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FACTORS AFFECTING ULTIMATE STRENGTH OF SOLID AND GLULAM TIMBER BEAMS

Suhaimi Abu Bakar[1], Abd Latif Saleh[2], Zainai B Mohamed[3],
[1]*Lecturer, Faculty of Civil Engineering, Universiti Teknologi Malaysia,*
Skudai 81310, Johor Bahru, Malaysia
[2]*Associate Professor, Faculty of Civil Engineering, Universiti Teknologi Malaysia,*
Skudai 81310, Johor Bahru, Malaysia
[3]*Professor, Kolej Universiti Teknologi Tun Hussein Onn,*
86400 Parit Raja, Batu Pahat, Johor, Malaysia.

Abstract: Phenol Resorcinol Formaldehyde is an adhesive commonly used in the fabrication of glued laminated (glulam) timber beams. Although, it has been widely accepted for softwood species, the verification of this type of adhesive for local timbers is not fully established. Four glulam beams and four solid beams were tested in bending in the laboratory. Phenol Resorcinol Formaldehyde was used as an adhesive for glulam beams. The strength of the glulam beam structure was equivalent to solid beam structure. Phenol Resorcinol Formaldehyde was able to provide sufficient bonding and strength for local timbers. The results indicated that the most significant factor influencing the strength of solid beam and glulam beam structure was the density of timber.

Keywords: *Glulam; Strength; Beam; Shorea acuminate; Phenol Resorcinol Formaldehyde.*

Abstrak: Fenol Resorsinol Formaldehid adalah perekat yang selalu digunakan untuk membuat rasuk kayu lapis berperekat (glulam). Sungguhpun perekat ini telah diguna untuk spesis kayu lembut, kesesuaiannya terhadap kayu tempatan masih belum dikaji. Empat rasuk glulam dan empat rasuk padu diuji secara lenturan di makmal. Fenol Resorsinol Formaldehid digunakan sebagai perekat rasuk glulam. Kekuatan struktur rasuk glulam ditemui setara dengan kekuatan struktur rasuk padu. Fenol Resorsinol Formaldehid ditemui boleh menghasilkan ikatan dan kekuatan yang baik ke atas kayu tempatan. Kajian menunjukkan faktor utama yang mempengaruhi kekuatan struktur rasuk padu dan rasuk glulam ialah ketumpatan kayu.

Katakunci: *Glulam; Kekuatan; Rasuk; Shorea acuminata; Fenol Resorsinol Formaldehid.*

1. Introduction

The emergence of glued-laminated (glulam) material in timber structure has given a significant impact to the timber construction industry. Glulam has a high strength to weight ratio. It can virtually be sized at any curved or straight shapes, spanned at a much higher length, designed at various strength requirements while maintaining the natural aesthetic appearance and reducing the timber waste. This engineered material can now pose a greater challenge to concrete, steel and other composite materials in the major structural applications. In advanced countries such as the U.S.A and Japan, glued laminated timber has been accepted as a material for heavy structure such as bridge, stadium and dome structure (Natterer, 2002; Forest Products Laboratory, 1990; Haruji et al, 2002).

Glulam construction has a long existence in Europe since early 1826 particularly in Britain, France, Germany, Sweden and Switzerland followed by the United States in 1934 and later by other western countries (Freas, 1950). Since then, many research findings have been published relating to this industry. In Malaysia, however, this industry has not been commercially developed (Zakaria, 1988). The only presence of glulam applications in the country are the footbridge and the mosque at Forest Research Institute Malaysia (FRIM) while the remaining are more of the nonstructural applications of laminated wood such as joinery works, utility furniture, paneling, partitioning and plywood manufacture (Mohd. Noh and Abdullah, 1988). At present very little research works on glulam materials are conducted locally.

In making up glulam structure, Phenol Resorcinol Formaldehyde is typically used as an adhesive for glulam. According to Vick, this type of adhesive is capable to give efficient bonding for glulam structure (Vick, 1973). This type of adhesive has been verified and accepted for use in softwood timber. However, the verification of this adhesive for local timber is not fully established. During loading process, adjacent laminates in glulam beam are capable to slip or separated from each other. Nonrigid interface may then present in glulam beam, thus the strength of glulam beam may be affected. The verification of the ultimate strength and the bonding of glulam beam compared to solid beam, particularly of local timber is yet to be established.

This paper presents the capability of glulam beams made up of local timber. The ultimate strength of glulam beam is compared to ultimate strength of solid beam. The capability of Phenol Resorcinol Formaldehyde as an adhesive for local timber is discussed.

2. Experimental Study

2.1 Preparation of Test Specimens

Meranti Rambai Daun (*Shorea acuminata*) species of Dark Red Meranti (DRM) family, was used to fabricate the test specimens. DRM is one of the most commonly utilized timber species in the country. It is also the most readily available materials in the state of Johor where this research was conducted. DRM is seen potential and capable to produce glulam structural members in a big scale.

A well-known property of timber is inhomogeneous. This property is reflected by the variation of strengths in timber even from the same species. In order to reduce the inhomogeneity effect as much as possible, all testing specimens were taken out from a single log.

Timber beams were fabricated and classified into two groups, SB and GB. Group SB constituted solid beam of 60 mm x 100 mm x 1600 mm, while group GB was a four-layer laminates glulam beam with the same dimensions. Each laminate thickness for GB beam was 25 mm, much lesser than the maximum thickness permitted by BS 4169: 1988. Four beam samples were prepared for each group of test specimens.

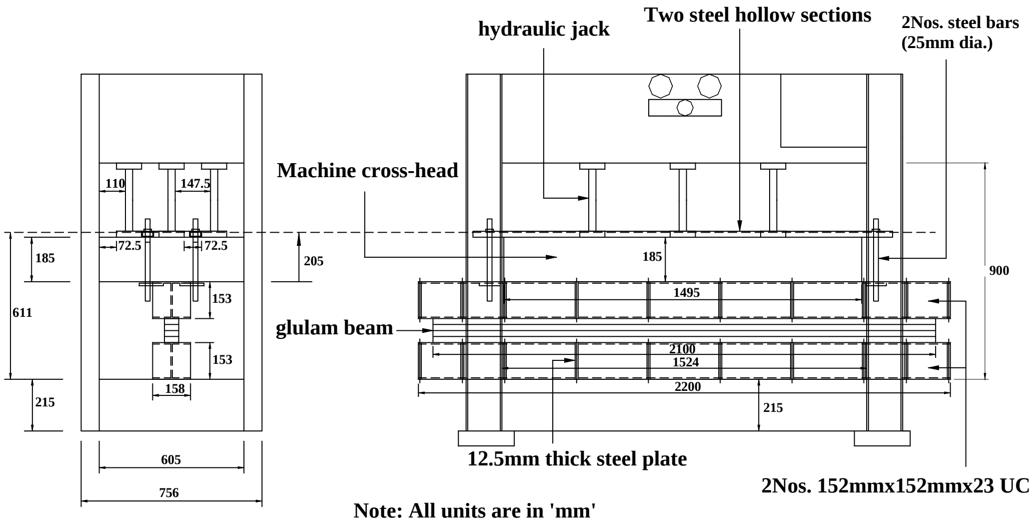
2.2 Fabrication of Glulam Beam Specimen

The fabrication of glulam beams in the laboratory followed similar procedures and practices to that of industrial glulam (Baharudin, 1996). The differences in fabrication for the laboratory glulam are the location and clamping method. Though the laboratory clamping in practice can be considered as a cold clamping which is similar to the industrial cold-pressed clamping, the difference in the two methods lies in the machinery that does the clamping. The method adopted in the preparations of laminated members follow closely to the one proposed by the British Standards (BS 4169, 1988).

For the preparation of glulam beam, four best pieces of timber boards were selected and cut in longitudinal direction. They were cut into four laminae, each has 25 mm thickness. In building up the beams, the laminae were placed in position by maintaining the original orientations.

Phenol Resorcinol Formaldehyde adhesive and its hardener, bearing the commercial name of CASCO NOBEL (Synteko Adhesive No.1711 and Synteko Hardener No.2623) were used to laminate the glulam beam. The glue, a synthetic resin adhesive, is weather resistant and is recommended for structural usage in which it satisfies the requirement as specified by the respective standard (BS 4169, 1988).

The glulam beam specimen was clamped by using Eurotrade machine with some modifications to enable effective clamping of glulam beam. The length limitation of existing machine was improved by adding extra components to the machine and ensures all area of the glulam specimen was under a uniform pressure (Figure 1).



Note: All units are in 'mm'

Figure 1: Glulam fabrication machine installed with additional components

A good structural joint should have a thin continuous glue line on both surfaces of the joint. To achieve this condition, an adequate clamping pressure was applied to the components to bring the contact surfaces as close as possible.

The clamping process was controlled using Eurotrade machine. The assembled laminae were placed inside the clamping machine. Two pieces of plywood were placed on top and at the bottom sides of the glulam to ensure that the extreme wood fibres were not overstressed during clamping process. The recommended pressure is 1 Nmm^{-2} (Chang, 1994). It is greater than the minimum pressure specified by BS 4169: 1988, i.e. 0.7 Nmm^{-2}. It is believed that by using the recommended value of pressure, excessive glue will squeeze out during pressing and flows inside the wood voids and timber joint to strengthen the joint.

2.3 Beam Test

a) Dimension of beam specimen

The dimension of beam specimen is shown in Figure 2. The beams were tested under two point loads. The dimension of the beam is prepared so that the ratio of shear span, a_v, and beam's depth, d, equals to 5.95. The adoption of this ratio was to ensure that the failure of beams would occur in the region of maximum moment (ASTM D198-84, 1992). The span-depth ratio chosen was 16 so that the failure would predominantly in flexural (Malhotra and Bazan, 1980).

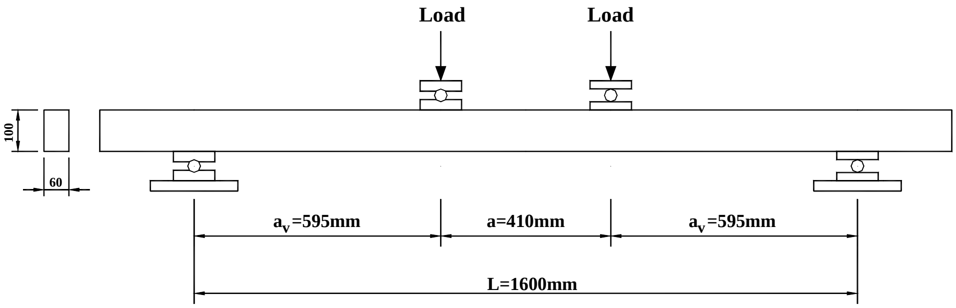


Figure 2: Dimension of beam test specimen

b) Instrumentation and test

The setup for the beam test is shown in Figure 3. A testing rig made of structural steel was prepared for the beam tests. The beams were tested in accordance with ASTM D198-84. During loading process, the deflections of the beam were recorded by deflection transducer (LVDT) and the corresponding strains were recorded using electrical strain gauges. All measurements were captured at regular interval by using Campbell CR23X data logger.

The speed of the cross head was manually controlled to the closest possible speed required by ASTM D198-84 which was set as 4.80 mmmin^{-1}. A computer system connected to a data logger was used to calculate the strain rate at the extreme fiber of the beam. The strain rate was maintained below 0.001 mmmm^{-1} min^{-1} as recommended by ASTM D198-84. All tests were conducted until the beams failed completely.

After the bending test was completed, test pieces for moisture contents and specific gravity measurements were cut off near the point of fracture. The size of test pieces and the method to determine the moisture content and specific gravity followed the BS 373: 1957.

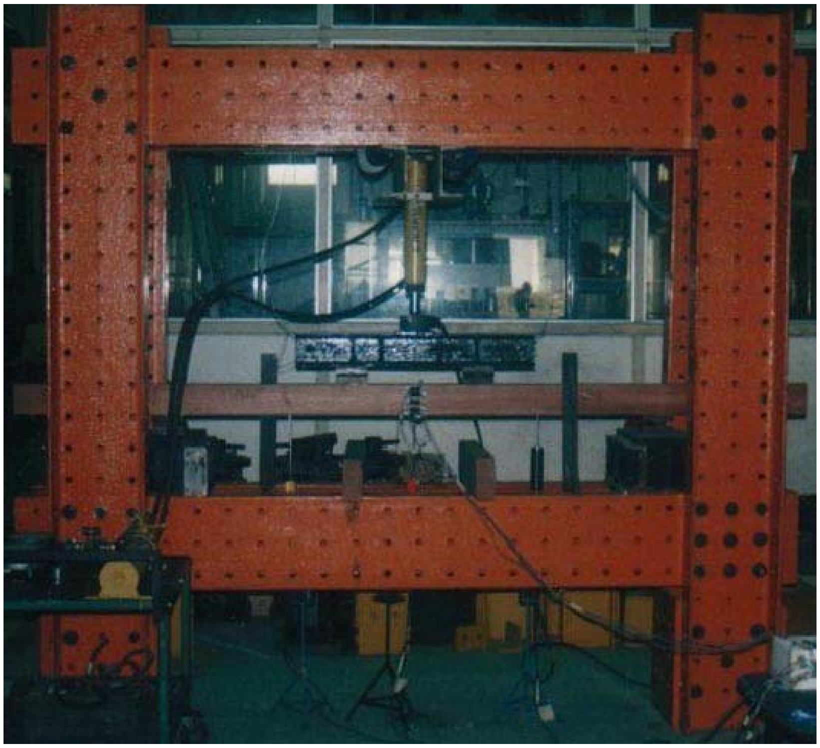


Figure 3: Set-up for bending test on group SB and GB beams

3. Results

3.1 Mechanical Properties of Timber

The moisture contents and specific gravity for all beam specimens are tabulated in Table 1. The average value of moisture content was 18.07%, which was about the equilibrium state for tropical timber (Grewal, 1979). The timber specimens can also be classified as light timber and moderate timber according to specific gravity. The specimens SB2, SB4 and GB2 were classified as light timber with average specific gravity 0.43 gcm^{-3}, while other specimens were classified as moderate timber with the average specific gravity 0.64 gcm^{-3}. Based on this result, the in homogeneity property of timber was still present in the timber of the same log.

Table 1: Moisture contents and specific gravity for all beam specimens

Specimen	Moisture content (%)	Specific Gravity (dry)
SB1	21.28	0.63
SB2	16.92	0.46
SB3	18.89	0.60
SB4	17.74	0.47
GB1	16.25	0.62
GB2	17.02	0.36
GB3	18.29	0.69
GB4	18.18	0.67

3.2 Beam Test Results

The load-deflection curves for all beam specimens are shown in Figure 4. The deflections in these curves are based on mid-span deflection.

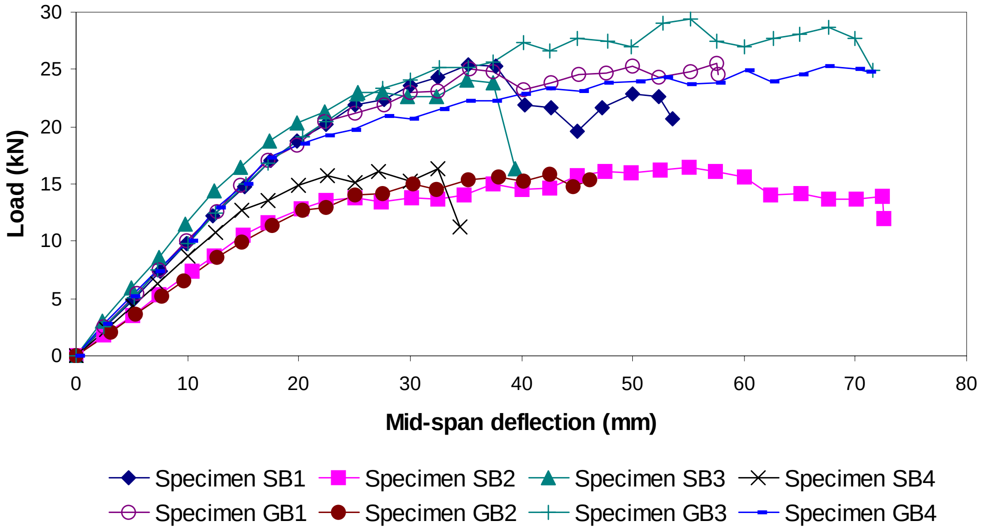


Figure 4: Load-deflection curves for all beam's specimens

Each curve in Figure 4 constitutes of linear and nonlinear parts. At the nonlinear part, the slope of the curve reduced and seemed approaching to zero. At this stage, the ultimate load was reached. Based on Figure 4, the load deflection curve for timber can be idealised as a perfectly elasto-plastic curve (Figure 5). Therefore, the timber can be idealised as a perfectly elasto-plastic material.

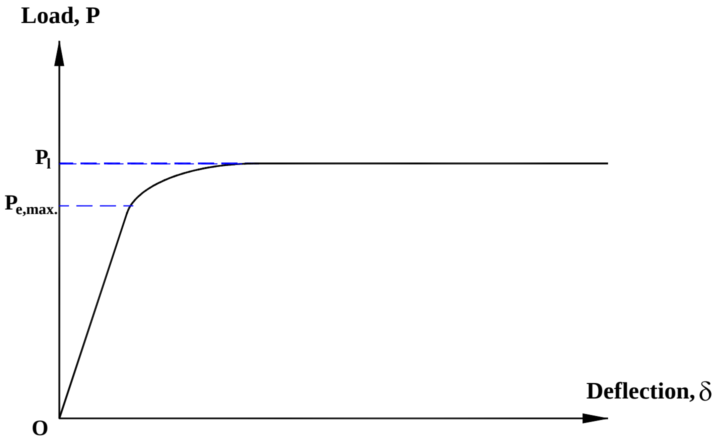


Figure 5: Load-deflection curve for perfectly elasto-plastic material

The maximum load at elastic stage, $P_{e,max.}$, or at the point where the curve changes from linear to nonlinear part was evaluated for each specimen. The maximum loads (at elastic stage) are tabulated in Table 2. The limit loads are also evaluated based on Figure 4 for all beam specimens (Table 2).

Table 2: Maximum load at elastic stage, average limit load and ultimate load

Beam specimens	Maximum load at elastic stage, $P_{e,max.}$ (kN)	Limit load, P_l (kN)
SB1	19.0	22.30
SB2	12.0	13.65
SB3	20.0	22.50
SB4	13.5	15.10
GB1	20.0	24.05
GB2	12.0	15.05
GB3	21.0	27.30
GB4	18.0	21.85

The average limit load is about 1.2 times maximum load at elastic stage (Table 2). The average limit load is not significantly different compared to maximum load at elastic stage. However, from Figure 4, the nonlinear part contributes a greater portion of total load-deflection curve. For all beam specimens, the average nonlinear part was approximately 60% of the total deflection. Based on the load-deflection curves, the specimens SB3, SB2 and GB4 contributed more ductility or non-linear part before the failure occurred. However, specimen SB4 contributed the smallest ductility compared to other specimens. This suggests that the timber was inhomogeneous.

The values of limit load are different for all specimens (Table 2). This shows the inhomogeneity effect that present in the timber was significant even for timber specimens taken from a single log. From Figure 4, the load-deflection curve can be divided into two groups based on the values of limit loads. Each group has approximately equal limit loads. The first group constituted of specimens SB1, SB3, GB1, GB3 and GB4 has higher limit load. While the second group constituted of specimens SB2, SB4 and GB2 has lower limit load. From Figure 4, the load-deflection curves for each group were approximately the same.

It was found that the different values of limit load or ultimate strength of the beams were caused by different specific gravity of the timber. The first beam group that has higher limit load (specimens SB1, SB3, GB1, GB3 and GB4) lies in higher moderate timber group as previously stated. While, the second group beam that has lower limit load (specimens SB2, SB4 and GB2) lies in light timber group. This result shows that the specific gravity of timber has large influence on the limit load of the beams (solid and glulam).

The three glulam beam specimens, GB1, GB3 and GB4 which lie in moderate group were capable to produce higher limit load compared to solid beams of light group (specimens SB2 and SB4). For this reason, the limit load for glulam beam was greater than the limit load for solid beam. Thus the Phenol Resorcinol Formaldehyde adhesive that present in the glulam beam was found not influent the strength of the beam. The strength of the beams was affected by the specific gravity rather than adhesive that present in the glulam beam. The Phenol Resorcinol Formaldehyde adhesive provides sufficient strength for local timber and can be recommended as adhesive for glulam beam.

4. Concluding Remarks

To conclude this paper, the following remarks are noted:

a) Timber is found to show more ductility before complete failure.
b) Timber can be idealised as a perfectly elasto-plastic material.
c) The inhomogeneous property of timber is still present in the timber of the same log.
d) The different values of limit load or ultimate strength of timber beam are caused by different values of specific gravity that present in the timber.
e) The presence of Phenol Resorcinol Formaldehyde adhesive did not reduce the strength of the glulam beam.

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