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ASSESSMENT IN BENDING AND SHEAR STRENGTH OF GLUED LAMINATED TIMBER USING SELECTED MALAYSIAN TROPICAL HARDWOOD AS ALTERNATIVE TO TIMBER RAILWAY SLEEPERS

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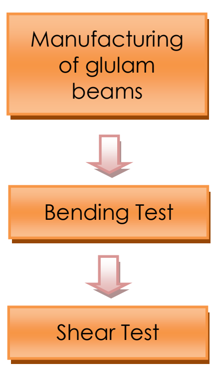
Graphical abstract



Abstract

This paper presents a pilot study on bending and shear strength of glued laminated (glulam) timber using selected tropical timber namely, Kekatong (*Cynometra spp.*) and Melagangai (*Potoxylon melagangai*) as an alternative for timber railway sleepers. Selected timbers were manufactured in accordance with MS758:2001 and the bending test was conducted according to ASTM D198:2013. The shear test for glue line integrity was performed to observe the bond performance in glulam accordance to MS758:2001.The results showed both species can be used as structural members since the bending strength obtained from the laboratory work is greater than the allowable bending strength. In terms of the percentage of wood failure, the bonding characteristics of both glulam satisfied the bonding requirement stipulated in the standard and have the potential to be used as glulam timber railway sleepers.

Keywords: Bending strength, glued laminated timber, tropical hardwood, shear strength, timber railway sleepers

1.0 INTRODUCTION

Hardwood solid timber sleepers are widely used in railway industry as reported by [1]. There are more than 2.5 billion timber sleepers are installed throughout the world. In Malaysia, the number of solid timber sleepers was recorded by local railway authority (*Keretapi Tanah Melayu Berhad*) as 26.4% from the total track length of 1724.5 kilometres. This lower percentage installed in railway tracks nowadays is instigated from the limited resources of the required grade hardwood timber (from SG1 and SG2). Moreover, depleting supply in large diameter timber logs limited the number of sleepers production and cause a lot of wastages. Consequently, the price for solid timber sleepers would increase. Timber sleepers are generally exposed to deterioration due to deleterious environmental effects [2], [3] particularly for non-durable timber and not properly treated which limited its structural strength.

Amongst the above shortcomings, timber sleepers are still in demand since, in certain location of railway track, the PSC sleepers are inappropriate to be used such as at station, yard and industrial lines, bridges and the soil area contributing pumping to locomotives [4]. Therefore, there is a need to find an alternative to solid timbers sleepers and this has spurred the use of engineered timber products such as glued laminated timber or glulam.

Glulam is a structural timber product manufactured by gluing together individual pieces of dimensioned and strength graded timber under controlled manufacturing conditions [5], [6]. Glulam can be designed and engineered to meet the needs of the construction industries. Presently, glulam has been broadly used in building structures such as in beams and roof trusses, and infrastructures for example in bridge girder. Nevertheless, the used of glulam as railway sleepers is still limited and focusing to softwood [7]–[9] and low grade hardwood [10] which required chemical treatment. Other study was conducted for untreated hardwood sleepers from Brazilian timber (*Eucalyptus Citriodora*) presented the good performance in bending. However, the bondability of this timber is not discussed [11].

Thus, this study proposed natural durable timber from the Malaysian tropical hardwood species namely Kekatong (*Cynometra spp.*) and Melagangai (*Potoxylon melagangai*) from strength group SG2 and SG3, respectively. These timber species are listed in the technical document of KTMB Permanent Way Manual [12].

The bending and shear strength of glulam Kekatong and Melagangai are more depend on the manufacturing process of lamellas by removing or dispersing the knots within layers particularly placing it at the neutral plane[13] and the integrity of their glue lines. With appropriate lamella configuration, the glulam timbers are more homogeneous and stronger with reliable properties. As in [14], the strength of glulam beam has been proven to improve into two grades higher from the original strength grade of medium hardwood timber. However, the naturally durable heavy hardwood timber, the strength of glulam timber is expected at least at par with the value of solid timber sleeper [15].

Therefore, the study is performed to assess the bending strength of glulam beams and the shear strength of glue lines for Kekatong and Melagangai. The strength and integrity of these glue lines are dominant for the reliability of whole pieces of sleepers.

2.0 MATERIAL

Kekatong and Melagangai species were selected as glulam beam in this study. These timbers are naturally durable [16], untreated and suitable for outdoor environment conditions [17]. The glulam beams were manufactured at a glulam factory in Johor Bahru. The timbers were visually graded in accordance with [18] by certified grader. Only timbers in HS grade were chosen and the production of glulam was done in accordance with [19]. Two numbers of each Kekatong and Melagangai glulam beams with size of 100mm x 200mm x 4000mm length were prepared. The production of glulam beams were taken from normal and controlled manufacturing processes and the grain for all timber pieces are parallel to the longitudinal axis of the sleeper. Phenol-resorcinol formaldehyde (PRF) adhesive was used as recommended in [19]. All the test specimens were in dried condition.

3.0 EXPERIMENTAL PROGRAMME

3.1 Bending Test

The bending test is conducted under third-point loading method as shown in Figure 1. The test apparatus including roller support, reaction bearing plates, load bearing blocks were set up according to ASTM D198:2013 [20]. These supports allowed the specimen to deflect without significant resistance and prevented buckling. Transducers were attached in vertical positions to monitor the deflection data during the test.

The bending strength, $f_{m,a,//}$, modulus of elasticity, and permissible stress, $f_{m,adm,//}$ were calculated using the Equation (1), Equation (2) and Equation (3) respectively which P_{max} is ultimate total load; L span of beam; b is width of beam; h is depth of beam;P is increment of applied load below proportional limit; Δ is deflection; k_1 duration of load factor; k_6 is depth factor;k_{11} is size factor; and k_{20} factor for service class. In this study, service class 3 was considered since the glulam will be used as railway sleepers which fully exposed to the external environment. However, grade stresses can be obtained from the preliminary study conducted before and not described in this study.

$$f_{m,a,//} = \frac{P_{max}L}{bh^2} \quad (1)$$

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

$$Permissible\ stress = \left((Grade\ stresses \times k_{20}) \times k_1 \times k_6 \times k_{11}\right) \quad (3)$$

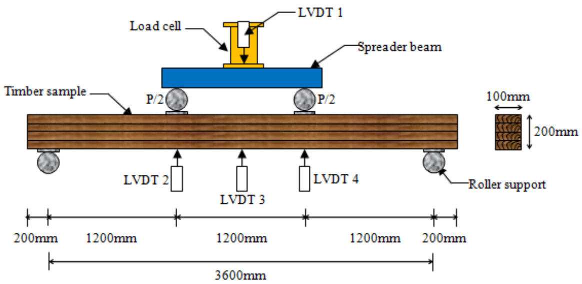


Figure 1 Bending test setup

3.2 Shear Test

Shear test of glue lines is required for quality control measurement in glulam manufacturing. The strength and integrity of glue lines in glulam lamellas can be derived by the test on block shear samples according to [19]. The requirement for glue line integrity is based on testing of glue lines in a full cross-sectional specimen which cut from the manufactured glulam member as representative of the production. The acceptance criteria for shear strength of each glue line shall be at least 6.0N/mm^2. For lighter density timbers, shear strength of 4.0N/mm^2 shall be regarded as acceptable if the wood failure percentage is 100%. The quality of the glue line can vary significantly between and within members. Therefore, multiple samples must be taken into account in order to get reliable global estimations of member's properties for the effect of irregularities [21].

3.2.1 Samples Preparation

Test samples were cut in the form of block with dimensions of 50mm x 50mm x 50mm for Kekatong glulam beam. For Melagangai glulam timber beam, test specimens were cut into a shape form and dimensions as in Figure 2 since the lamella thickness was less than 25mm thick. The loaded surfaces were cut parallel to each other and perpendicular to the grain direction. Test specimens were taken from the full cross-sectional of glulam timber beam with at least three (3) glue lines were tested in each of the lower, middle and upper part of the glulam timber beam cross-sections.

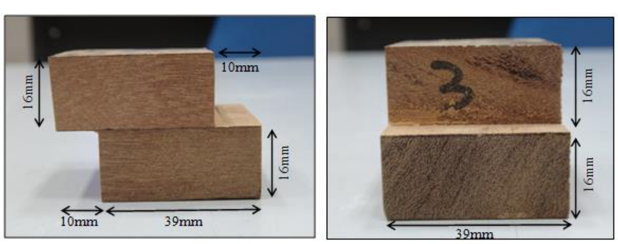


Figure 2 Glue line shear test specimen; (a) Dimensions; (b) Loaded surface at transverse surface

3.2.1 Testing Method

Prior to testing, the specimens were keeping in laboratory environment for climatization in order to have equilibrium moisture content in a range of 10%-14%. The specimens are placed into shear test apparatus with the glue line oriented parallel to the loading direction. The quasi-static tests were performed under displacement control at a constant rate of 0.3mm/sec.

The sheared area and the maximum loads were recorded and the shear strength(f_v) was computed for each specimen using Equation (4) where A is the shearing area; F_u is maximum load and; $k = 0.78 + 0.0044$ is modification factor that modifies the shear strength for test specimens when the sheared area is less than 50mm.

$$f_v = k\frac{F_u}{A} \quad (4)$$

Besides the shear strength, the wood failure percentage (WFP) has to be determined to identify the quality of a bond which usually measured by visual examination. However, the WFP over a cross sectional specimen in average or any individual value shall exceed the minimum wood failure percentage as stated in MS758:2001.

4.0 RESULTS AND ANALYSIS

4.1 The Relationship of Load and Deflection

Figure 3 shows relationship between load and deflection for Kekatong and Melagangai glulam beams. In general, both glulam timber species show similar behaviour in performance until the test sample reached the first fibre crack (P_p) then continued and attained the maximum load (P_{max}). From the graph, Kekatong showed the steepest slope in elastic region with higher stiffness compared to Melagangai but then failed abruptly. Table 1 show the average value of P_p for glulam Kekatong beam is 33.18% higher than that of glulam Melagangai beam. For the average ultimate load, the glulam Kekatong beam is 46.66% higher than that of glulam Melagangai beam with small difference in average midspan deflection of 1%. In order to reach the average ultimate load, glulam Kekatong beam achieved 34% higher after the first fibre crack occurred while for glulam Melagangai beam is 17% after the first fibre crack.

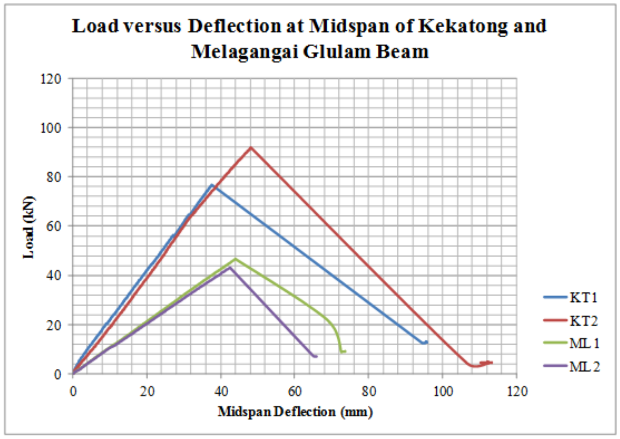


Figure 3 The relationship of load and deflection graph

Table 1 The average bending strength for Kekatong and Melagangai glulam beams

Timber Species	Beam Marking	P_p (kN)	Δ_p (mm)	P_{ult} (kN)	Δ_{ult} (mm)	σ_p (N/mm²)	MOR (N/mm²)	MOE (N/mm²)	Moisture Content (%)	Density (kg/m³)
Kekatong	KT1	45.88	22.05	76.59	37.59	41.29	68.93	24655.18	8.44	1003.23
	KT2	65.55	32.76	91.77	48.12	59.00	82.59	24728.78		
	Average	55.72	27.41	84.18	42.86	50.15	75.76	24691.98		
Melagangai	ML1	31.32	29.20	46.65	44.00	28.19	41.99	13109.28	6.65	792.97
	ML2	43.14	42.50	43.14	42.50	38.83	38.83	12237.89		
	Average	37.23	35.85	44.90	43.25	33.51	40.41	12673.59		

4.2 Bending Strength Properties

Table 1 presents an average basic properties on strength (MOR) and stiffness (MOE) for the Kekatong and Melagangai glulam beam calculated using Equation (1) and Equation (2). MOR for glulam Kekatong beam showed the higher average value compared to glulam Melagangai beam which the percentage of difference is 46.66%. During the bending test, glulam Kekatong beam shows the higher fibre stress at proportional limit with the average value of 50.15N/mm² while glulam Melagangai beam reached the average fibre stress at the proportional limit of 33.51N/mm². The results indicate that the glulam Kekatong beam attained the average maximum stress about 34% after the first fibre cracked and glulam Melagangai beam reached the maximum stress about 17% after the first crack. From the observation, the glulam Kekatong permits the beam to sustain longer time after the first crack before it reached the total failure but this scenario is not applicable for the glulam Melagangai beam.

The average MOE value for glulam Kekatong timber is higher compared to glulam Melagangai timber with the percentage of difference of 48.67%. According to the graph in Figure 3, proves that the steepest slope for glulam Kekatong timber indicates the higher stiffness of the beam before reaching the first fibre crack.

4.3 Permissible Bending Strength of Glulam Beams

Table 2 shows the bending strength and the permissible stress of glulam beams for Kekatong and Melagangai timber. The bending strength values are obtained from Table 1whereas the permissible stress is calculated using Equation (3).

Table 2 Bending strength and permissible stress

Timber Species	Strength Group (MS544: Part 3)	Strength Group (MS544: Part 2)	Bending Strength (N/mm²)	Permissible Stress (N/mm²)
Kekatong	D60	SG2	75.76	22.67
Melagangai	D50	SG3	40.41	17.87

The bending strength and the permissible stress values for both timbers are compared and the results indicated that the value of bending strength is higher than the permissible bending stress design. It can be concluded that the glulam beam for both species are suitable to be used as structural member.

4.4 Glue Line Shear Strength

For Kekatong and Melagangai timber, the minimum requirement for shear strength is set as 6N/mm² while the wood failure percentage is at least in 74%. Table 3 summarised the global shear strength and wood failure percentage for Kekatong and Melagangai glulam test specimens. Both timbers of Kekatong and Melagangai show good performance in shear strength with the average values of 12.25 N/mm² and 10.67 N/mm² respectively. The average values of wood for both timbers show the decreases as timber density increases while the average values of shear strength increases.

Table 3 Shear strength and wood failure percentage

Timber species	Shear strength (N/mm²)		Wood failure percentage (%)
	Mean (N/mm²)	COV (%)	
Kekatong	12.25 (1.90)	15.50	74
Melagangai	10.67 (2.57)	24.09	92

Note: Standard deviation is show between parentheses

Figure 4 shows the results for each individual test specimen for Kekatong and Melagangai glulam timber considering their simultaneous fulfillment of the acceptance criteria requirements established in MS 758:2001. Considering the criteria of shear strength and wood failure percentage, generally Kekatong and Melagangai test specimens comply with the requirements.

In this study, two types of failure modes are identified which are cohesive failure and adhesive failure. Cohesive failure was found as dominant failure surface for both timbers of Kekatong and Melagangai block samples. However, a few block samples in Kekatong are failed in adhesive mode generally for wood failure percentage below than 75% as shows in Figure 5(a). From the observation in this test, 36% of test blocks were failed in adhesion failure mode for Kekatong timber while in Melagangai this type of failure is not found. Figure 5(b) shows cohesive failure mode in Kekatong and Figures 6 (a) and (b) in Melagangai block samples.

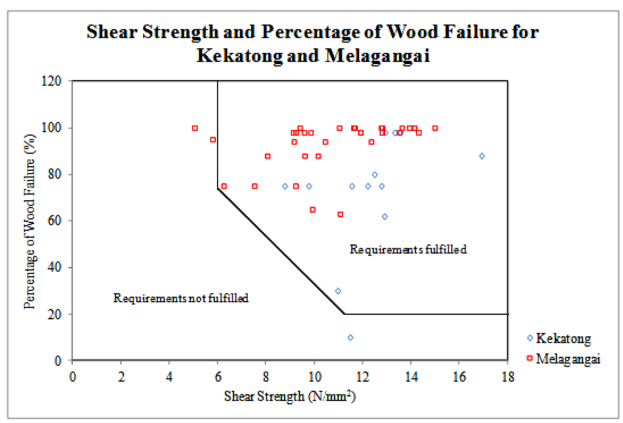
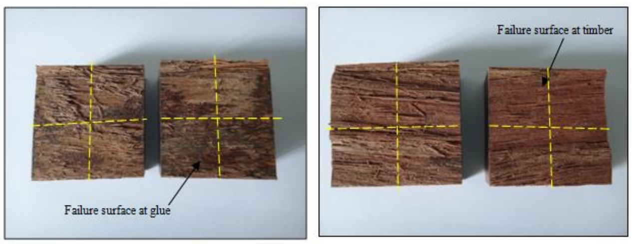


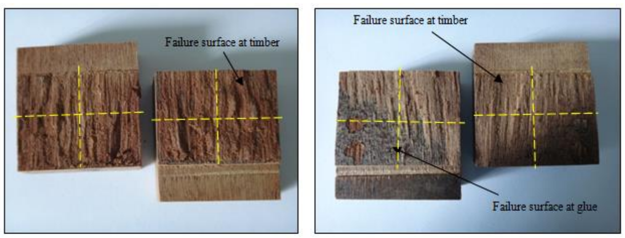
Figure 4 Shear strength and percentage of wood failure in test specimens of kekatong and melagangai glulam timber, the solid line represents the requirements outlined in MS758:2001

The dark area on the surface as shown in those figures is the PRF adhesive. For the failure surface occurred in timber there is less appearance of PRF indicating that there is a good adhesion and wetting between the adhesive and timber.



(a) (b)

Figure 5 Surface Failures for Kekatong Test Blocks; (a) Adhesive Failure at 50% of Wood Failure; (b) Cohesive Failure at 100% of Wood Failure



(a) (b)

Figure 6 Surface Failures for Melagangai Test Blocks; (a) Cohesive Failure at 100% of Wood Failure; (b) Cohesive Failure at 75% of Wood Failure

5.0 CONCLUSIONS

The bending and shear strength of glulam using selected Malaysian tropical hardwood in different strength group were investigated and concluded as following:

1. Glulam Kekatong and Melagangai have the higher value of maximum bending capacity compared to the permissible bending strength, therefore these glulam are suitable to be used as structural member and can be recommended as glulam timber railway sleepers.
2. For good bonding, the bond need to have good shear strength and the failure should occur in timber rather than in the glue line. Both Kekatong and Melagangai glulam has satisfactory bonding performance.
3. Data from the above experimental work can be used as pilot data for selecting the suitable material and adhesive type for application of glulam timber railway sleepers. The reliability of glulam timber as railway sleepers will investigate in the next testing phase under the sleeper performance tests.

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