

The Effect of Span Lengths on the Bending Strength Properties of Glued Laminated Timber Beam

Reza Andasht Kazeroon, Zakiah Ahmad
and Norshariza Mohamad Bkhari

Abstract This paper presents the effect of span length on the bending strength properties of glued laminated (glulam) timber beam using tropical hardwood timber namely Mengkulang (*Heritiera* spp.). The timbers have been visually graded according to MS 1714:2003 and the glulam manufacturing followed MS 758:2001. Four-point bending tests were conducted according to ASTM D198:2009. The moisture content and specific gravity of the test pieces were investigated following MS 837:2006. The failure characteristics were also analysed and reported. The results showed that the modulus of elasticity increases as the span length increases. The failure occurred mostly at the finger joints.

Keywords Bending strength properties · Glued laminated timber · Glulam · Mengkulang · Tropical hardwood

1 Introduction

Glued laminated timber, generally known as Glulam, is a type of structural timber products including numerous layers regarding dimensioned timber bonded combined with durable, moisture-resistant structural adhesives. Individual pieces superbly selected using dimensioned and also strength ranked timber within controlled production conditions, the grain for many pieces essentially parallel towards longitudinal axis from the member [1–3].

R.A. Kazeroon (✉) · N.M. Bkhari
Faculty of Civil Engineering, Universiti Teknologi Mara,
Shah Alam, Selangor, Malaysia
e-mail: reza.andasht@gmail.com

Z. Ahmad
Institute for Infrastructure Engineering and Sustainable Management (IIESM),
Universiti Teknologi Mara, Shah Alam, Selangor, Malaysia
e-mail: zakiah@salam.uitm.edu.my

Glulam construction has an extended lifestyle throughout European union given that early 1826 specifically throughout Britain, France, Germany, Sweden and Switzerland as well as accompanied by United States throughout 1934 and later by other western countries [4]. Glulam has been used as a heavy structure material on the manufacturing of bridge, stadium and dome structure [4–7] in some developed countries such as United States and Japan; since then, many research works have been done related to this industry.

Glulam offers many advantages if compared to solid-sawn timber. By combining small components of solid timber, the larger cross section and also the longer length involving structural grade timber could be manufactured. In architectural perspective, glulam solid timber provides free of charge column space and has aesthetic price either throughout straight in addition to curve order, and most often left exposed to be a decorative element in building construction. In comparison with solid wood, glulam demonstrates many advantages for instance improved strength and stiffness properties [8].

Glulam has been used in many applications, including headers or support beams in residential framing to major structural elements in roof framing of domed stadiums with span length over 500 ft (150 m). Glulam might be produced in any size and desired shape, including large, long-span straight beams to complex curved-arch configurations [9].

It has been accepted that the beam apparent strengths are influenced by timber sizes or dimensions. Bohannan [10] investigated the effect of beam size and derived the size factor based on Weibull weak link theory. This theory relates the apparent strength of a beam to its volume and assumes beam strength is governed by tension failure.

Studies have shown that the tensile strength of defect-free specimens decreases strongly with increasing length of the specimens [11–14]. Their findings indicate that the strength depends on the cross-sectional area rather than span length. For clear bending specimens, the strength was reduced by the size effect [15, 16].

Chudziński [13] tested beams with different lengths, resulting in higher bending strength values for longer beams. Schneeweiß and Felber [17] reported the work done by [10] whom investigated the effect of length of using 343 and 210 Douglas fir beams tested with centre point loading at span lengths of 36 and 46 mm, respectively, and resulted in average bending strength values of 91.4 and 92.1 N/mm². According to [15], in general the bending strength decreases with increasing span length which is independent of the loading configuration (centre loading, two-point loading, and third-point loading).

In the design of timber structures, there is adjustment factor for this effect. At present, the size effect for timbers either solid or glulam as stated in Malaysian standard adopted British standard which is based on softwood with no validation when using Malaysian hardwood timbers. This may introduce error in the design. Therefore, this study investigated the effect of span lengths on bending strength of glulam using Malaysian tropical timber.

2 Experimental Procedures

2.1 Manufacturing of Glulam Sample

The glulam beams were manufactured at a glulam factory in Selangor, Malaysia in accordance with MS 758:2001 [18]. The timber species used was Mengkulang (*Heritiera* spp.) and has been visually graded prior to the glulam manufacturing. The glulam pieces were graded visually in accordance with MS 1714:2003 [19] and classified into hardwood structural (HS) grade. Timbers used were dried to the required moisture content in the range of 8–15 %.

Phenolic resorcinol formaldehyde (PRF) Prefere 4001 with slurry hardener Prefere 5837 W obtained from Dynea NZ Limited was used to join the finger joints and laminate the glulam beams. PRF is a durable liquid–liquid system suitable for the manufacturing of structural finger joints and laminates the glulam species. The properties of Prefere 4001/5837 W are shown in Table 1. As recommended by the manufacturer, the mix ratio of adhesive is 2.5 parts resin to 1 part hardener slurry by weight.

A series of beams with different lengths were prepared. The dimension of the beams is shown in Table 2. Five replicates were prepared for each beam.

2.2 Test Method

Bending tests on full size Mengkulang glulam beams were performed at the Civil Faculty of Universiti Teknologi Mara. The experiment was carried out with large

Table 1 Properties of Prefere 4001/5837 W

Appearance	Viscosity at 25 °C	Specific gravity at 25 °C	Solid content	pH
Red-brown liquid, free from foreign material	16,000–20,000 mP	1.145–1.165	56–60 %	9–10

Table 2 Dimension of glulam beams

Beam length (m)	Dimension (mm)	
	Width, b	Depth, h
6	100	300
	130	300
8	100	400
	130	400
10	100	500
	130	500
12	100	600
	130	600

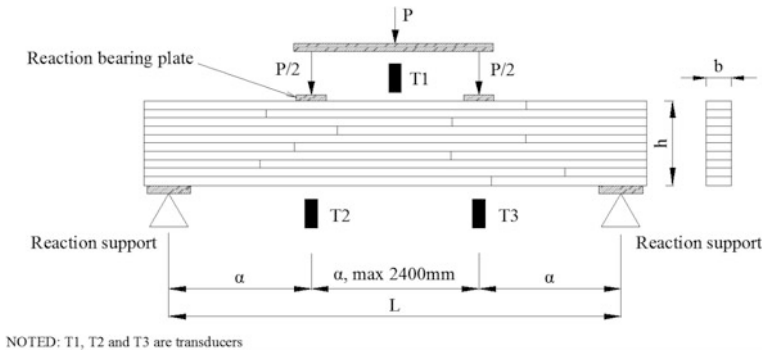


Fig. 1 Schematic diagram of bending test setup

dimension of the Mengkulang as shown in Table 2 for the beams with two different widths (100 and 130 mm) according to ASTM D198:2009 [20] by applying 1000 kN at two-point loading, using universal testing machine (UTM). The machine was set for cross-head position with rate of 0.001 mm/s to apply load perpendicular to the wide face of laminations. The deflection was measured by the movement of testing machine movable cross-head using linear variable differential transformer (LVDT) transducer. The details of the bending test are shown in Fig. 1. All tests were conducted until the beams failed completely.

The bending properties, modulus of rupture (MOR) and modulus of elasticity (MOE) are calculated using (1) and (2) respectively:

$$\text{MOR} = (P_{\max}L)/(bh^2) \quad (1)$$

$$\text{MOE} = Pa(3L^2 - 4a^2)/(4\Delta bh^3) \quad (2)$$

where

- P_{\max} maximum load on beam,
- h depth of beam,
- b width of beam,
- L span of beam = 18 h [20],
- a distance from reaction to nearest load point (1/2 shear span),
- Δ Increment of deflection of beam's neutral axis measured at mid-span,
- P Increment of applied load below proportional limit

The following bending test was accomplished; test pieces for moisture content and also specific gravity measurements were cut off near the point of fracture. The size of three test pieces (cross section \times 25 mm) from every single sample as well as the method to look for the moisture content and specific gravity is in accordance to MS 837: 2006 [21]. The pieces were dried using oven at 103 ± 2 °C.

3 Results and Discussions

3.1 Effect of Span Lengths on the Bending Properties

The bending properties, modulus of rupture (MOR) and modulus of elasticity (MOE) of glulam beams are tabulated in Table 3 as well as the characteristic shapes of the load–displacement graph of the bending members are illustrated in Figs. 2 and 3, respectively.

Table 3 shows that changes in the bending strength or modulus of rupture (MOR) of the glulam beams for different cross sections were small. However, it can still be seen that as the cross section increases, the MOR increases. When comparisons were made on the effect of span lengths on MOR, it was found that the MOR decreases as the span length increases. These results are contradicting with the findings of [13] but supported the report by [15]. For modulus of elasticity, it can be seen that the MOE values of specimens are almost improved by the

Table 3 Bending strength properties of glulam beams with different span lengths

Beam length (m)	Dimension (mm)		MOR		MOE	
	Width, b	Depth, h	Mean (N/mm ²)	STDEV	Mean (N/mm ²)	STDEV
6	100	300	47.6	5.62	14751.6	499
	130	300	42.7	2.76	16967.3	876
8	100	400	36.6	8.16	16974.0	717
	130	400	46.9	7.78	18032.0	498
10	100	500	28.8	5.47	17276.5	435
	130	500	35.8	7.45	17044.4	365
12	100	600	29.3	7.90	16160.5	1663
	130	600	34.9	7.44	17350.2	84.9

Fig. 2 Load versus deflection graph for glulam beams with 100 mm width

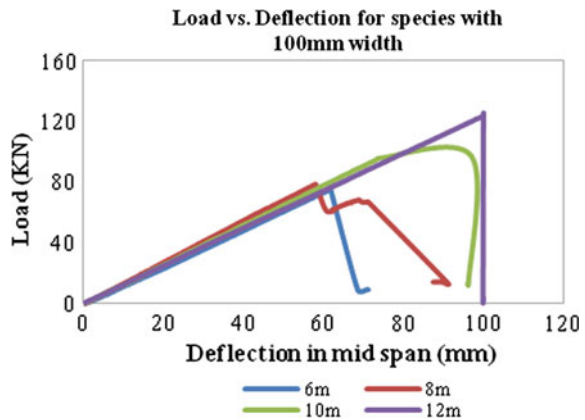
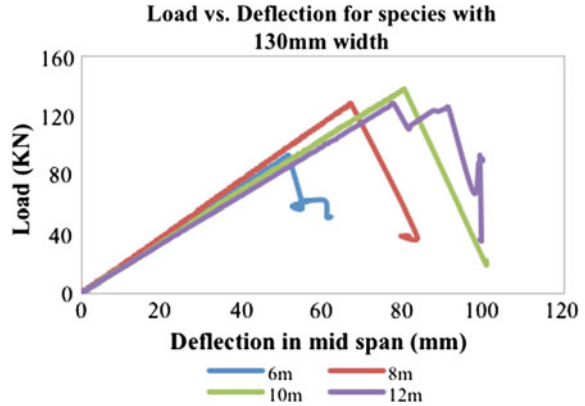


Fig. 3 Load versus deflection graph for species with 130 mm width



increment of beam span lengths (14751.6, 16,974 and 17276.5 N/mm² for 6, 8 and 10 m, respectively).

The load versus displacement graphs were also analysed for different beam widths. Figure 2 shows 100-mm-width beam and Fig. 3 shows 130-mm-width beam. The graphs were plotted using the graph that has almost similar value with the average values of the replicates. The graphs show similar pattern but with different optimum and deflection values. This indicates that the manufacturing process is quite consistent since the stiffness is not significantly different. Stiffness is the material properties.

3.2 Failure Mode Characteristics

This section analyses the failure mode characteristics of Mengkulang glulam beams under bending. The different failure modes that occurred during the testing of Mengkulang glulam beams with different widths (100 and 130 mm) and spans (6, 8, 10 and 12 m) are shown in Figs. 4, 5, 6, 7 and 8. From the figures, it shows that the

Fig. 4 Failure mode of Mengkulang glulam, failed in timber

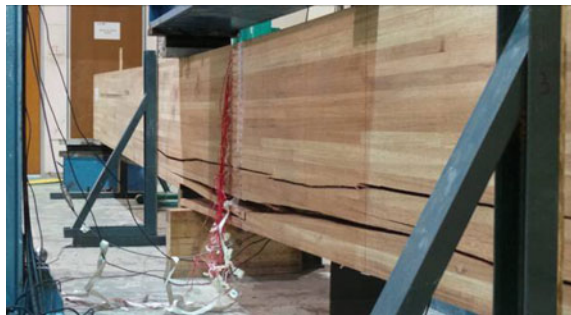


Fig. 5 Failure mode of Mengkulang glulam, the timber failure at finger joint (indicates good manufacturing process)



Fig. 6 Failure mode of Mengkulang glulam, failure start at tension zone

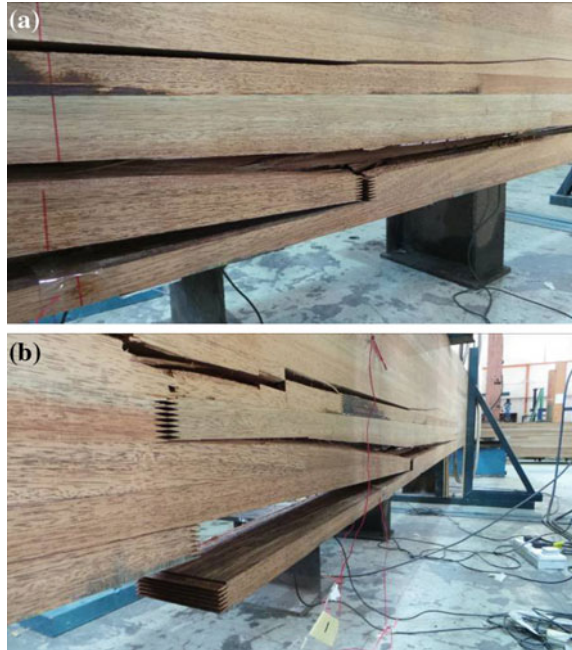


Fig. 7 Failure mode of Mengkulang glulam, the beam failed in ductile manner



cracks originated at the bottom of the tension zone and progressed with the application of load for all the glulam beams. The fractures of the glulam timbers began to tear the wood fibres until it reached the next weaker point, which reflected in high bending strength. Typical weaker zone for glulam is at finger joint areas. The failed surface, which is in timber, indicates that the glulam was adequately manufactured where the failure is in timber rather than at the glue line.

Fig. 8 Failure mode of Mengkulang glulam, **a** the crack proceed to weaker zone which is finger joint, **b** failure at finger joint area



4 Conclusions

The bending characteristics and behaviour of glulam manufactured using Mengkulang with different spans were investigated and the following conclusion has been acquired:

- As the cross-sectional area of replicates increases, the value of MOR increased. On the other hand, MOR decreased as the span length of replicates increases.
- As the span length of replicates increases, the value of MOE might be improved.
- Generally, the failure mode of Mengkulang glulam for all replicates showed almost same crack patterns. This crack pattern indicates that the glulam was adequately manufactured where the failure is in timber rather than in glue lines. Observation on finger joint also showed that the failure occurred in timber not in glue line.

Acknowledgments We would like to thank all the technical staff in heavy structure laboratory, Faculty of Civil Engineering for their assistance. Gratitude also extended to the final year students who helped in manufacturing the samples.

References

1. N. M. Bhkari, A. A. Bakar, P. M. Tahir and Z. Ahmad, "Flexural strength of glued laminated timber beam from selected Malaysian tropical hardwood," Proceeding the 6th Civil Engineering Conference in Asia Region: Embracing the Future through Sustainability, *ISBN* 978-602-8605-08-3. 2012.
2. Anon, Forestry Statistic for the Year 2011, 2011, Retrieved from www.forestry.gov.my
3. ASTM International, "Standard practise for establishing allowable properties for structural glued laminated timber (glulam) (ASTM D3737: 2009)," 2009.
4. A. Bakar, S. Saleh, A. Latif and M. Zainai, "Factors affecting ultimate strength of solid and glulam timber beams," *Jurnal Kejuruteraan Awam*, 16 (1), pp. 38–47, 2004.
5. J. K. Natterer, "Modern timber construction: from new simple techniques to high tech construction," The 7th World Conference on Timber Engineering. Shah Alam, Malaysia. 2002.
6. Forest Product Laboratory, Wood Engineering Handbook. New Jersey: Prentice Hall. 1990.
7. T. Haruji, M. Shyouhe and Y. Arata, "Innovative large timber buildings—Design of semi rigid hanging roof structure composed of glulams and steel plate," The 7th World Conference on Timber Engineering. Shah Alam. 2002.
8. G. Fink, J. Kohler and A. Frangi, "Bending tests on glued laminated timber beams with well-known material properties," *Institute of Structural Engineering*, no. 350, Zurich, July 2013.
9. R. Moody, R. Falk and T. Williamson, "Strength of glulam beams-volume effects," In: Sugiyama, Hideo, ed. Proceedings of the 1990 International timber engineering conference; 1990 October 23–25; Tokyo. Tokyo: Steering Committee of the International Timber Engineering Conference: 1990, Vol. 1. pp. 176–182.
10. B. Bohannon, "Effect of size on bending strength of wood members," Research Paper FPL 56. Madison, Wisconsin: U.S. Forest Products Laboratory. 1966.
11. R. Brandner and G. Schickhofer, "Length effects on tensile strength in timber members with and without joints," *Materials and joints in timber structures*, RILEM book series, 2014, vol. 9. pp. 751–760.
12. K. Sumiya and H. Sugihara, "Size effects in the tensile and bending strength of wood," *J. Japan Wood Res. Soc.*, 3(5): 1957, pp. 168–173.
13. Z. Chudziński, "Strength Properties Determined by Different Testing Procedures for Solid Pinewood, Veneer-, Fibre-, Chip-, and Flax-Boards," *Holztechnologie*, 5(4): 1964, pp. 233–240.
14. R. H. Kunesh and J. W. Johnson, "Effect of Size on Tensile Strength of Clear Douglas-fir and Hem-fir Dimension Lumber," *For. Prod. J.*, 24(8): 1974, pp. 32–36.
15. B. Madsen and A. H. Buchanan, "Size effects in timber explained by a modified weakest link theory," *Can. J. Civ. Eng.*, 13(2): 1986, pp. 218–232.
16. B. Madsen, "Size effects in defect-free Douglas fir," *Can. J. Civ. Eng.*, 17(2): 1990, pp. 238–242.
17. G. Schneeweiß and A. Felber, "Review on the bending strength of wood and influencing factors," *American journal of material science*, 3(3): 2013, pp. 41–54.
18. Malaysian Standard, "Glued laminated timber—Performance requirements and minimum 219 production requirements," 2001, MS 758:2001.
19. Malaysian Standard, "Specification for visual strength grading of tropical hardwood timber," 221 2003, MS 1714:2003.
20. ASTM International, "Standard test method of static tests of lumber in structural size (ASTM 210 D198:2009)," 2009.
21. Malaysian Standard, "Solid Timber—Determination of moisture content (First Revision)" 2006, MS 837:2006