The flexural strength of glue laminated timber beams based on deflection and strain rate with four point bending loading system

S Maricar1, K Sulendra2, H Listiawaty3, and H O Baide
Department of Civil Engineering, Tadulako University, Palu, Central Sulawesi
Email: maricarshyama@gmail.com1, ketutsulendra5@gmail.com2, hlistiawaty@yahoo.com3

Abstract. The development of utilization of low quality wood as construction material is needed to reduce the exploitation of natural forests. However, low quality wood species have disadvantages in terms of mechanical properties. The mechanical properties of Sengon wood are relatively low, so it does not qualify as a structural element. Therefore, the system glulam can be applied to overcome this problem. The system glulam can produce relatively light structural elements with adequate performance. This system has been extensively developed, even at the stage of applying external reinforcement, to improve the performance of structural laminated beams. On that basis, this study aims to determine the flexural strength of laminated beams of Sengon wood as a low quality wood species. In order to achieve this goal, the laminated beam was tested using method four point bending test method. Tests were carried out on long span laminated beams ($L = 2750$ mm) to observe flexural strength. There are five (5) laminated blocks tested, namely (BLS-1, BLS-2, BLS-3, BLS-4 and BLS-5). Each group has dimensions of 55 mm in width and 155 mm in height. Each specimen consists of six layers of wood boards with a density Falcata $0.3 \text{ g/cm}^3$. The thickness of each layer was 26 mm and bonded with resin urea formaldehyde cold setting. Double-sided adhesive laying of 350 gr/m² at a compressive force of 2 MPa. The analysis result shows that the load-deflection relationship between BLS-L consists of linear and nonlinear phases. The load performance characteristics of the two types of laminated beams are expressed as the ratio of the proportional limit load to the maximum load. The ratio value is expressed in the form $P_{\text{el},L} = 0.7P_{\text{m},L}$ and $M_{\text{el},L} = 0.7M_{\text{m},L}$. This form is similar to previous studies with a $P_{\text{el}}$ to $P_{\text{m}}$ ratio of 0.80-0.9. In this case, the average flexural strength of the laminated beam is 17 MPa with a maximum strain of 0.004.

Key words: Laminated Beam, Low Quality Wood, Flexural Strength

1. Introduction
It is known that low quality wood has a relatively low weight. This of course will be very beneficial, especially to anticipate earthquake loads. However, the problem is that the inadequate performance of low quality wood is a major limitation of its use as structural beams. For this reason, lamination technology is an alternative that can be done to optimize the performance of wooden beams. The objective of this research is to determine the bearing capacity of beams made of low quality wood, so the problem of how laminates are treated to the flexural strength of low-quality beams and how is the difference in flexural strength of laminated beams based on deflection and strain data. Based on the background and problems that have been described, the specific objectives of this study are: Determine the change in the flexural strength of low-quality wood beams due to lamination treatment and determine the difference in the flexural strength of laminated wood beams based on deflection and strain data so that there are alternative raw materials for structural beams with different weights. Small and additional information for the development of construction material technology.
As a natural material, low quality wood has physical and mechanical properties with relatively low intensity. For example, Sengon wood, has a reference flexural strength value of ± 6000 MPa with a parallel tensile strength of 12,000 MPa [2]. Low quality wood is generally in the form of fast growing tree species, with a diameter of ± 60 cm. A log ductility analysis can generally be based on deflection (D) or curvature (f). Deflection is obtained through a series of vertical deflection measurements while curvature can be based on the relationship between strain and flexural stress.

To increase efficiency and reduce the effect of wood defects that are common in low-quality wood species, a lamination system either without reinforcement or with external reinforcement was developed. However, the lamination process itself has a reinforcing effect on beams, especially those designed with tensile bending collapse. There are three types of reinforcement that are being developed, namely: (1) flexural reinforcement, (2) shear reinforcement, (3) combined bending and shear strengthening with GFRP on the underside of the beam causes ductile collapse with an increase in MOR 11%, MOE 5% Flexural strengthening [15]. The laminated beam system can reduce the negative effect of wood defects [14]. The bending capacity of laminated blocks with a combination of lamina types will increase along with the increase in MOE in the outer layer [18]. With the strengthening of 0.82% of the steel bar area, there was an increase in stiffness of 25.9%, ultimate load of 48.1% and ductility of 43.8% [13]. Strengthening laminated beams with GFRP increases the flexural strength. is very significant and causes a shift in the location of the crack from the shear area [15]. Beams with FRPs reinforced behave more ductile and experience significantly increased stiffness. In addition, there is also an increase in the ultimate moment of capacity and beam compressive strength [16]. Reinforcement will reduce the need for high-strength wood in the outer layer of the laminate beam (may use low grade). The volume of wood can be reduced and will reduce product variability [11]. The increase in flexural strength with fiber glass reinforcement on the lower fibers of the laminated beam is 9.52% - 12.53%. Specifically, for the application of 1.2% FRP with a thickness of 0.7 mm combined with fl axfies, the upright tensile capacity of laminated wood beams increased by 74% and increased in stiffness by 41%. In this case the collapse that occurred was semiductile[6].

2. Research Methods

2.1 Research Framework and Data Collection Methods

The research was carried out by using experimental methods in the laboratory. Experiments were carried out through the bending test of a full-scale laminated beam structure model. Experiments are carried out in accordance with the stages as presented in the research framework. The data analysis includes:
1. Interpretation of tensile and compressive test results parallel in the context of their effect on the flexural strength of solid wood.
2. Interpretation of full-scale beam test results by comparing the performance of the beam from the reading of the strain rate and deflection rate and formulating conclusions based on the results of both
2.2. Research Materials
The main material used is Sengon wood planks with a width of 6 cm, a thickness of 3 cm and a length of 300 cm. The sheets of the board are first dried for about 3 months. This is done in order to achieve a balanced moisture content of 10-12%. After the sheets are in equilibrium or air dry, then the tensile, compressive and laminated beams are made. The adhesive used for the manufacture of laminated blocks is cold setting urea formaldehyde resin. One beam requires 120 grams of resin powder and 60 grams of water. The raw material for Sengon wood and the adhesive used is presented in Figure 2.

![Figure 2. (a) Sengon Wood Planks, (b) The Adhesive](image)

2.3 Making Test Objects
Tensile specimens, compressive tests and laminated beams are made in accordance with ASTM D-143 requirements. 02. As for the number of each specimen as presented in Table 1 and figure 3.
Table 1. Types of Testing and Dimensions of Test Objects

| No | Types of Testing                                      | Total Sample (n) | Test Results                                              |
|----|-------------------------------------------------------|------------------|----------------------------------------------------------|
| 1  | Strong Pull History                                   | 3                | Tensile Strength and Stress-Strain Curves                |
| 2  | Strong Press Along                                    | 3                | Parallel Strength and Stress-Strain Curves               |
| 3  | Block Bible Test with The Four Point Bending System   | 3                | Flexural Strength, Load-Strain Curves and Deflection-Load Curves |

Figure 3. Tool for Making Test Objects. (a) Planer Machines for Leveling and Grading (b) Cutting Machine (Cycular Saw) (c) UTM for Laminated Block Pressing (d) Sett Clamp Tool
Figure 4. Shape of tensile and compressive specimens according to ASTM. D143-03 (a) Fiber Parallel Tensile Test Object (b) Test specimens are parallel to the fibers.

The manufacturing of laminated blocks is carried out in stages: 1) Leveling of the laminate; 2) Gluing; 3) Pressing and 4) finishing. In this case, the laminate beam is formed from six sheets of laminate board which are glued together to form a complete structural beam, with dimensions of 55 mm in width, 155 mm in height and 2750 mm in span. Because there must be an oversteck at both ends of the pedestal, the total length of the beam made is 3000 mm. Schematically the whole process of making laminated blocks is presented in Figure 5.
Figure 5. The process of making laminated blocks. (a) Leveling Lamina (b) Adhesives (250 gr / block) (c) Deployment of 2 MPa per 25 cm beam length (d) Pressing (The blocks are put in place clamp is flat for 24 hours) (e) Finishing (f) End Result

Lamination leveling is carried out using a planer machine to clean the surface of the bonding plane, as well as to achieve the target net thickness of 26 mm. In addition, this leveling or cleaning process will remove the extract content that is on the surface of the lamina material. At this stage, alignment is only carried out on the two sides of the wide surface of the lamina. This process is carried out 24 hours before the gluing process, so as not to give the wood material the opportunity to extract the extract. In this case, the extract content in the bond area will reduce the quality of the adhesive.

After all the laminations are ready, then gluing is carried out with an adhesive material in the form of a mixture of powdered resin and water in a 2:1 ratio. The adhesive resurfacing is done manually on both sides of each lamina with the duration of laying each block (six layers of lamina) a maximum of 15 minutes. This is to avoid exceeding the setting time of the adhesive. After the adhesive laying process, the clamping device is then installed for further pressing and pressing. The duration of this pressing is 24 hours in order to achieve the optimal level of adhesion layer maturity between each lamina material.

After 24 hours, the clamp is opened and the finishing process is continued. At this stage, the leveling process is carried out again for each beam to achieve a width dimension of 55 mm. The leveling process is carried out with a planer machine on only two sides of the beam height, because the beam height achieved during the pressing process is in accordance with the target, namely 155 mm.

2.4. Implementation of Testing

2.4.1. Tensile and Test Parallel

The tensile and parallel compressive tests are carried out according to the procedure specified by ASTM D143-02 as presented in Figure 6. In the implementation of the tensile test, the main tool is used in the form of a strain meter to read the length increase that occurs in the test object due to loading.

Tensile axial loading was applied using the Universal Testing Machine. The parallel compression test is carried out using a compression test machine as a loading application tool. Meanwhile, to read the deformation used LVDT -150 mm and data logger as data reading instruments. The loading application in the parallel compression test is carried out until there is no additional loading value.
2.4.2 Test of Laminated Beams with the Four Point Bending System

The setting up of a full-scale laminated beam bending test is presented in Figure 6. Implementation of tensile and compressive tests parallel to Sengon wood. In this case the loading application is implemented using load cell and hydraulic jack. The loading is carried out slowly based on a deflection rate of 1 mm per minute. The loading application is applied until the beam collapse occurs.

For deflection and strain reading, the LVDT and the TDS-650 data logger were used. In this case, the average beam collapse occurs after a loading application for 25 minutes. In this test, three LVDTs were used which were placed at three points in the middle area of the beam span.

3. Results of Testing and Discussion

3.1 Tensile and Compressive Strength of Sengon Wood

Based on Table 2. It is known that the parallel tensile strength of Sengon wood fibers in solid form is 34.3 MPa and the maximum parallel tensile strength is 0.0046. There is no yield stress and the curve tendency is linear as illustrated at figure 8. In this context, the collapse of Sengon wood is brittle and sudden.
Table 2. Result of Parallel Tensile Test for Sengon Wood

| No | Test Object Name | P (kN) | \( f_{\text{max}} \) (MPa) | \( \varepsilon_{\text{max}} \) | Trend Curva |
|----|-----------------|--------|----------------|----------------|-------------|
| 1  | TR1             | 15.6   | 35.3           | 0.00436       | Linear      |
| 2  | TR2             | 15.4   | 33.6           | 0.00464       | Linear      |
| 3  | TR3             | 15.5   | 34             | 0.00484       | Linear      |

Average: 34.3 0.00461

Figure 8. Parallel Tensile Stress Curve of Sengon Wood

Based on Table 3. It is known that the parallel compressive strength of Sengon wood fibers in solid form is 24.97 MPa and the maximum parallel compressive strain is 0.055. There is an average yield stress of 15.53 MPa at 0.0098 strain, and the trend of the curve is linear-nonlinear as seen at Figure 9. In this context, the collapse of Sengon wood is ductile and gradual.

Table 3. Result of Parallel Compressive Test for Sengon Wood

| No | Object Name | Condition | P (kN) | \( f \) (MPa) | \( \varepsilon \) | Trend Curve |
|----|-------------|-----------|--------|--------------|--------------|-------------|
| 1  | Sengon 1    | Yield     | 36.9   | 14.76        | 0.0085       | Linear - non Linear |
|    |             | Ultimate  | 63     | 25.2         | 0.0141       |             |
| 2  | Sengon 2    | Yield     | 40.9   | 16.36        | 0.0113       | Linear - non Linear |
|    |             | Ultimate  | 64     | 25.84        | 0.0191       |             |
| 3  | Sengon 3    | Yield     | 38.7   | 15.48        | 0.0096       | Linear - non Linear |
|    |             | Ultimate  | 59.7   | 23.88        | 0.0098       |             |
3.2. Flexural Strength of Sengon Laminated Beams based on Deflection Rate

Next is the test for the bending results of laminated beams with a four point bending loading system to determine the flexural strength of the beam, stress, strain and deflection and beam collapse patterns.

Based on Table 4. It is known that the flexural strength of Sengon wood laminated beams is 21.33 MPa and the maximum deflection is 47.3 mm. There is an average yield stress of 17.31 MPa at 27.61 deflection, and the trend of the curve is linear-nonlinear as Figure 10. Deflection Load Curve of Sengon Laminated Beams. In this context, block collapse is ductile and gradual.

| No. | Name Test Object | $f_{y{	ext{yield}}}$ (MPa) | $f_{max}$ (MPa) | $\delta_{yield}$ | $\delta_{max}$ | Eb (MPa) |
|-----|------------------|-----------------|----------------|---------------|---------------|----------|
| 1.  | BLS-1            | 18              | 20             | 24.98         | 32.32         | 7,534    |
| 2.  | BLS-2            | 17.53           | 24.32          | 26.09         | 43.68         | 6,913    |
| 3.  | BLS-3            | 20              | 23.19          | 28.3          | 35.76         | 6,711    |
| 4.  | BLS-4            | 20              | 30.34          | 27.68         | 70.67         | 7,582    |
| 5.  | BLS-5            | 21              | 28.8           | 30.99         | 54.22         | 7,000    |
|     | Average          | 17.31           | 21.33          | 27.61         | 47.33         | 7,148    |

Figure 9. Parallel Compressive Stress Curve of Sengon Wood

Figure 10. Deflection Load Curve of Sengon Laminated Beams
3.3 Flexural Strength of Sengon Laminated Beams based on the Strain Rate

Table 5 shows for the BL-S-2 specimen that the largest compressive stress is on the Lam-2 fiber at 21.81 MPa and the largest tensile stress is at the lowest fiber at 43 MPa. and the trend of the curve is linear - non-linear as illustrated in Figure 11. The failure pattern can be seen in Figure 12

| BEAM LAYER | $f_{b, \text{collaps}}$ | $f_{b, \text{elastic}}$ | $f_{b, \text{max}}$ |
|------------|-------------------------|-------------------------|---------------------|
| above      | -16.73                  | -20.29                  | -16.80              |
| lam-1      | -21.59                  | -16.63                  | -21.60              |
| lam-2      | -21.81                  | -12.76                  | -21.81              |
| lam-3      | -12.05                  | -5.00                   | -11.98              |
| lam-5      | 18.36                   | 12.74                   | 18.39               |
| under      | 43.00                   | 27.00                   | 43.00               |

The sign (-) indicates the compressive stress

![Strain Curve of Sengon Woods Laminated Beam BL-S-2](image_url)

**Figure 11.** Strain Curve of Sengon Woods Laminated Beam BL-S-2

![Beam Failure Pattern with four point bending system](image_url)

**Figure 12.** Beam Failure Pattern with four point bending system
4. Conclusion

From the test results it can be concluded that the load relationship - BS-L deflection consists of linear and nonlinear phases. The load performance characteristics of the two types of laminated beams are expressed as the ratio of the proportional limit load to the maximum load. The ratio value is expressed in the form $P_{BL-S} = 0.7P_{\text{max BL-S}}$ and $M_{BL-S} = 0.7M_{\text{max BL-S}}$. This form is similar to previous studies with a $P_e$ to $P_{\text{max}}$ ratio of 0.8-0.9. In this case, the average flexural strength of the resulting laminated beam is 17 MPa with a maximum strain of 0.004.

5. Suggestion

For the manufacture of composite beams it is advisable to increase the variety of wood types to obtain significant strength and more efficient materials.

Further analysis is needed regarding the manufacture of composite blocks using other waste that is more environmentally friendly at low cost and significant strength.

Reference

[1] Ahmad, Y. 2010. Bending Behavior of Timber Beams Strengthened Using Fiber Reinforced Polymer Bars and Plates. Phd. Thesis. Kuala Lumpur: Universiti Teknologi Malaysia.

[2] Awaludin, A. 2011. Research on the Physical Properties and Mechanics of Wood Glugu and Sengon in Merapi Area to Accelerate the Economic Recovery of the Merapi Community after the 2010 Merapi Eruption. Yogyakarta.

[3] Blass, HJ, P. Aune, BS Choo, R. Gorlacher, DR, Griffiths., And G. Steck, 1995. Timber Engineering Step I. Centrum Hout, The Nederland.

[4] Bourreau D., Y. Aimene, J. Beauchêne and B. Thibaut, 2013. Feasibility of Glued Laminated Timber Beams With Tropical Hardwoods. European Journal of Wood and Wood Products. Vol. 71, No. 5.p: 653-662.

[5] Breyer, DE, KJ Fridley, and KE Cobeen, 1998, Design of Wood Structures ASD. Mcgraw-Hill Inc. New York.

[6] Bustos, C., Mohammad, M., Hernandez, RE and Beauregard, R. 2003. Effects of Curing Time and End Pressure on The Tensile Strength of Finger-Joined Black Spruce Lumber. Forest Products Journal, Vol. 53, No. 11.p: 85-89.

[7] Čizmar, D, D. Damjanović, K. Pavković, and V. Rajčić, 2014. Ductility Analysis of Laminated Timber Beams of Small Section Height, Građevinar Vol. 66, No.5, p: 395-406. Doi: 10.14256 / Jce.874.2013

[8] Falk, RH, & Colling, F., 1995. Laminating Effects in Glued-Laminated Timber Beams. Journal of Structural Engineering. 121 (December): 1857–1863.

[9] Fathi, L. 2014. Structural and Mechanical Properties of The Wood From Coconut Palms, Oil Palms and Date Palms. PhD Thesis. Fakultät Für Mathematik, Informatik Und Naturwissenschaften, Universität Hamburg.

[10] Forest Products Laboratory. 2010. Wood Handbook Wood as An Engineering Material. Robert J. Ross, (Ed). Madison, WI: Department of Agriculture, Forest Service, Forest Products Laboratory.
[11] Issa, CA & Kmeid, Z. 2005. Advanced Wood Engineering: Glulam Beams. Construction and Building Materials., 19 (2005): 99-106.

[12] Krisnawati, H., Eveliina, V., Maarit, K., Markku, K. 2011. Paraserianthes Falcataria (L.) Nielsen: Ecology, Silviculture and Productivity. Bogor: Center for International Forestry Research.

[13] Luca VD, and C. Marano, 2012. Prestressed Glulam Timbers Reinforced with Steel Bars. Journal Construction and Building Materials. Vol. 30, p: 206–217

[14] Nadir Y & Nagarajan P. 2014. The Behavior of Horizontally Glued Laminated Beams Using Rubber Wood. Journal Construction and Building Materials. 55: 398 – 405.

[15] Osmannezhad, S., Faezipour, M. & Ebrahimi, G., 2014. Effects of GFRP on bending strength of glulam made of poplar (Populus deltoids) and beech (Fagus orientalis). Construction and Building Materials, 51, pp. 34–39.

[16] Raftery, GM, & Harte, AM 2011. Low-Grade Glued Laminated Timber Reinforced with FRP Plate. Composites: Part B.42 (4): 724-735.

[17] Tomasi, R., Maria, AP, & Maurizio, P. 2010. Ductile Design of Glued-Laminated Timber Beams. Practice Periodical on Structural Design and Construction. 14 (3): 113-122.

[18] Yang, TH, Song-Yung, W., Cheng-Jung, L., & Ming-Jer, T. 2008. Evaluation of The Mechanical Properties of Douglas-Fir and Japanese Cedar Lumber and Its Structural Glulam by Nondestructive Techniques. Construction and Building Materials. 22 (2008):