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Bending Strength Properties of Keruing and Light Red Meranti in Structural Size in Accordance with Eurocode 5

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Abstract: In designing timber structures based on Eurocode 5, the referencestrength data are given in EN338 where the data are formulated from testing structural size specimens. Malaysian standard established strength grouping using grade stresses based on small clear specimens where as in EN 338 is in characteristic strength. . Therefore, it's important to obtain the data of strength properties from the structural size specimen as its represent the real behavior of the timber even though the timber strength might be reduce due to the nature of the timber characteristics. This paper reports the investigation on the bending strength properties of keruing and light red meranti from the Malaysian tropical hardwood species in structural size in accordance with EN408. The characteristic values of bending strength, mean modulus, and density are 47.63 N/mm^2, 19440.3N/mm^2 and 603.38kg/m^3, respectively for keruing and 23.05N/mm2, 12182.19 N/mm^2 and 302.39kg/m^3 respectively for light red meranti. At this moment Keruing can be group in strength class D40 and light red meranti in class D25. These results were different from BS 5268 where Keruing is grouped as D50 and light red meranti as C22 in MS 544 Part 2.

Keywords: Characteristic value, Bending strength properties, hardwood timber.

I. INTRODUCTION

Malaysia is popularly known by the land area that around 62% are covered by its tropical rainforest. There are plenty of species are found in the tropical forest and its over 3000 known species, but only 100 species that their strength properties information is published [1] and the information is recently increasing up to 120 species[2]. The information of Keruing and Light red meranti species is also included in the 120 species that already published. However the recorded data on the mechanical properties of the timbers are still based on the small clear specimens as published in MS 544 Part 2 [3]. Clear wood refers to clear and defect-free of small size wood, usually used in laboratory investigations for standard tests.

At present, Malaysian standard established the strength properties of structural timber into grades or classification on the basis of appearance only (visual grading rule). However, full size in-grade structural timber and clear wood specimen show quite different behavior in most cases[4]. The present of defects in timber makes it more brittle than clear wood and timber mechanical characteristics are affected by defect considerably, especially the brittle fracture properties of timber, tension strength. Because the size, location and distribution of the defects in timber elements are hard to investigate, their effects on timber properties are difficult to predict. Although the trees are from the same species, but the origin of the tree can affect the mechanical properties of the timber [5]. Structural size specimen representing the true properties of the timber as it is quite impossible to get defect free timbers. The characteristic of the specimen that affect the strength of the timber itself and these characteristics can be randomly positioned especially in any service spans that can risk the safety of the user. This is vital as the data of strength properties that obtain from small clear wood testing cannot be assumed as timber strength properties. The strength of timber might reduce due to the characteristics possess by the timber such as slope of grain, knots, checks, and splits. Therefore the bending strength in structural size is clearly represent the real behavior of the commercially available timber compared to the bending strength gather from the clear size specimen that has been used in MS544 Part 2:2001[6].

There are few strength properties of tropical timbers in structural size have been published in EN1912 such as Kempas and Kapur (D60), Balau, Keruing and Merbau (D50) as given in Table 1, EN 338 [7]. However, these timbers are stated as from South East Asia. These strength classes are based on characteristic values and not grade stresses. Therefore, this study is conducted to determine the bending strength properties of the selected species from Malaysian tropical hardwood namely Keruing and Light Red Meranti in structural size samples as well as to evaluate the strength classes.

II. MATERIAL AND METHOD

A. Material

The timbers were sourced from two different regions, namely Kelantan and Sarawak and denoted as A1 and A4 respectively. The species were selected based on the common types of timber available from the local saw-mill.

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All the samples from two regions were cut and sawn into structural size in accordance with EN408. After the sawing process, the samples were air-dried to moisture content (MC) less than 19%. The air dried process period varies among species depending on the density and sizes. Then the samples were visually graded by MTIB into HS grade in accordance with EN1912. The total numbers of samples used in this study is 78.

The testing arrangement of structural size sawn timber is accordance with the current version of EN408, EN338 and EN384. The testing span of the sample can be changeable according to the testing depth. The dimension used in this study is 100x150x300 as shown in Figure 1. The desire output parameters are local modulus of elasticity (MOElocal i.e. Em,l), global modulus of elasticity (MOEglobal i.e. Em,g) and bending strength (fm). The test prescribed by the standard represents a 4-point bending with loading speed is being adjusted so that the failure load is reached within 300±120 s. The test was carried out using a universal testing machine.

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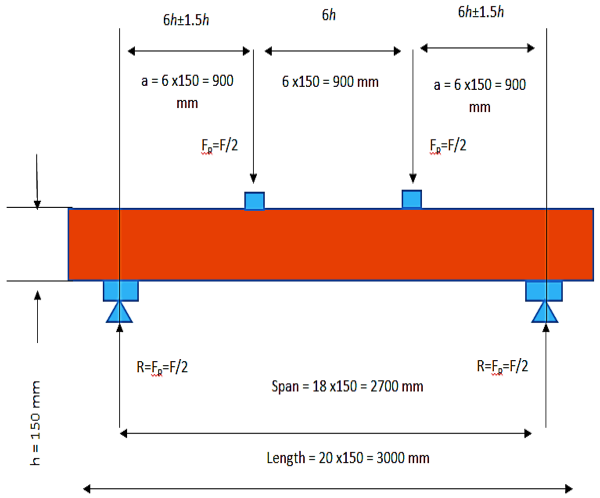

Figure 1. Test setup for bending test (Source: EN 408)

The size specification of each sample such as width and thickness is recorded prior to the destructive test. The bending tests were conducted to the each sample until failure. The MOE and MOR of each sample are calculated. After the test the moisture content and density of each sample were measured and determined for structural size specimen. The oven-drying method is the most common and universally accepted method in determining the moisture content. The weights were recorded and the moisture content was computed by the formula:

$$Moisture\ content\ (\%) = \frac{(Weight\ at\ test) - (Oven\ dry\ test)}{(Oven\ dry\ test)}\ x\ 100$$

III. RESULT AD DISCUSSION

A. Load versus deflection and fracture

Figure 2, shows the recorded piston load vs. midspan deflection curves of one of the specimen for each species as a representative curve until global failure. The graph was taken at random from 2 specimens out of 78 specimens. Combination of linear and non-linear behavior is seen in all cases. From the curve, both species behave in a ductile manner since the sample did not abruptly failed after reaching the maximum load. This journal uses double-blind review process, which means that both the reviewer (s) and author (s) identities concealed from the reviewers, and vice versa, throughout the review process. All submitted manuscripts are reviewed by three reviewer one from India and rest two from overseas. There should be proper comments of the reviewers for the purpose of acceptance/ rejection. There should be minimum 01 to 02 week time window for it.

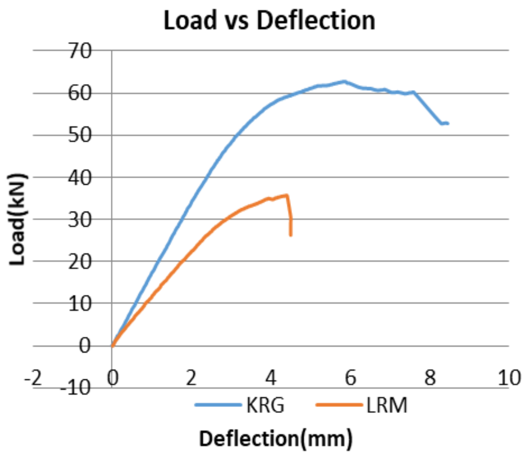

Figure 2: Load vs Deflection Curve for Keruing and Light Red Meranti

In general the graph for Keruing is higher than light red meranti, which indicates that keruing has higher bending strength compared with light red meranti. The failure often occurs normally due to the presence of defects such as knots, cross grain, and splits that cause the material to experience the complex stress distribution when subjected to mechanical test. Variety of failure patterns were observed and the typical failure pattern of four bending tests of keruing and light red meranti species are as shown in Figure 4. In this study the most highest failure pattern observed was cross grain tension for both keruing (42%) and light red meranti (40%) . Followed by simple tension, brash and compression for keruing. In light red meranti the second highest failure types are brash and followed by simple tension and compression. Splintering tension and horizontal shear is rarely occur compared to other failure pattern. Figure 3 shows that the bending strength of three random samples of Keruing and Light red meranti that represent the three most common failure modes which is cross grain tension, simple tension and brash. The bending strength of samples that have cross grain tension and simple tension as its failure mode have higher bending strength compared to the samples with brash failure mode.

This proves that the failure mode are observed to have a certain effect on the bending strength value especially in brash type.

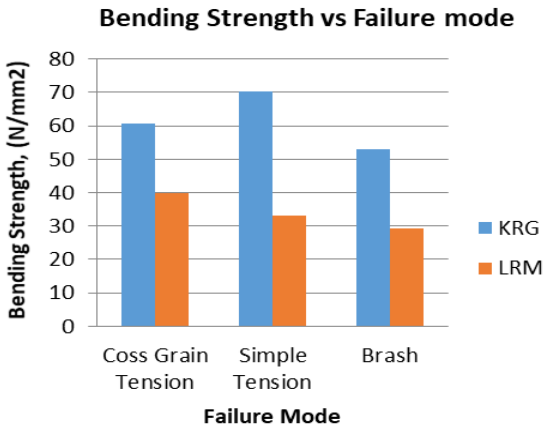

Figure 3: Bending Strength vs failure mode for Keruing and Light red meranti

According to [8], the cross grain tension occurs due to the existing of cross grain in the samples. The causes of simple tension normally occurs in wood of high density. The brash pattern of failure is frequently occurs in light red meranti sample compared to keruing due to the presence of compression wood or decay in samples[9].

Figure 4: Types of Bending Failure for keruing and light Red meranti.

(a) Simple tension (b) Cross-grain tension (c) Splintering tension (d) Brash (e) Compression (f) Horizontal shear

B. Density, moisture content and 5-percentile value of bending strength and modulus of elasticity

The bending strength properties of keruing and light red meranti from two regions were analysed and tabulated in Table 1 which also includes the 5th percentile value of bending strength ($f_{m,0.5)}$ The $f_{m,0.5}$ was calculated in accordance with EN 14358. The mean density and moisture contents of keruing and light red meranti are also given. The densities of 38 keruing from regions A1 and A4 are in the range of 686.07 and 1041.98 kg/m^3, with mean of 882.46 kg/m^3 ± 99.95 and 885.85 kg/m^3 ± 93.90 respectively. The densities of 40 light red meranti from regions A1 and A4 are in the range of 341.34 and 705.08 kg/m^3, with mean of 478.75 kg/m^3 ± 52.51 and 514.84 kg/m^3 ± 102.79 respectively (Table 1). The moisture content of 38 keruing are in the range of 13.6 to 34.1% from region A1 and A4,with the mean of 23.1 and 24.0% respectively. The moisture content of 40 Light red meranti are in the range of 11.94 to 24.63% from region A1 and A4,with the mean of 17.38 and 17.26% respectively.As the moisture content of the samples were higher than 12%, the calculated referenced densities at 12% MC were made using Equation 1 based on modification densities for compressive strength in accordance with EN384:2016.

$$\rho = \rho(u)(1 - 0.005(u - u_{ref})) \quad (1)$$

$$f_{c,o} = f_{c,o}(u)(1 + 0.03(u - u_{ref})) \quad (2)$$

$$E_0 = E_o(u)(1 + 0.01(u - u_{ref})) \quad (3)$$

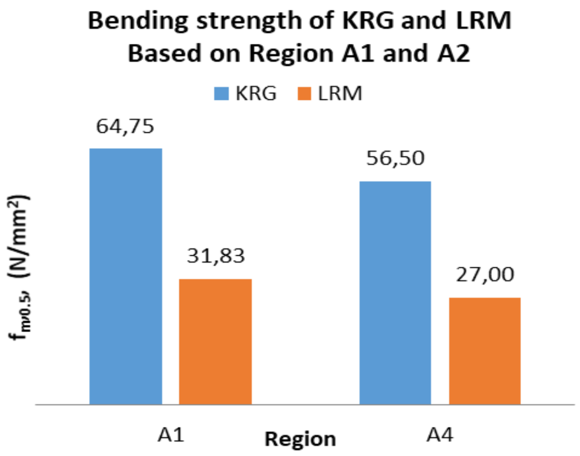

Figure 5:Differences of bending strength of KRG and LRM based on region A1 and A4

The adjusted mean densities for keruing from regions A1 and A4 are 832.61 and 831.97 kg/m^3 respectively and light red meranti from regions A1 and A4 are 465.78 and 501.10 kg/m^3 respectively. In terms of 5th percentile bending strength and modulus of elasticity, there are no significant difference for light red meranti between both regions.

However there is marginal significant difference in the 5th percentile bending strength and modulus of elasticityfor keruing. The strength and modulus of elasticity increased after including the adjustment factor by using the equation 2 and 3, while the densities decreased compared to the value before the adjustment. Figure 5 shows that the significant differences between the value of 5 percentile of bending strength of keruing and light red meranti based on region A1 and A4. The region of A1 gives the higher bending strength compared to A4 for both species. This proves that the region of the tree can influence the mechanical properties of the timber especially in strength eventhight from the same species.

Table 1. Bending strength properties of timber from two regions based on 5-percentile

Species	$f_{m,}$(N/mm^2)	$f_{m,0.5}$, (N/mm^2)	$E_{m,mean,}$ (N/mm^2)	$E_{m,0.5,}$ (N/mm^2)	ρ_{mean} (kg/m^3)	Adjusted ρ_{mean} (kg/m^3)	MC (%)
KRG-A1	86.95	64.75	19275.43	13767.86	882.46	832.61	23.1
KRG-A4	84.22	56.50	20889.40	15833.6	885.85	831.97	24.0
LRM-A1	52.23	31.83	12790.55	9454.06	478.75	465.78	17.38
LRM-A4	55.80	27.00	12673.95	8182.85	514.84	501.10	17.26

C. Density, moisture content and 5-percentile value of bending strength and modulus of elasticity

The characteristics bending strength, and modulus of elasticity was computed in accordance with EN384 as shown in Equation 4 and 5 respectively.

$$f_{k} = \min\left(1.2 f_{05,i,min}, \frac{\sum_{i=1}^{ns} n_i f_{05,i}}{n}\right) * k_n \quad (4)$$

$$f_{0,mean} = \min\left(1.1\bar{E}_{i,min}, \frac{\sum_{i=1}^{ns} n_i E_i}{n}\right) * k_n/0.95 \quad (5)$$

Table 2. Characteristic Value of Bending strength properties of keruing and light red meranti

	KRG	LRM
Characteristic Bending Strength, fm,k(N/mm^2)	47.63	23.05
Mean Modulus, Em,0,mean (N/mm^2)	19440.3	12182.19
5 percentile modulus, Em,0,k(N/m^2)	13703.6	7880.2
5 percentile Density (kg/m^3)	603.38	302.39
Mean Density (kg/m^3)	832.20	487.86

Table 2 shows the summary statistics of characteristic bending strength properties for two species based on the combination of two regions. The bending strength and modulus of elasticity increases as density increases [10]. The characteristic value for bending strength is 47.63N/mm^2 and density is 603.38kg/m^3 in keruing which 106.5% and 99.5% higher than light red meranti respectively. The mean and 5 percentile modulus of elasticity is 19440.3N/mm^2 and 13703.6 N/mm^2 for keruing which is 59.6% and 73.9% higher than light red meranti. The mean modulus of elasticity value is higher compared to 5percentile value for both keruing and light red meranti. This data proved that the density can affect the mechanical properties, mostly on the strength and stiffness of wood [11].

D. Relationship of bending strength and density

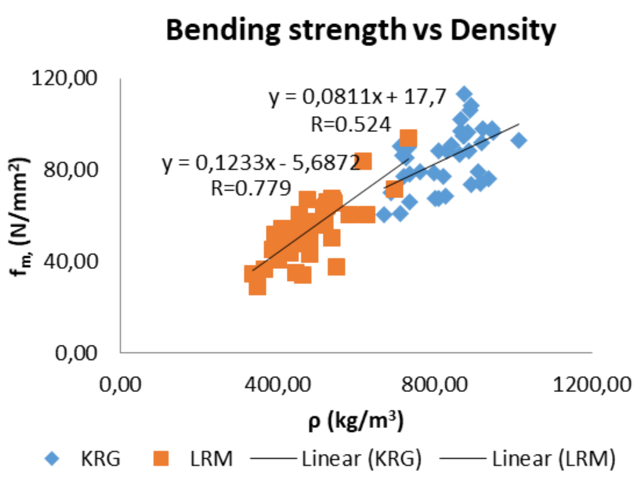

Figure 6: Relationship of f_m and Density

Figure 6 shows the relationship between bending strength and density, the regression, R for the light red meranti is higher than regression for keruing which are 0.779 and 0.524 respectively. The good regression value for linear proportion is when the value is approaching 1.0. It can be concluded that the MOR value for keruing and light red meranti are directly proportional to the density as the regression value for both species is close to 1.0 . The differences occur due to the high density, which results in high bending strength in keruing compared to light red meranti. According to [5], the density of wood varies according to the wood species, location of tree, site condition and genetic sources and normally range from 320 kg/m3 to 1040 kg/m3 and more based on anatomical characteristic of wood. As the specimen for this study were taken from two different region in Malaysia that influence the density of specimen are varies from 602 kg/m^3 to 1041 kg/m^3 for keruing and 300 kg/m^3 to 760 kg/m^3 for light red meranti. the variation of density for each specimen result in the bending strength and modulus of elasticity as shown in the relationship graph in figure 6.

IV. CONCLUSION

Bending strength properties of keruing and light red meranti were investigated. The following list are the conclusion that can be derived based on this study:

1. Keruing and light red meranti is not in the same group as there is a significant difference in bending strength found for both species. According to MS 544 these two species also belong to different strength group. Keruing in SG5 and light red meranti in SG6.
2. Keruing can be group in strength class D40 and light red meranti in class D25. These results were different from BS 5268 where Keruing is grouped as D50 and light red meranti as C22 in MS 544 Part 2.
3. The 5th percentile of bending strength characteristic value for keruing higher than light red meranti.
4. The mean modulus of elasticity for keruing is higher compared to Light red meranti as the value were found to have a significant difference for both species.
5. The typically failure behavior patterns for both species, mostly in cross grain tension, simple tension and in brash.

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