Bending Strength Properties of Glued Laminated Timber from Selected Malaysian Hardwood Timber

Wan Hazira Wan Mohamad, Mohd Azran Razlan, Zakiah Ahmad

Abstract- **The use of timber as structural member have come under serious review and study recently as good quality logs are alarmingly becoming scarce besides the chronic problems of traditional sawn timber. Several technologies, like plywood, OSB, glued laminated timber (glulam) and laminated veneer lumber (LVL) have been developed to improve the properties of timber.**

This paper present the results of a preliminary investigation on the bending strength behavior of glulam manufactured from selected Malaysian tropical timber namely, resak and keruing in accordance with MS 758. Tests were carried out on four isolated simply supported beams according to procedure set forth in BS EN 408:2003. The bending strength of glulam was compared with the permissible strength of the timber under bending in accordance with MS 544 Part 3. The results shown that the glulam produced passed the required allowable strength value.

Index Term-- **Glulam, Bending strength, Lamination, Timber**

I. INTRODUCTION

Glued-laminated timber is an engineered products produced by structurally glued up individual graded sawn timber laminations. The thickness of individual laminations may not exceed 50 mm. The advantage of glulam is shorter lengths of commercially available sawn timber can be structurally end jointed with adhesives to produce the required full-length laminations.

Glulam offers the additional advantage of virtually unlimited flexibility in shape and size. Straight beams can be designed and manufactured with horizontal laminations (load applied perpendicular to the wide face of laminations) or vertical laminations (load applied parallel to the wide face of the laminations). An important characteristic of glulam manufacturing is that the bonding of laminations can result in beams of higher strength than the strength of single laminations from which they are constructed. Besides that, laminating allows control over the location of different grades of timbers within the glulam member cross-section. By placing the strongest timbers in the regions of greater stress (the top and bottom in the case of a bending member), the performance of glulam member are improved. Laminating also allows the dispersion of timber defects throughout the length of the glulam member.

Nearly any species or mixed-species combination can be used to produce glulam provided its physical and mechanical properties are suitable and the timbers can be glued together. According to Moody and Hernandez [3], species and mixed-species combination commonly used for glued-laminated timber in the United States include southern pine (*Pinus* spp.), douglas fir (*Pseudotsuga menziesii*)–larch (*Larix occidentalis*), hemlock (*Tsuga heterophylla*)-douglas fir and spruce (*Picea* spp.)-pine-fir. Red maple (*Acer* spp.) species was also used by Janowiak et al. [4] to study the performance of glulam beam made from two distinct timber resources namely sawn logs and lower-grade, smaller dimension timber. In Europe, on the other hand, Norway spruce is the most commonly used species for glulam [5].

Structural glulam members have been widely used in developed countries particularly in America, Europe and Japan. These members are used in straight or curved form in the construction of sport complexes, commercial buildings, churches and residential houses. Unfortunately, in Malaysia none of the structures have used glulam except for special project undertaken by Forest Research Institute of Malaysia (FRIM) in 1970s. Efficient use of glulam in construction requires an understanding of the structural behavior of numerous species and species groups due to the large inherent material variations. In order to be able to promote the application of glulam in Malaysia, more data are needed on the glulam manufactured using Malaysian indegenous species including the mechanical properties, bondability, durability etc.

An important distinction between timber and other structural materials is that timber is living material thus is quite difficult to meet performance requirements, where as man-made products like steel and concrete can be easily modified

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through the manufacturing process for a specified use. The tremendous diversity of tropical hardwoods available for structural applications significantly compounds the complexity of matching a particular species of timber with specific performance requirements. The number of merchantable species of timber available has been reported at 200 for Thailand [6]; 650 for Malaysia [7]; and 2500 in the Amazon [8]. From the reports, there is an indication of the tendency in most regions is to use clear material from a few species for which considerable experience is available on long-term structural performance. In most cases the choice of species will significantly influence both the manufacturing process of glulam and the properties of glulam.

Design factors that were developed for use on solid sawn lumber are also applied to structural composite lumber, although the two types of products have separate and distinct properties. The major difficulties associated with establishing bending strength of full size material according to standard bending test setups are that the members may fail in various modes such as shear or compression perpendicular to grain depending on the wood and the quality of bending between the laminates and the end-joint of the timber within the laminations.

Considerable research has already been done in investigating the various properties influencing parameters, method of preparation and testing of lamination [9,10,11,12,13]. Of particular interest has been the use of Malaysian timbers in the manufacturing of glulam. However, few studies have been made so far to investigate the mechanical and physical properties of glulam using local timbers. This is due to the problem encountered in the preparation of glulam specimens i.e, glueability of timber and phenomenon of wood movement during lamination process using different combination of species. Another problem encountered is the availability of the specific species.

The main purpose of this study was to evaluate the bending strength behavior of glulam manufactured using two timber species from different strength grouping namely keruing (*Dipterocarpus spp.*) from strength grouping SG 5 and resak (*Vatica spp.* and *Cotylelibium spp.*) from strength group SG 4.

II. EXPERIMENTAL PROCEDURES

A. *Preparation of specimens*

The objective of this study is to determine the bending strength of glued-laminated beams using selected Malaysian hardwood timber. The species used to manufacture the beam specimens are keruing (*Dipterocarpus* spp.) and resak (*Vatica* spp. and *Cotylelibium* spp.). The glulam beams were prepared in accordance with MS758.

Prior to glulam manufacturing, all timbers were visually graded for strength properties according to MS 1714:2003 ‘Specification for Visual strength grading of tropical hardwood timber’ by a certified timber grader. The timbers were graded into Hardwood Structural (HS) grade, the grade specifically used for manufacture structural glulam using Malaysian hardwoods. Timber used was dried to the required moisture content in the range of 8% to 15%.

Once graded, the individual timber pieces are end jointed into full length laminations. Phenol Resorcinol Formaldehyde (PRF) adhesive and hardener obtained from Dynea NZ Limited (Prefere 4001-2 and Prefere 5837) were used to forming the finger joint and laminate the glulam beams. This adhesive is an exterior, liquid-liquid system that is recommended for the manufacture of structural finger joints, I-joists and glued laminated beams. Prefere 4001-2/5837 is specifically formulated to be used with both conventional heating and room temperature cure above 20°C. The adhesive mix ratio is 2.5 parts resin to 1 part hardener slurry by weight, as recommended by the manufacturer. The total assembly time was 25 minutes.

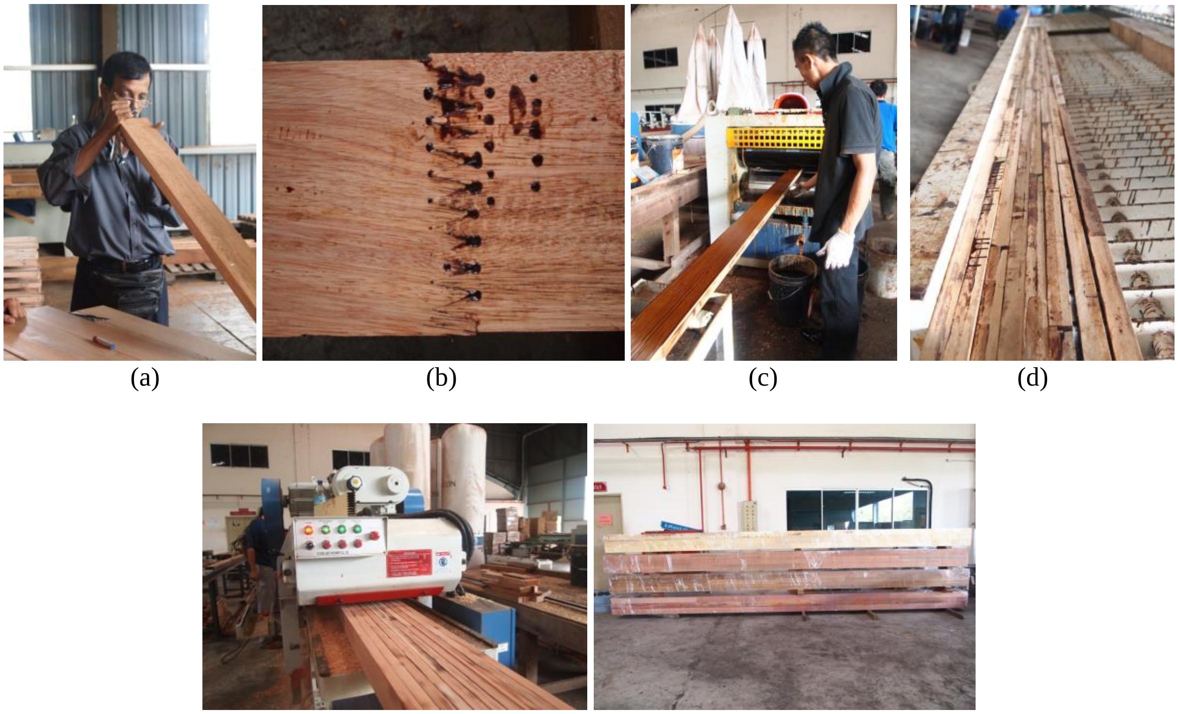
Then each lamination moves through a glue applicator and the pieces are re-assembled for clamping. The laminations are arranged so that the positions of the end joints are disperse. Hydraulic or manually activated clamps are placed around the members and brought into contact with steel jigs with recommended pressure. Once full clamping pressure is reached, the members were stored until the adhesive is fully cured.

The glulam fabricating process consists of four phases: The glulam fabrication process is shown in Figure 1.

Glulam beam specimens of 6000 mm in length, 150 mm in width and 300 mm in depth were prepared for each species. Each beam had 10 laminations with approximately 30 mm thickness for each lamination.

B. *Experimental methods*

A two point load method, as shown in Figure 2 was applied to test all specimens. The test apparatus, including roller supports, reaction bearing plates, load bearing blocks were set up according to BS EN 408:2003 [14]. These lateral supports allowed the specimen to deflect without significant resistance and prevented buckling. Load was applied at a constant rate of 0.5 mm/s. Load readings were continuously recorded using a computerized data acquisition system up to the ultimate load within 300 seconds.



(a) (b) (c) (d)

(e) (f)

Fig. 1. Glulam manufacturing process; (a) drying, cutting and grading of the timber; (b) finger jointing the timber into long lamination; (c) face gluing laminations; (d) glulam formation; (e)final planning and (f) sample glulam ready for testing.

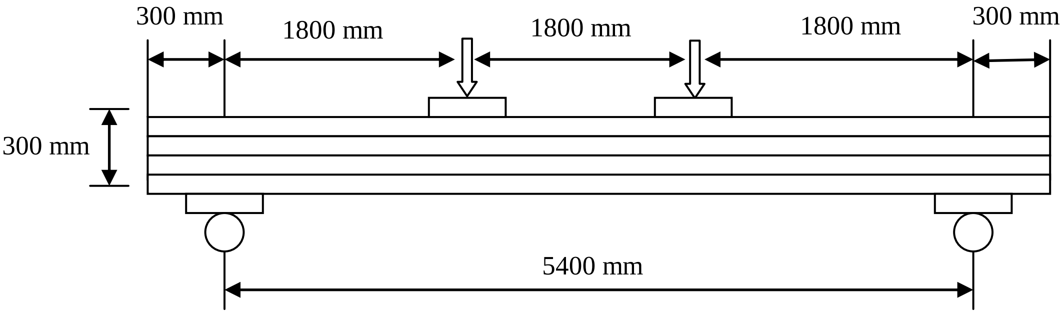


Fig. 2. Bending test set up

The internal traducers recorded the deflection readings. The readings from external traducers were also recorded. The bending strength, *fm* and permissible stress were calculated using the following equations:

$$f_m = \frac{aF_{\max}}{2W} \quad [1]$$

where

fm = flexural stress, N/mm^2

Fmax = ultimate total load, N

W = section modulus

Permissible stress = Grade stresses x K_1 x K_{11} [2]

where

K_1= direction of load factor

K_{11} = size factor

Grade stresses obtained from Table II MS 544 Part 3

III. RESULTS AND DISCUSSION

A true appreciation of the relevant properties of any material is necessary if a satisfactory end product is to be obtained and glulam in this respect is no way different from other materials. The performance of all types of glulam is much influenced by the production process, quality control and the manner in which the material is placed in position. Figure 3 shows a general behavior of glulam under bending.

Changes in the maximum bending load of glulam for different species are small (resak, 117.4 kN and keruing, 116.3 kN respectively) even though they are from different strength groupings. The presence of parallel orientations of the timber grain in flexural members may enhanced the properties of the solid sawn timbers. Thus, the load at which the fiber cracking is observed, the load, deflection and failure and toughness may all be increased. From the load-deflection curves (Figure 2), the ultimate bending strength for resak is bigger than keruing. Resak can sustain bigger load and bigger deflection. This indicates that resak is able to absorb higher energy before it fails as represented by the bigger area under the graphs. Based on the slope of the graphs, it can be concluded that keruing has higher stiffness than resak. From the load-deflection graph it can also be seen that there was no abrupt decrease in flexural load capacity after initial cracking which indicate that there was adequate ductility in tension, thus flexural strengthening can occur. Of much greater importance are the post-cracking behavior and the ability to absorb energy as fibers pull out.

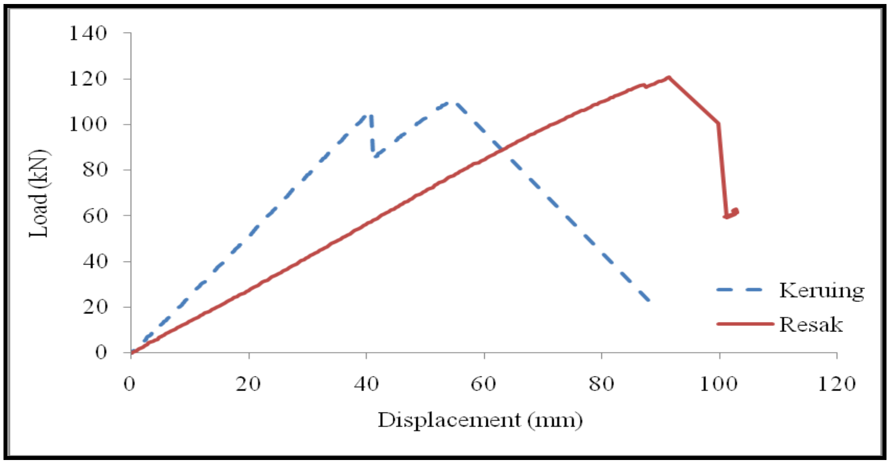


Fig. 3. Load versus displacement graph

The graph shows that after initial cracking, there was very minimum or slow crack growth, which suggests that the crack propagation has been minimized by the lamination process and the parallel orientation of the grains. The specimen has not been broken entirely, just very gradual crack propagation.

As the traditional sawn timbers, the failure occurs suddenly at ultimate load and that the specimens break apart into two separate pieces in a brittle manner. The glulam specimens remain intact as one piece even after the maximum load is reached and continue to carry a significant amount of load in the post-maximum load stage. The lamination process thus converts the brittle matrix into a ductile material. The lamination serves as crack arrester in the tension mode. In addition the species as well as the distribution of the interfacial bond stress between the lamination considerably influence the post-cracking behavior. Although the beams have reserved capacity after the first failure, it was felt that the redistribution of stresses in the member after the first bending failure might cause additional difficulties in the interpretation of results.

The different types of failure modes that occurred during testing of keruing and resak glulam beams are shown in Figures 4 and 5. The cracks initiated in timber (Figure 4b) in the middle of the specimen near tension zone (Figure 4a). Then the cracks slowly propagate until it reached weaker zone, finger joint area (Figure 4c). Figure 4d shows that the failed surface which is in timber. This indicates that the glulam was adequately manufactured where the failure is in timber rather than at the glueline. The failure mode of resak also showed same pattern as keruing (Figure 5).

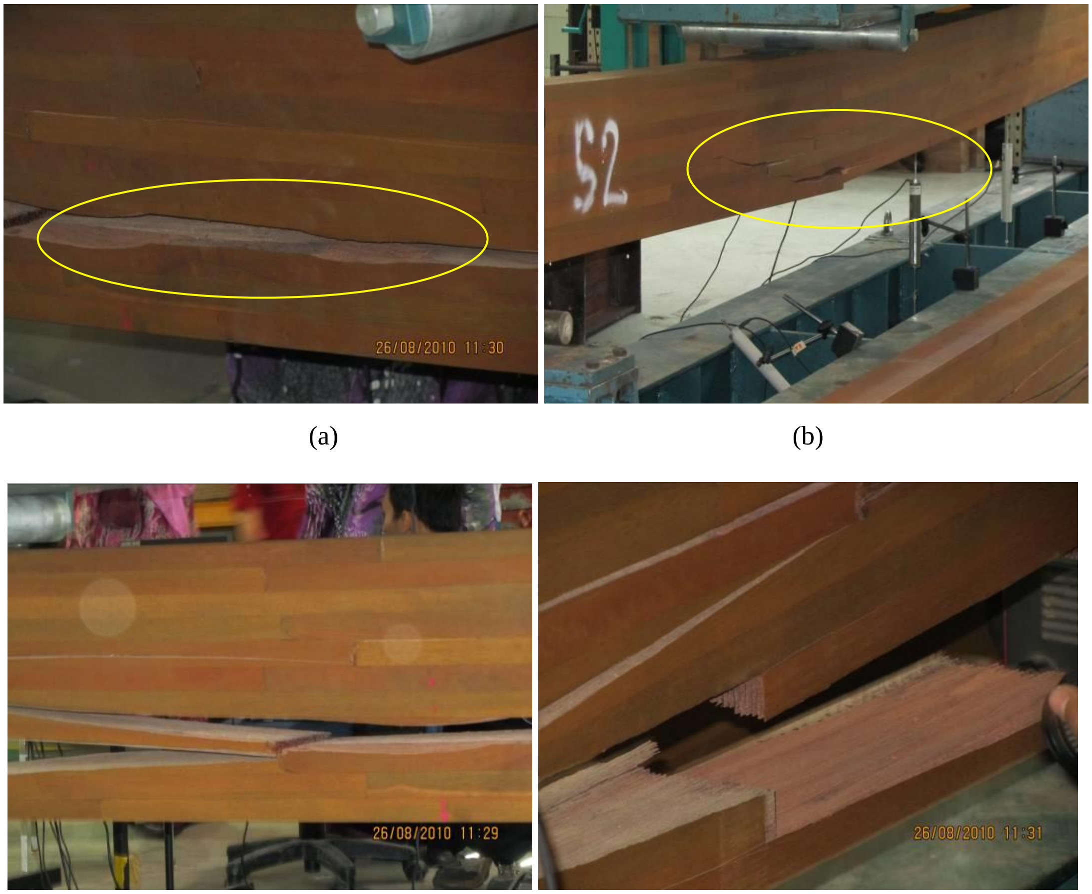
The results of maximum load, bending strength and permissible stress for the different species of glulam beams are summarized in Table I.

Table I
Summary statistics for bending properties of glulam

Species	Strength Group	Max Load (kN)	Bending Strength (N/mm^2)	Permissible Stress* (N/mm^2)
Resak	4	117.4	47.0	33.6
Keruing	5	116.3	46.7	33.6

*short term loading

From Table I it can be seen that there is no significant difference in the bending strength of resak and keruing glulam beam although they are in different strength groupings (SG4 and SG5 respectively. The strength groupings of timber was formulated based on the test values conducted using small clear specimens and grouped together according to strength and density. The glulam is manufactured using sawn timber in large size with 30 mm thickness of the laminates. This shows that the strength grouping does not correlate well with the strength of timbers in structural size. The bending strength values of glulam also affected by the ability of timber to bond well between laminates in relation of the density of the timber. However the bondability test was not reported here.



(a) (b)

(c) (d)

Fig. 4. Failure of Keruing beams; (a) failed in timber, (b) failure started at tension zone, (c) the cracks proceed to weaker zone, finger joint area and (c) showing failed at timber surface not at the gluline.

Fig. 5. Failure of Resak beams showing similar pattern as Keruing, failed in timber

The maximum bending strength of the glulam was also compared with the allowable bending strength as shown in Table I. It was found that the maximum bending capacity of the glulam is higher than the allowable bending strength. Therefore the glulam beam is suitable to be used as structural member. The results for the MOR values of African wood glulam beams are ranged from 31.1 to 46.8 N/mm^2[15]. In this study it can be seen that all of the MOR values for glulam beams of resak and keruing exceed the minimum requirement of 30.0 N/mm^2 set forth by JAS 234:2003 and also the MOR value of American wood glulam beams.

IV. CONCLUSION

The bending characteristics and behavior of glulam manufactured using different strength groupings of Malaysian tropical timber were investigated and the following results were obtained.

- There is no significant difference in bending strength of resak and keruing glulam beams even though they are in different strength groupings.
- Comparing the deflection performance, resak can sustain bigger deflection than keruing, therefore resak is tougher material than keruing.
- Comparing the load-displacement graph, keruing is stiffer than resak.
- Both glulams showed failure in timber which indicates good manufacturing practice.
- The maximum bending capacity of the glulam is higher than the allowable bending strength. Therefore the glulam beam is suitable to be used as structural member.

ACKNOWLEGMENT

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