

BENDING AND BONDING PROPERTIES OF MIXED-SPECIES GLUED LAMINATED TIMBER FROM MERPAUH, JELUTONG AND SESENDOK

Wan Hazira Wan Mohamad^a, Norshariza Mohamad Bhkari^b, Zakiah Ahmad^{b*}

^aFaculty of Applied Sciences, Universiti Teknologi MARA Malaysia, 40450 Shah Alam, Selangor, Malaysia

^bFaculty of Civil Engineering, Universiti Teknologi MARA Malaysia, 40450 Shah Alam, Selangor, Malaysia

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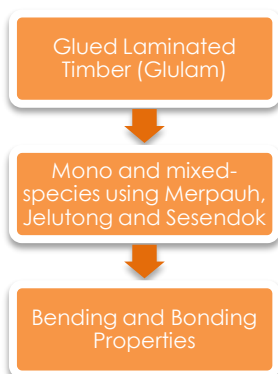
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*Corresponding author
zakiah@salam.uitm.edu.my

Graphical abstract



Abstract

This study investigates the bending and bonding performances of glued laminated timber beams manufactured using a combination of Malaysian lower and higher-grade timber species. Two types of beams were prepared which were mono-species and mixed-species glulam. Mono-species glulam with uniform layup were fabricated using Merpauh, Jelutong and Sesendok. Mixed-species glulam with balanced layup were fabricated whereby Merpauh was positioned equally at the outer layers and either Jelutong or Sesendok were positioned at the inner layers. Three replicates of ten-layered glulam beams measuring 100 mm in width, 300 mm in depth and 6200 mm in length were manufactured according to MS758 for each mono and mixed-species glulam. Bending, delamination and block shear tests were done on all the glulam beams. The results show that glulam manufactured from the combination of Sesendok and Merpauh obtained the highest bending properties and structural efficiency. In addition, the bonding performance at the interface between Sesendok-Merpauh lamellas proved to be excellent.

Keywords: Glulam, Mixed-species, Bending properties, Bonding properties, Delamination, Shear glue line

Abstrak

Kajian ini dijalankan bagi melihat prestasi lenturan dan lekatan bagi rasuk kayu berperekat yang dihasilkan melalui gabungan kayu tropika Malaysia dari spesies kayu berkekuatan rendah dan kayu berkekuatan tinggi. Dalam kajian ini, dua jenis rasuk telah dibangunkan iaitu dari spesies tunggal sebagai sampel kawalan dan juga rasuk dari spesies campuran. Rasuk dari spesies tunggal dibina secara seragam dengan menggunakan spesies kayu Merpauh, Jelutong dan Sesendok. Rasuk spesies campuran pula dibina dengan kedudukan simetri di mana lapisan luar pada bahagian atas dan bawah rasuk adalah dari spesies kayu Merpauh manakala bahagian lapisan dalaman adalah dari spesies kayu Jelutong atau Sesendok. Bagi ujikaji makmal, tiga batang sampel dari setiap rasuk kayu berperekat dari spesies tunggal dan spesies campuran telah dibina. Sampel rasuk yang dibina ini terdiri daripada sepuluh lapisan kayu panel yang dilekatkan dengan keratan rentas rasuk berukuran 100 mm lebar dan 300 mm dalam. Panjang setiap rasuk pula berukuran 6200 mm. Semua rasuk ini dibina berpandukan standard Malaysia, MS758. Ujikaji lenturan, delaminasi dan blok rician telah dijalankan ke atas semua sampel kajian. Keputusan kajian menunjukkan rasuk kayu berperekat dari spesies campuran Sesendok dan Merpauh telah memperolehi sifat lenturan yang tinggi dan mempunyai struktur rasuk yang lebih kuat berbanding dari sampel rasuk yang lain. Dalam kajian ini juga, prestasi lekatan bagi antara muka lapisan kayu bagi rasuk spesies campuran Sesendok dan Merpauh dibuktikan lebih baik.

Kata kunci: lapisan kayu berperekat, spesies kayu campuran, sifat lenturan, sifat lekatan, delaminasi, rician garisan lekatan

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1.0 INTRODUCTION

Glue laminated timber is defined in ASTM D3737 Standard Practice Establishing Allowable Properties of Structural Glued Laminated Timber (Glulam) as “a material glued up from suitably selected and prepared pieces of wood whether in straight or curve form with the grain of all pieces essentially parallel to the longitudinal axis of the member.” Structural glulam is one of the oldest and established structural members and is widely used in developed country yet in Malaysia, the usage is only gaining acceptance in the construction industry. Recently, the Malaysia Timber Industry Board built an iconic glulam building using Resak and Keruing in Johor and it was recognized as the first building completed using glulam in Malaysia. Another recently completed project incorporating glulam is the Head Quarters of the Crops for the Future in Semenyih, Selangor.

One of the important characteristics in glulam manufacturing is that bonding of laminations produces beams with higher strength as compared to the strength of solid timber with the same dimensions [2]. This increase in strength is important because the quality of lamination is dependent on its magnitude. Laminating also allows the dispersion of timber defects throughout the length of the glulam member by redistributing stress of the defect through the clear wood of adjacent laminations [3]. In addition, laminating allows control over the positioning of different grades of timber within the glulam member cross-section. By placing the strongest timbers in the regions of greater stress e.g. the top and bottom of a bending member, the performance of the glulam members can be further enhanced [4].

Nearly any species or mixed-species combination can be used to manufacture glulam, provided its physical, mechanical and bonding properties are suitable and the timbers can be glued together [2]. Glulam members predominantly consist of softwood as they are the main source of structural timber, however hardwoods are slowly gaining importance in glulam production [5]. Mixed species combination commonly used in the United States include Douglas Fir (*Pseudotsuga menziesii*)–Larch (*Larix occidetalis*), Hemlock (*Tsuga heterophylla*)–Douglas Fir and Spruce (*Picea* spp.)–Pine (*Pinus* spp.)–Fir–Red Maple (*Acer* spp.) [6]. Other mixed species combination studied by other reserachers includes Poplar (*Populus X euramaricana*) - Eucalyptus (*Eucalyptus grandis*) [4] as well as Sugi (*Cryptomeria japonica*) - Hinoki (*Chamaecyparis obtuse*) and Douglas Fir [7].

Although extensive research has been conducted on glulam [8-11], limited studies have been conducted to investigate the physical and mechanical properties of glulam using Malaysian hardwood timbers. Among the recent studies conducted include works done by Wan Mohamad *et al.* (2011), Wan Hazira *et al.* (2014) and Norshariza *et al.* (2014 and 2016). Wan Mohamad *et al.* (2011) studied the bending strength of Resak

and Keruing glulam and reported that the maximum bending capacity of both glulam beams were higher than the allowable bending strength stated in MS544 Part 3. This indicates that glulam beam using Malaysian timber is suitable as structural members. It was also found that glulam fabricated using lower density timber namely Merpauh (Strength Group 4) and Bintangor (Strength Group 5) was able to improve the strength of the timber through glulam technology (Wan Hazira *et al.*, 2014). However, for timber with higher density (such as Strength Group 2 and Strength Group 3), the bending strength of glulam was at par with the bending strength of solid timber for that particular strength grade [14-15].

In Malaysia, heavy and medium hardwoods (SG1-SG4) are normally used as load bearing members. However not all of these species are suitable for glulam manufacturing. These higher grades, higher density timbers have difficult gluing characteristics and are expensive. On the other hand, light hardwoods (SG4-SG7) are mostly used for non-structural applications and do not represent efficient use of available timber. One way of fully utilizing and upgrading these timbers is by converting them into glulam and by combining with proven high quality timber species. The main objective of this study is to determine the effect of using Malaysian lower-grade species combined with higher-grade species on the bending and bonding properties of glulam beams.

2.0 METHODOLOGY

2.1 Materials

The species used to manufacture glulam beams were Merpauh (*Swintonia* spp.), Jelutong (*Dyera* spp.) and Sesendok (*Endospermum* spp.). The strength group and density of each timber species are shown in Table 1. The species selected is based on availability and strength groups namely SG4 for Merpauh, SG6 for Jelutong and SG7 for Sesendok. Phenol resorcinol formaldehyde (PRF) adhesive and hardener obtained from Dynea NZ Limited (Prefere 4001-2 and Prefere 5837) were used during end jointing and lamination.

Table 1 Strength group and density of timber species

Timber species	Strength Group (SG) [16]	Density (kg/m ³) [17]
Merpauh	4	640 – 880
Jelutong	6	415 – 495
Sesendok	7	305 – 655

2.2 Specimen Preparation

All timbers used for glulam manufacturing were graded into Hardwood Structural (HS) grade in accordance with MS1714. Two types of glulam beams were prepared; (i) mono-species with uniform layup and (ii) mixed-species with balanced

layout (Figure 1). Three mono-species glulam were prepared using only Merpauh, Jelutong and Sesendok. For the mixed-species glulam, the positioning of the higher and lower strength grade timber in a beam was according to recommendations made in MS544 Part 3. The higher strength grade timber species i.e. Merpauh were equally positioned at the outer layers while the lower grade timber species, namely Jelutong and Sesendok were positioned at the inner layers of the beam. The depth of the higher-grade species was 40% of the total glulam beam depth. The lower grade species for the inner lamella was 2 to 3 grades lower than the outer lamella, as shown in Figure 1. The compositions of the mixed-species glulam were Jelutong-Merpauh and Sesendok-Merpauh. The glulam beam manufactured had dimensions of 6200 mm in length by 100 mm in width and 300 mm in depth, as shown in Figure 2.

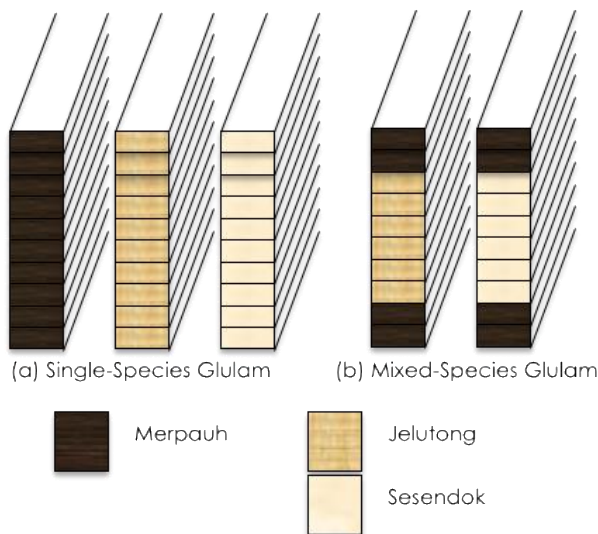


Figure 1 Beam composition of glulam

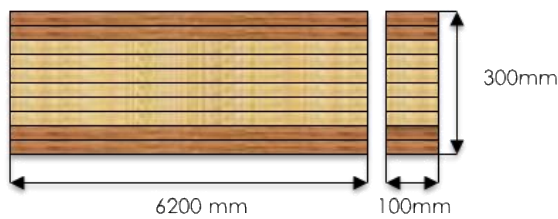


Figure 2 Dimension of glulam

2.3 Test Method

2.3.1 Bending Test

A three-point load bending test was set-up as shown Figure 3. The test was conducted according to ASTM D198. The bending strength, S_R and modulus of elasticity, E_f were calculated according to the following equations. The actual bending test set-up is shown in Figure 4.

$$\text{Modulus of rupture, } S_R = \frac{P_{max} \times L}{bh^2} \quad (1)$$

$$\text{Modulus of elasticity, } E_f = \frac{23PL^3}{108bh^3\Delta} \quad (2)$$

where P_{max} is the maximum load borne by beam loaded to failure (N), L is the span of the beam (mm), b is the width of the beam (mm), h is the depth of the beam (mm), a is the distance from reaction to nearest load point (1/3 shear span) (mm), P is the increment of applied load below proportional limit (N) and Δ is the increment of deflection of beam's neutral axis measured at mid span.

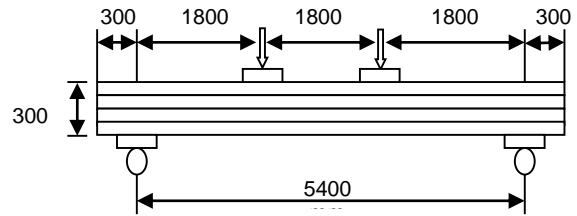


Figure 3 Schematic diagram of bending test set-up



Figure 4 Actual bending test set-up

2.3.2 Delamination Test

Delamination test was conducted in accordance with MS758. Method A was applied because the adhesive used in this study to manufacture glulam beams was Type I Adhesive. The specimens for delamination test were extracted from the full cross section of the glulam beam and represented the glulam production run. The specimens were cut perpendicular to the grain of the glulam member and had dimensions of 75 mm in length (along the grain) by 100 mm in width and 300 mm in depth. Five replicates were tested for each glulam beams. The test specimens were subjected to two test cycles and an extra cycle was carried out for test specimens having a total delamination percentage of 5 and above. The lengths of the open glue lines on end grain surface for each test specimen were measured at the end of the test.

2.3.3 Block Shear Test

Block shear test on the glue lines were conducted according to MS758. The test specimens were taken from the full cross-section of the glulam beam and 1100 mm away from the edge of the beam. Specimens were cut perpendicular to the grain direction. All nine glue lines of each glulam beam specimens were tested. The dimension of the test specimens were 50 mm in length by 50 mm

in width and 50 mm in depth, with the glue line at the center of the specimen. A 1000 kN universal testing machine was used to test all the specimens. Constant load was applied and load readings was continuously detected and recorded up to the ultimate load, after at least 20 seconds. Shear strength were calculated and wood failure percentage were also determined.

3.0 RESULTS AND DISCUSSION

3.1 Bending Properties of Glulam

The bending properties of mono and mixed-species glulam beams were analyzed in terms of modulus of rupture (bending strength) and modulus of elasticity. Three replicates were tested for each glulam beam and the mean and coefficient of variation (COV) was calculated. From Figure 5 and Figure 6, a clear difference between mixed Sesendok-Merpauh and others can be seen, both in the case of mono and mixed-species glulam. Figure 5 shows that the highest modulus of elasticity, with respect to Merpauh was obtained using mixed Sesendok-Merpauh (+35.73%) while mixed Jelutong-Merpauh showed lower increase (+20.10%).

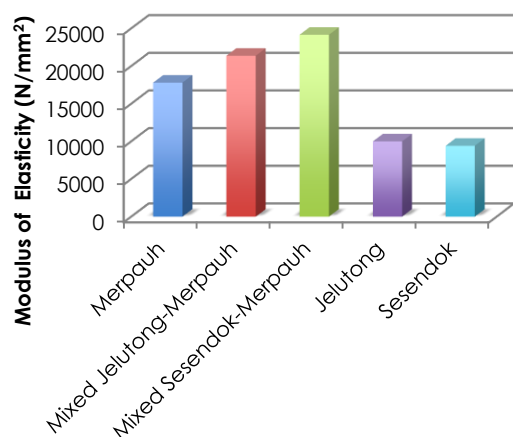


Figure 5 Modulus of elasticity in static bending

In the case of bending strength, as shown in Figure 6, the maximum increase (+36.50%) with respect to Merpauh was also found for mixed Sesendok-Merpauh glulam while mixed Jelutong-Merpauh showed lower increase (+18.68%).

Out of the two mixed-species glulam, Sesendok-Merpauh obtained the highest bending properties whereby the percent increase of bending strength was 36.50%, 4.86% and 28.83% when compared against Merpauh, Jelutong and Sesendok, respectively. In addition, the percent increase of modulus of elasticity for Sesendok-Merpauh glulam when compared against Merpauh, Jelutong and Sesendok were 35.73%, 141.84% and 156.75% respectively.

Table 2 shows the summary of the mean values for density, bending strength modulus of elasticity and structural efficiency for all glulam beams studied. The COV values are quite low indicating a low dispersion of mean values for both bending strength and modulus of elasticity.

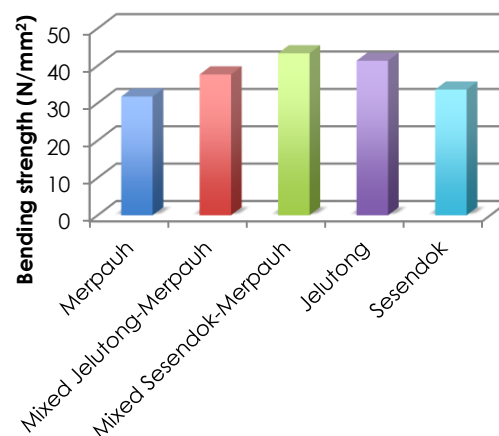


Figure 6 Bending strength

Figure 5 Load versus displacement curve

Table 2 Mean values, coefficient of variation and structural efficiency of each species of beams for the bending characteristic

Species	Density (kg/m³)	Bending strength (N/mm²)	Structural efficiency for Bending strength	Modulus of elasticity (N/mm²)	Structural efficiency for Modulus of elasticity
Merpauh	8.69 (0.66)	31.75 (7.15) ^c	0.04	17800 (0.56) ^c	20.48
Mixed Jelutong-Merpauh	626 (1.88)	37.68 (2.44) ^{ab}	0.06	21370 (8.56) ^b	34.14
Mixed Sesendok-Merpauh	613 (1.15)	43.34 (13.73) ^a	0.07	24160 (8.49) ^a	39.41
Jelutong	492 (2.39)	41.33 (1.4) ^a	0.08	9990 (12.61) ^d	20.30
Sesendok	487 (1.93)	33.64 (6.78) ^{bc}	0.07	9410 (2.55) ^d	19.32

Note: COV in parentheses. Same letters are not significant at 0.05 according to Duncan's Multiple Range Test.

The load displacement curve under bending for all the beam studied is presented in Figure 7. Generally, all the beams had linear elastic behavior until failure occurred. The curve pattern indicated brittle behavior because all the beams failed abruptly after reaching ultimate load.

Mixed-species glulam obtained higher ultimate load compared to mono-species glulam, which indicates that mixed-species glulam beams are able to sustain bigger load when subjected to bending.

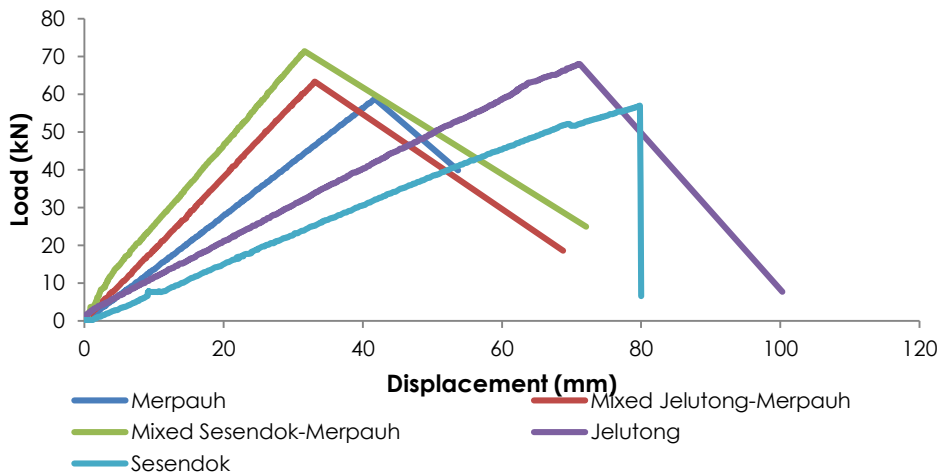


Figure 7 Load versus displacement curve

3.2 Delamination in the Glue Line

Figure 8 shows the average total delamination percentages after two cycles for all the glulam beams studied. The data indicates excellent quality of the glue lines in both mono and mixed species glulam beams. Eventhough Merpauh showed mixed results whereby one replicate exceeded the allowable maximum value set forth in MS758, the mean value of the average total delamination percentage for Merpauh was 4.3% which is below the maximum requirement value of 5%. Low delamination percentage in the glue lines between Merpauh and Jelutong as well as Merpauh and Sesendok indicated non-existence of gluing problems at the interface between these wood species. This could be due to the similarity in shrinkage values for the species studied, as shown in Table 3.

Table 3 Shrinkage percentages of Merpauh, Jelutong and Sesendok

Species	Shrinkage percentage (%)	
	Radial	Tangential
Merpauh (<i>S. Schwenkii</i>)	1.4	2
Jelutong (<i>Dyera spp.</i>)	0.8	2
Sesendok (<i>Endospermum spp.</i>)	1.2	1.3

Note: Data obtained from a dictionary of Malaysian Timbers [12].

3.3 Shear Strength of Glue Line

The average glue line shear strength and relative wood failure of all the glulam beams studied are summarized in Table 4. Generally, all the glulam beams fulfill the MS758 requirement which set forth a minimum of 6.0 N/mm² shear strength, while for lighter density timber, a shear strength of 4.0 N/mm² is acceptable provided the wood failure percentage is 100%. For wood failure that did not reach 100%, the values obtained were compared against the acceptance criteria stated in MS758. For shear strength of 11 N/mm², the minimum wood failure must be above 45% thus Merpauh, mixed Jelutong-Merpauh and mixed Sesendok-Merpauh met the requirement.

For shear strength of 8 N/mm², the minimum wood failure must be above 72% so both Jelutong and Sesendok met the requirement. This indicates good load carrying capability of the glue line in all the glulam studied as well as confirms the reliability of bonding found in the delamination tests.

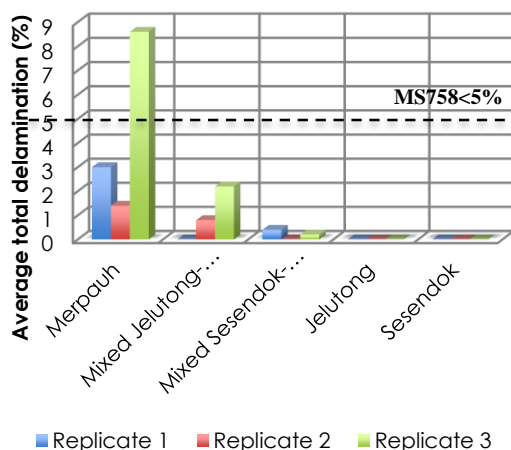


Figure 8 Average total delamination after two initial cycles in percentage

Table 4 Shear strength and relative wood failure

Species	Shear Strength (N/mm ²)	Wood Failure (%)	Criteria
Merpauh	16.56 (12.51)	80.86	Met
Mixed Jelutong-Merpauh	10.36 (35.06)	77.13	Met
Mixed Sesendok-Merpauh	14.29 (22.39)	88.68	Met
Jelutong	8.07 (7.33)	85.81	Met
Sesendok	9.56 (15.27)	77.13	Met

Note: COV in parentheses.

4.0 CONCLUSION

For all the glulam beams studied, mixed species beams showed higher bending properties as well as structural efficiency than those constructed entirely from Merpauh, Jelutong or Sesendok. The best bending performance between mixed species glulam is the combination of Sesendok and Merpauh. In addition, the excellent quality of the glue lines between laminates also contributed to the performance of the glulam beams. The results obtained from this study confirm the possibility of producing high structural efficiency glulam beams by combining two different timber species.

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