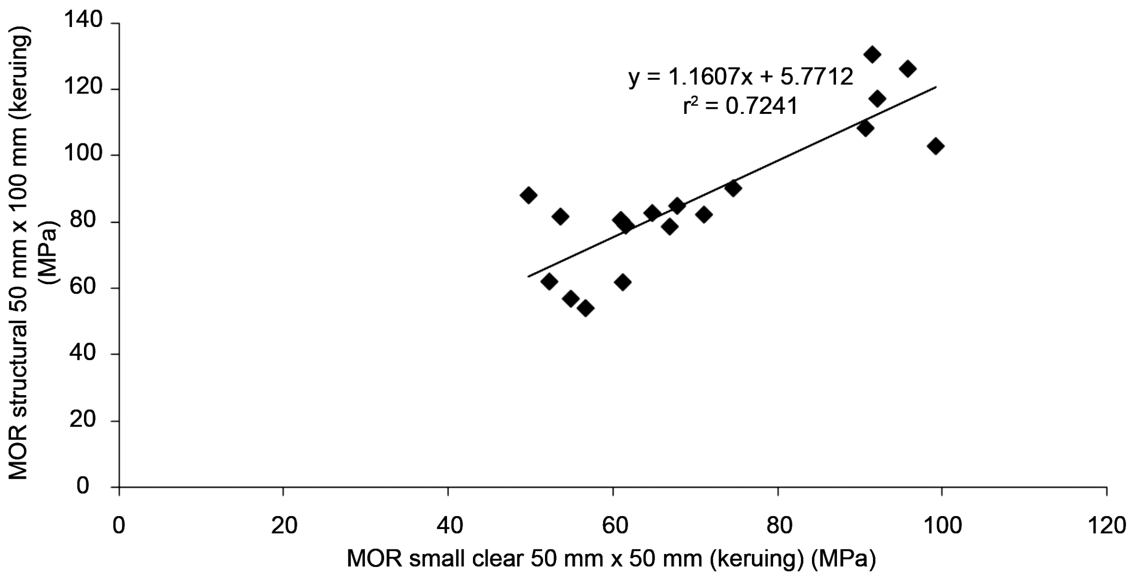

Figure 5 Linear correlation of MOR between structural size and small specimens of keruing; MOR = modulus of rupture

influence the strength of timber, it will still be found that one piece of timber is inexplicably 10 to 15% stronger than another (Thomas 1931). Until today, the main scientific conclusion for this is the genetic variability of timber as a natural material (Desch & Dinwoodie 1996).

Linearity analysis was replicated using this data. Obviously, r^2 for linear relationship showed better value compared with exponential, logarithmic and power functions as illustrated in Figure 6. Figure 6d demonstrates that polynomial function reveals better r^2 than linear. However, referring back to Figure 3, the polynomial function earlier was a negative function. On the other hand, the polynomial function in Figure 6 was a positive function. It was unreasonable for the same data and range; the values were correlated through both

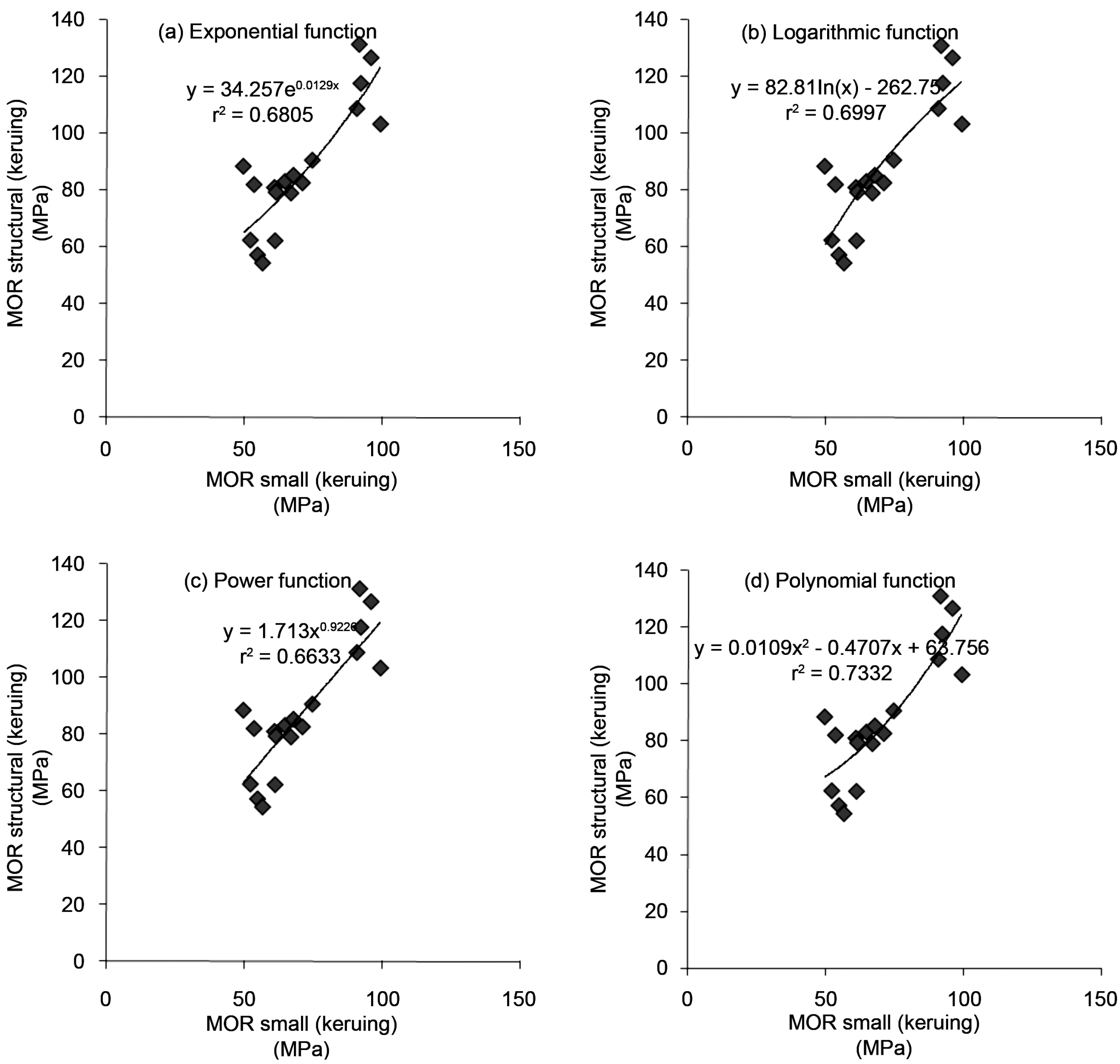

Figure 6 Exponential, logarithmic, power and polynomial analyses for correlation of MOR of structural size and small specimens of keruing

positive and negative functions. Therefore, a polynomial correlation was improper for these data.

The local and global MOE values showed even correlation throughout the specimens. Local MOE values were generally higher than global MOE. Figure 7 shows that they are correlated at $r^2 = 0.84$. Good correlation justified the consistency and reliability of the two measurements. Consistent results were also obtained by Simon et al. (2002). However, Figure 7 shows some values with great deviation between the two MOEs. The deflection measurements for local MOE values were excessively small, often less than 1 mm. Hence the method is sensitive to measurement error. The result was similar to a previous study on the two MOEs, which showed that the local MOE was greater than the global (Boström 1999). The risk of inaccurate deflection measurement was reported to be much higher for local MOE compared with global (Solli 1996). This is due to the different sizes of the local and global deflections since the global deflection is normally about 10 times the local. The major source of error in edgewise bending will be linked to initial twist of the timber piece. The effects of twisting will depend on how the deflection is measured, for example from one or two sides at the neutral

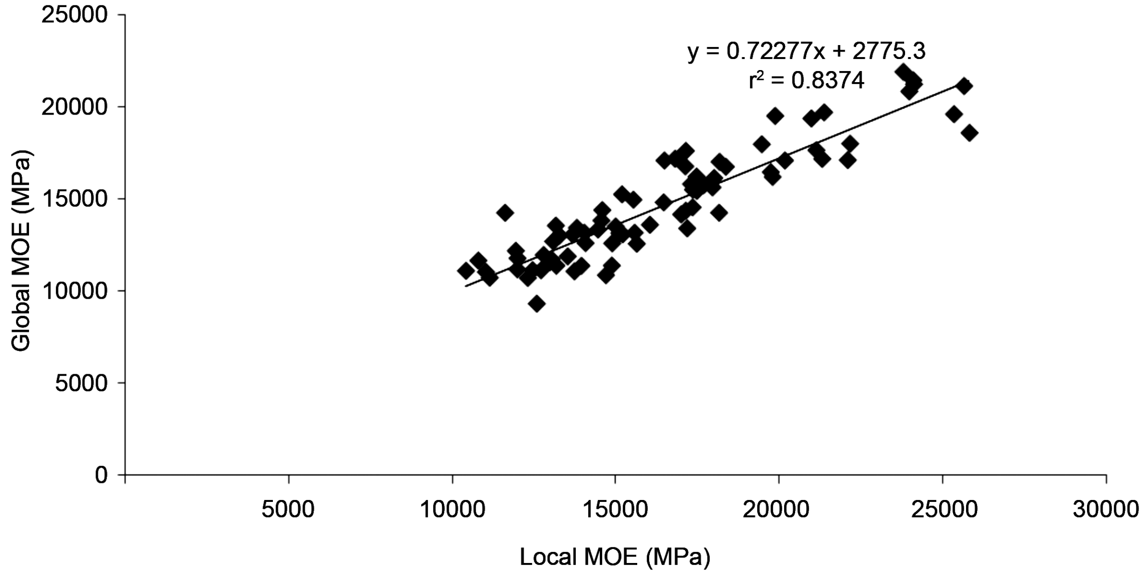

Figure 7 Linear correlation between global and local MOE values; MOE = modulus of elasticity

axis, on the tension or the compression edge. Since the local deflection is just a tenth of the global, any effect from initial twist will be more vital.

This was also agreed by Boström (1999) as some extreme values were obtained on the local MOE. The circumstance was also observed and shown in Figure 8. This was possibly because the deformation was only measured from one side, thus twisting of the timber during the test led to erroneous deformation values. Hence, the accuracy requirement for deflection over the gauge length in EN 408 will be quite difficult to achieve (Hugh 2010). Even if the beams were preloaded to a stress of 3 MPa, the influence of initial twist did not disappear (Kallsner & Ormarsson 1999). However, it was observed during testing that deflection error could be reduced by placing a thin plate in the gap between the twisted plank and support.

Figure 9 shows that the ultimate values of full size MOE are higher compared with those of small clear. The relationship of MOE structural and small clear was shown to be more consistent compared with MOR. The two measurements were correlated at $r^2 = 0.64$. The MOE data points for structural size and small clear specimen followed the same trend, which meant that the local MOE could be predicted from small clear and global MOE. Apart from that, consistent trend between global and dynamic MOE was also observed for tropical hardwood (Geert & van de Kuilen 2010).

Density, moisture content and timber defects had trivial effect on the ratio of small clear to structural size MOE. Thus, MOE values correlated well for structural size and small clear regardless of the conditions of the specimens. There were very few comparative studies on full size and small clear species of Malaysian timbers to support the MOE result obtained from this assessment. A study conducted by Ahmad et al. (2010) demonstrated that the mean MOE from structural size tensile tests of kedondong timber was higher than the small clear MOE. Lanvin et al. (2009) took the mean MOE of the small clear specimen as the value for structural size MOE or in brief, $MOE_{structural}/MOE_{small\ clear} = 1$. Stiffness and density values were less dependent on defects, so they were taken from small clear data without modification (Hugh 2010).

CONCLUSIONS

The bending strength of structural size specimen was lower than that of small clear specimen. However, the differences were uneven and did not compare well to fit a

Figure 8 Twisted specimen during test

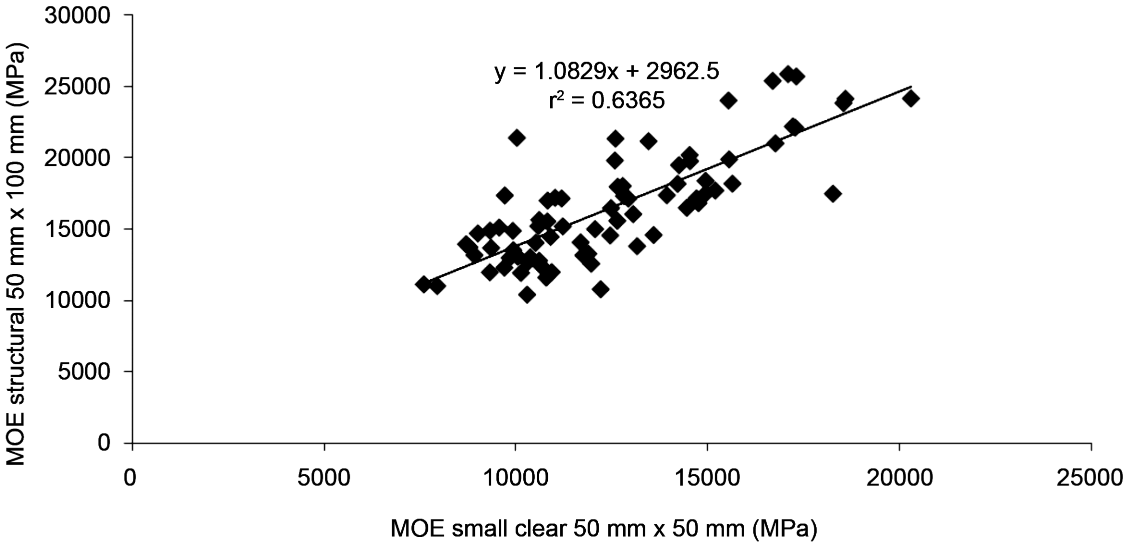

Figure 9 Linear correlation between MOE values of structural size and small clear specimens of mixed hardwoods; MOE = modulus of elasticity

straight relationship. Defects such as knots and distorted grain influenced the strength of timber. In terms of MOE, structural size values were generally higher than small clear specimens. The relationship was shown to be consistent even for mixed species timbers and specimens with defects. However, the deflection measurement for local MOE was prone to error. Since the local deflection was just a tenth of the global, any effect from initial twist would be very important. Deflection measurement should be made on both sides to reduce errors due to twisting of the beam.

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