Comparative Study of Flexural Behavior of Bolted-Laminated and Glue-Laminated Sengon Timber Beams (*Albizia falcataria*)

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Abstract

This study aimed to study the flexural behavior of bolt-laminated and glue-laminated sengon (*Albizia falcataria*) timber beams, which are flexural strength, modulus of rupture (MoR), and beam ductility. The study was conducted using an experimental testing method in the laboratory with reference to the ASTM D198. The number of test objects were three consecutively for bolt-laminated beams and glue-laminated beams. Results obtained from this study indicated that the flexural strength of bolt-laminated and glue-laminated sengon timber beams was not significantly different; the flexural strength of bolt-laminated beams were 3.1% higher compared to glue-laminated beams. The MoR and ductility of bolt-laminated beams were 8.4% and 14.2% higher compared to glue-laminated beams. These results indicate that the glue has an impact to the brittle behavior or limited ductility, while the bolts have an impact to make a more ductile beams. The general conclusion is that mechanical laminated timber technology can be an alternative to producing beams with larger cross-sectional sizes compared to solid timber, especially for low-grade wood, so that it can be used as part of the structural elements of buildings.

Keywords: Flexural strength, beam ductility, laminated timber, sengon, ASTM D198.

Introduction

Beams, as one of the main elements of a building besides columns, functioning for withstanding loads, both gravity and lateral loads, in the form of internal forces, namely bending moments and shear forces. The beam deflection must be designed not to exceed the permitted limit so that it meets the stiffness requirements. For the case of wide span beams, a larger cross-section is required according to the needs, while on the other hand, timber, especially low grades, is difficult to obtain because trees with large diameters are limited in number.

Timber lamination technology for building components, especially for beam elements, provides several benefits. It can be solutions for making beams with dimensions and cross-sectional sizes according to demands, thus it can be used as a structural component, for example, beams and columns for building construction. Examples of lamination technology are mechanical laminated timber with bolt that function as shear restraints and chemical laminated wood with glue as an adhesive between timber laminae.

A mechanical or bolt-laminated beam system is a beam composed of two or more laminae with bolts used as a shear-resistant connecting device. By having bolts installed at a certain distance, sliding that occurs between the laminae can be prevented (Pranata *et al.*, 2011). A glue lamination beam system is a beam composed of two or more laminae bonded with glue. The function of the glue is to prevent sliding between the laminae due to the load acting on the beam.

This study aims to study the flexural behavior of bolt-laminated and glue-laminated sengon (*Albizia falcataria*) timber beams, which are flexural strength, modulus of rupture, and ductility ratio. Sengon trees are found in many tropical climates such as India, Vietnam, Thailand, Cambodia, Burma, Laos, China, and Indonesia. Sengon wood is classified as Strength Class III, with limited mechanical properties. Sengon trees are profitable in terms of production at a relatively shorter harvest period, which is around 3-6 years (Larasati, 2019; Prijono and Saputra, 2024), and as consequence, the diameter of log is also relatively small.

Researches have tried to increase the strength of sengon wood, namely by processing raw log materials into engineered wood product, for example, Laminated Veneer Lumber (LVL). Study on LVL high beams and its flexural capacity has been conducted (Putri and As'ad, 2015; Handayani, 2016; Awaludin *et al.*, 2018; Awaludin and Wusqo, 2021). Effendi and Awaludin (2022) studied the slender LVL beams, and research on LVL beams with non-prismatic cross-sections has also been conducted by Awaludin *et al.* (2019).

Further studies to form beams with a larger cross-sectional size according to needs by using glue lamination technology (chemical lamination) and bolt lamination (mechanical lamination) have been carried out. This product is used as a structural component for wide-span buildings. Beams are joined mechanically using fasteners (Fraserwood, 2024). Research on the flexural capacity, compressive capacity, and elastic modulus of sengon glue laminated wood has been conducted by Fahkri (2001), Lilis (2010), Wulandari and Ami (2022), Mutiara (2022), and Hadi and Lestari (2022). Table 1 shows the results of the flexural strength and the modulus of rupture of solid and glue laminated of sengon timbers.

Table 1. Flexural strength of sengon (*Albizia chinensis*) timber

Timber Products	References	F_b ((MPa)	MoR (MPa)
Sengon (solid)	Wicaksono *et.al.*, 2017	-	20.65
Glue-Laminated Sengon	Anshari *et.al.*, 2018	-	24.31
Glue-Laminated Sengon	Chauf, 2019	14.00	17.00

Materials and Methods

The timber studied is Sengon (*Albizia falcataria*). The behaviors studied include flexural strength, modulus of rupture (MoR), and beam ductility. Flexural strength and MoR are parameters required for design of beam strength capacity, while ductility is a parameter required for design of beam stiffness.

There are several experimental testing methods for beam flexural testing. In this study, the four point bending test method was used according to the ASTM D198-22 (ASTM, 2022) with 1500 mm clear span. The four point bending test method consists of two load points and two support points. With the concept of two load points as shown in Figure 1, empirical data of the force in the pure bending moment can be obtained in the load span section, which is an important parameter for calculating the normal bending stress.

The test specimens of glue-laminated beams and bolt-laminated wood consisted of 4 laminae 60mm x 40mm (lamina thickness is 40mm), so the beam size was 60mm x 160mm. In bolted-laminated beams, the spacing between bolts was 100mm with 10mm bolt's diameter. The function of bolts is to prevent horizontal sliding due to internal forces, namely shear forces.

The number of test objects was 3 (three) for bolt-laminated beams and 3 (three) for glue-laminated beams. All test objects were made in dry conditions (moisture content ranging from 12% to 16%). The flexural strength referred to in this research is the flexural stress calculated under proportional load condition (F_b), while the MoR is the flexural stress calculated under ultimate or peak load.

Flexural Tests

Flexural testing for all specimens are carried out using a Universal Testing Machine (UTM) HT-9501 Electro-Hydraulic Servo (maximum load capacity 1000 kN) with output data in the form of a history curve of the relationship between flexural load and mid-span of beam deformation. Figure 1 shows the test equipment that used in the research.
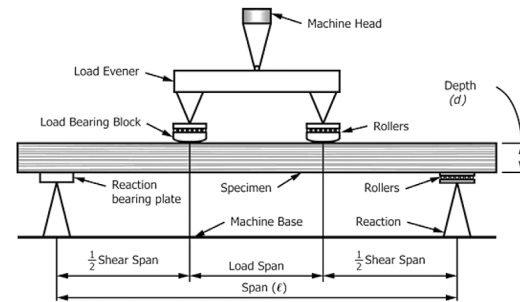

Figure 1. The flexural test in accordance with ASTM D198-22 (ASTM, 2022)

The general equation of normal (flexural) stress (Hibbeler, 2023) can be solved using Equation 1a.

$$\sigma = \frac{M.y}{I_x} \qquad (1.a)$$

$$I_x = \frac{1}{12}b.d^3 \qquad (1.b)$$

Flexural stress is calculated using Equation 2 (Goodno and Gere, 2021). Flexural strength is one of a material properties of a beam, which is the stress that occurs in a material before it yields in a flexural test using destructive method. In term of yield or proportional point,

$$F_b = \sigma \qquad (2)$$

$$M = P_y.a \qquad (3)$$

where σ is normal (flexural) stress, F_b is flexural strength (MPa), M is moment at yield point (N.mm), P_y is yield point (N), a is length of ½ shear span (meter) or 500mm in this research (see Figure 1), y is distance from surface area of cross-section to center of cross-section (meter), I_x is the cross-section moment of inertia (m^4), b is the beam width (mm), and d is the beam thickness (mm).
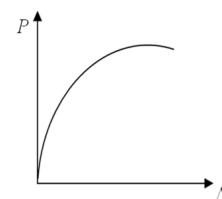

Figure 2. Flexural Load vs Mid-span deformation curve.

Figure 2 shows a schematic history of the flexural load vs mid-span of beam deformation relationship curve obtained from experimental test results. Modulus of Rupture (MoR) is a material property, defined as the stress in a material just in term of ultimate or peak load in a destructive method which is flexure test. MoR represents the ultimate stress experienced within the material at its moment of collapse of specimen.

$$MoR = \frac{M_{ult}.y}{I_x} \qquad (4)$$

where MoR is modulus of rupture and M_{ult} is moment at ultimate point (N.m).

Determining The Proportional or Yield Load

In this study, the determination of proportional or yield load uses the reference of SIA 265 Code (SIA, 2003). This is because most of beam members are not able to develop mechanisms of full plastic at failure.

In this study, the definitions of ductility ratio, as a ratio between an ultimate or peak deformation divided by yield or proportional deformation (Jorissen and Massimo, 2011), as shown in Figure 3. The ductility ratio (μ) of beam can be calculated using Equation 5.

$$\mu = \frac{\Delta_u}{\Delta_y} \tag{5}$$

where Δ_y is the displacement in term of proportional or yield load and Δ_u is the displacement in term of ultimate or peak load.
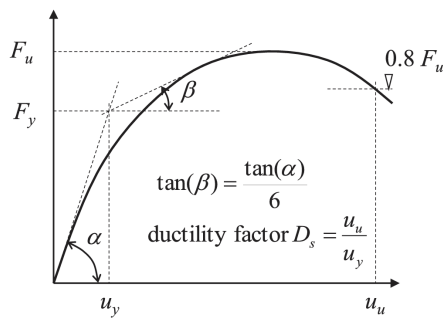

Figure 3. Determining the yield or proportional deformation (uy) according to SIA 265 (SIA, 2003).

Results and Discussion

Figure 4 shows the bending test of a bolt-laminated beams in the laboratory. The specimen has a rectangular cross-section with a width of 60 mm (b) and a height of 160 mm (d), not included in the slender category, so that in testing up to the ultimate or peak load, no buckling and no horizontal deformation occured in the middle of the span. The test results, namely the beam failure pattern, are shown in Figure 5 for the bolt-laminated beam specimens and Figure 6 for the glue-laminated beam specimens.

Figure 4. Flexural testing of specimens according to ASTM D198-22 (ASTM, 2022)

Figure 5. Bolt-laminated specimens after flexural tests

Figure 6. Glue-laminated specimens after flexural tests

The test results of all laminated-bolted beams generally consist of simple tension failures that occur in laminates that experience tensile stress. Meanwhile, for the glue-laminated beam test specimens, the failures that occurred were simple tension on first specimen and in the glue part on second and third specimens.

Figure 7 shows the test results of the bending load vs deflection curve of the glue-laminated beams. While Figure 8 shows the test results of the bending load vs deflection curve of the bolt-laminated beams. However, bolt-laminated beams has a smaller stiffness than glue-laminated beams, but exhibits more ductile behavior.
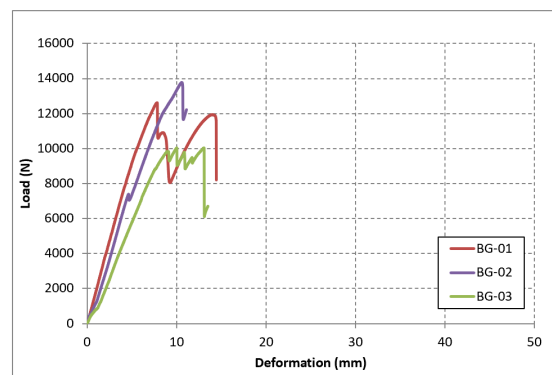

Figure 7. Flexural load vs mid-span of beam deformation curve obtained from glue-laminated timber specimens
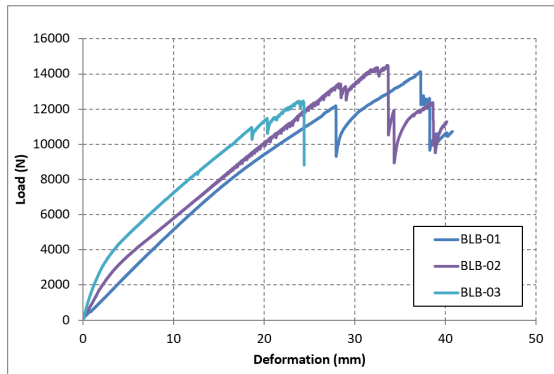
Figure 8. Flexural Load vs Mid-span of beam Deformation Curve obtained from bolt-laminated timber specimens

Table 2. Tests results: Load, Deformation, and Ductility ratio of bolt-laminated timber beams (BLB).

Spec.	P_y (kN)	Δ_y (mm)	P_u (kN)	Δ_u (mm)	μ
BLB-01	10.87	18.43	12.28	24.32	1.32
BLB-02	12.33	25.97	14.32	33.58	1.29
BLB-03	12.19	27.30	14.12	37.24	1.36
Mean	11.80	23.90	13.57	31.71	1.33

Table 3. Tests results: Load, Deformation, and Ductility ratio of glue-laminated timber beams (BG).

Spec.	P_y (kN)	Δ_y (mm)	P_u (kN)	Δ_u (mm)	μ
BG-01	11.78	6.96	12.59	7.83	1.13
BG-02	13.12	9.82	13.75	10.64	1.08
BG-03	9.40	8.33	10.04	10.03	1.20
Mean	11.43	8.37	12.13	9.50	1.14

Table 2 and Table 3 shows the calculation results, namely load at proportional limit conditions (P_y), load at ultimate limit or pak conditions (P_{ult}), deformation at proportional conditions (Δ_y), deformation at peak conditions (Δ_u), and ductility ratio (μ) which was calculated using Equation 5.

Table 4. Results of Flexural Strength and Modulus of Rupture of bolt-laminated timber beams.

Specimen	M_y (kN.m)	F_b (MPa)	M_{ult} (kN.m)	MoR (MPa)
BLB-01	2.72	10.62	3.07	11.99
BLB-02	3.08	12.04	3.58	13.99
BLB-03	3.05	11.90	3.53	13.79
Mean	2.95	11.52	3.39	13.26

Table 5. Results of Flexural Strength and Modulus of Rupture of glue-laminated timber beams.

Specimen	M_y (kN.m)	F_b (MPa)	M_{ult} (kN.m)	MoR (MPa)
BG-01	2.94	11.50	3.15	12.30
BG-02	3.28	12.81	3.44	13.43
BG-03	2.35	9.18	2.51	9.80
Mean	2.86	11.16	3.03	11.84

Table 4 and Table 5 shows the results of the calculation of flexural strength (F_b) which was calculated using Equation 2 and the modulus of rupture (MoR) which was calculated using Equation 4. Proportional limit or yield load (P_y) is the condition when a change occurs from an elastic to an inelastic condition.

The calculation results of ductility ratio (μ) as shows in Table 2 and Table 3 indicated that bolts as mechanical connection devices, namely horizontal shear restraints on laminated beams, provide an impact, namely more ductile behavior than laminated beams bonded with glue. Glue is, however, a brittle material.

Laminated-bolt beams have a flexural strength (F_b) of 11.52 MPa or 17.71% lower than solid beams (Chauf, 2019), while laminated-glued beams have a flexural strength of 11.16 MPa or 20.28% lower than solid beams. This is the impact of the influence of slip between laminae when the load acts on the beam. However, the laminated cross-section will not be the same as the solid cross-section.

Conclusions

Results obtained from this study indicated that the flexural strength of bolt-laminated and glue-laminated Sengon (*Albizia falcataria*) timber beams is not significantly different. The results of the study were that the flexural strength of bolt-laminated beams were 3.1% higher compared to the flexural strength of glue-laminated beams.

The modulus of rupture of bolt-laminated beams were 8.4% higher compared to the modulus of rupture of glue-laminated beams. The ductility of bolt-laminated beams were 14.2% higher compared to glue-laminated beams. These results indicate that the glue has an impact, namely the beam has brittle behavior or limited ductility, while the bolts have an impact, namely the beam behaves more ductile.

The general conclusion is that mechanical laminated timber technology can be an alternative to produce beams with larger cross-sectional sizes compared to solid timber, especially for low-grade wood, so that it can be used as part of the structural elements of buildings.

Acknowledgements

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