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Elastic Cross-Section Modulus Ratio of Jabon (Anthocephalus cadamba Miq.) Bolt-Laminated Timber Beams

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Abstract. The strength and stiffness of the beams are related to the elastic cross-section modulus of the beam, which are related to the cross-section moment of inertia. The elastic cross-section modulus of mechanically laminated (bolt-laminated) timber beams are not the same as solid timber beam for the beam with the same cross-section, this can be happened due to the inertia moment of cross-section of the bolt-laminated beam is lower than the solid beam due to slip between laminae and the elastic modulus of every lamina are varying. The aim of this research was to study the elastic cross-section modulus of mechanically laminated timber using bolts as a shear connectors. The scope of the study are the beam specimens made from Jabon timber (Anthocephalus cadamba Miq.) 60 mm x 160 mm cross-section size, three beam specimens with 1500 mm clear-span length, four lamina layers, lamination system using bolt as a shear connectors to reduce slip between laminae, flexural testing using the four-point loading test method according to the ASTM D198, the flexural behavior reviewed in this research are the flexural strength, the elastic cross-section modulus ratio, and the displacement ductility ratio. The bending strength of bolt-laminated timber beams obtained from an experimental test is 12.11 MPa (average) in the term of proportional limit load, while the bending strength of a solid timber beam is 37.96 MPa. The results showed that the elastic cross-section modulus and the flexural stress of the bolt-laminated timber beams were lower with a ratio of 0.32 than the solid timber beam, and the ductility ratio of the bolt-laminated timber beams was 1.18 so that they were categorized in the limited ductility criteria. The test results indicate that the failure of bolt-laminated Jabon timber beams are a failure of bending. The elastic modulus cross-section parameters of laminated timber beams are useful for the design of beam structure components in buildings, especially in the calculation of beam strength and beam stiffness as a serviceability requirement.

1. Introduction

Laminated timber, especially mechanically, has been widely applied to bridge structures and agricultural support building structures for a long time in America. The concept of mechanical lamination is that the wooden laminates are connected to a bolt joint, which acts as a shear barrier so that the slip that occurs between the laminates due to working loads can be prevented. The laminate system is one of the engineered wood solutions amidst the limited production of large diameter whole wood from forests. Mechanical laminated wood elements are structural components composed of horizontal or vertical laminates, which are mechanically joined using nails, screws, or bolts [1]. The bonding behavior between the laminae occurs as a result of the horizontal slip between the laminae being prevented and restrained by the sliding linkage device at certain intervals with the mechanical coupling.

The aim of this research was to study the elastic cross-section modulus of mechanically laminated timber using bolts as a connectors. The scope of the study are the beam specimens made from Jabon timber (Anthocephalus cadamba Miq.) 60 mm x160 mm cross-section size, three beam specimens with 1500 mm clear-span length, four lamina layers, lamination system using bolt diameter 10 mm as a shear-connectors, flexural testing using the four-point loading test method according to the ASTM D198 [2], the flexural behavior reviewed in this research are the flexural strength, the elastic cross-section modulus ratio, and the displacement ductility ratio.

This study is a continuation of previous research conducted by Pranata et.al. [3], namely the ratio of the elastic section modulus of mechanical laminated wood beams with mechanical joining devices. The research studied beams made from Acacia Mangium, Keruing, Meranti Merah, Mersawa, Nyatoh, and Durian timbers. Results obtained from previous research indicated that the elastic cross-section modulus ratio were ranged from 0.38-0.91. In general, the parameters of specific gravity, bolt diameter, and the ratio of the number of rows per bolt distance contribute to the elastic section modulus ratio of laminated beam-bolts.

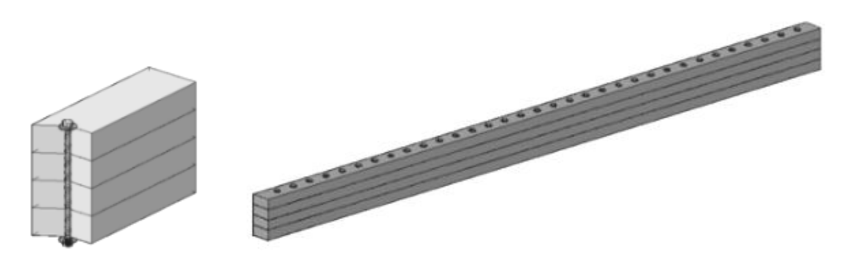

Figure 1. Schematic of bolt-laminated timber beams [4]

The research methodology is testing the test object experimentally in the laboratory. The study consisted of four stages, the first stage was a literature study on timber elastic modulus, timber flexural rigidity, and mechanical laminated timber. The second stage is the manufacture of mechanical laminated timber beam specimens using a bolt connection tool. The third stage is experimental testing in the laboratory. The fourth stage is a study to process the flexural capacity curve data, namely the load vs displacement relationship curve for the calculation of flexural rigidity, flexural strength, and displacement ductility ratio of mechanical laminated beams related to solid beams.

2. Basic Theory

2.1. Jabon Timber (Anthocephalus cadamba Miq.)

The Jabon tree (Anthocephalus cadamba Miq.) grows on various islands in Indonesia and is included in the strength-class III-IV category with a bending strength of 37.96 MPa, a modulus of rupture 67.79 MPa, and a modulus of elasticity of 6670.80 MPa. Jabon timber is included in the moderate class category of durability. Durability of timber as a building component against wood termite attacks, Jabon timber is included in the class II category, then resistance to wood rot fungus is included in the class IV-V category [5].

2.2. Elastic Section Modulus

The Elastic Section Modulus (S) in the elastic limit load range can be calculated by Equation 1 [6], which is based on the effect of the moment of inertia parameter of the cross section (I) and the distance from the outer edge fibre to the centre of gravity (y),

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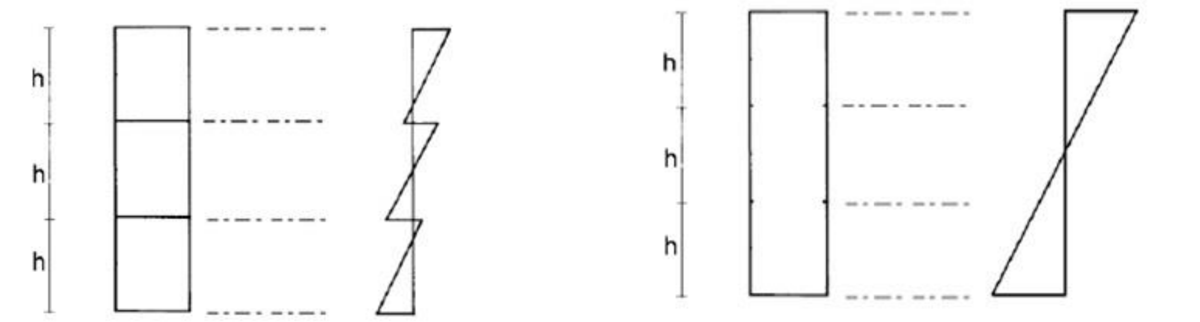
$$S = \frac{I}{y} \tag{1}$$

In the context of a mechanical laminated beam, the elastic section modulus is lower than that of a solid beam, the ratio can be calculated using Equation 2 and Equation 3 as follows,

$$S_{eff} = k_S \, . S \tag{2}$$

$$f_{B\text{-}lam} = \frac{M}{S_{eff}} \tag{3}$$

where M is the bending moment, Seff is the effective elastic modulus of the bolted laminated beam, kS is the ratio of the elastic section modulus of the laminated beam to the solid beam, and fB-lam is the flexural strength of the laminated beam [3].



(a). Horizontally laminated beam (pranata et.al., 2012).

(b). Solid beam (Pranata et.al., 2020).

Figure 2. Cross-section of beam.

2.3. Deformation of Beam

The modulus of elasticity is the proportional slope of the linear line of the load and deformation curve (range of elastic load), in this context the bending load on the beam and deformation is the deflection of the beam due to the load acting. For a simple beam condition with a load of two centred on each distance as far as a from each support, the deformation relationship to the load is expressed in Equation 4 [6].

$$\delta = \frac{P.a}{24EI}\left(3L^2 - 4a^2\right) \tag{4}$$

With δ is deformation of beam due to flexural, P is concentrated load, L is length of beam span, E is modulus of elasticity (which is MoE parallel to the grain), and is the cross section moment of inertia. With the presence of more than one number of laminae, there is an interaction or slip between the laminates, because the compatibility of the strain mechanism between the bolt as a mechanical joint and lamina timber does not work perfectly and there is a partial interaction between the laminates, so that the bending behavior of the laminated beams is not the same as the solid beam (Figure 2.a and Figure 2.b). Equation 5 is the development of Equation 1 in the context of calculating the deformation of mechanical laminated beams, with the magnitude of the flexural rigidity of

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laminated beams being lower than those of solid beam, which is in the form of parameters for the flexural rigidity ratio of mechanical laminated beams (laminate-bolt) or k_{EI}.

$$\delta = \frac{P_{lam} a}{24(k_{EI}.E.I)}(3L^2 - 4a^2) \quad (5)$$

2.4. Method to Determine Proportional Point

The flexural capacity of timber beams is obtained from the results of experimental testing in the laboratory in the form of a bending load versus beam deformation curve. To obtain information on changes in the condition of the beam material from elastic to post-elastic, it is necessary to know the location of the proportional point. There are several methods to determine the proportional point of the previous research by Munoz et al. [7] One method of determining the proportional point is the Yasumura and Kawai method, with the basic principle that initial stiffness is calculated at conditions 0.1, 0.4, and 0.9 peak points (PU). The condition of the elastic material is determined by the intersection of two linear lines, namely the meeting point formed between the 0.1-0.4PU lines and the 0.4PU and 0.9PU lines. The meeting point is then shifted parallel to coincide with the load vs deformation curve of the experimental test results.

3. Experimental Tests and Discussion

In this study, a mechanical laminated timber beams were tested with a mechanical connectors, namely a 100 mm diameter bolts. Timber beams made of Jabon timber (Anthocephalus cadamba Miq.). The timber lamina has a cross-sectional size of 60 mm x 40 mm, the lamination system used is horizontal with 4 (four) laminae, so that the beam's final cross-section size is 60 mm x 160 mm. The distance between the bolts (spacing) is 100 mm.

Figure 3. Flexural test of the beam specimen using Universal Testing Machine.

Figure 3 show the testing process for one specimen of laminated timber beams. The test method is the four-point loading test with a distance of 500 mm (1/3 beam span). Furthermore, Figure 4 show the variety of beam failures that occur in the test object, namely simple tension, this is in accordance with one of the flexural test object failure models based on ASTM D143 [2] so that the expected failure occurs in accordance with the test results.

Figure 4. Failure type of the beam for all beams specimens which are simple tension.

Figure 5 show a curve diagram of the load versus beam deformation relationship. The test results of all specimens show almost the same curve trend, the maximum deformation ranges from 24.32 mm to 37.27 mm, while the maximum load ranges from 12.28 kN to 14.13 kN. Figure 6 show an example of calculating the proportional point (proportional load) and the ultimate point (ultimate load). The complete calculation results are shown in Table 1. The results of Table 1 show that the average beam turnover ductility ratio is 1.18. The average proportional limit load is 12.40 kN, the ultimate limit load is 13.58 kN. Furthermore, using Equation 3, the flexural rigidity ratio of laminated beams is calculated. The complete calculation results are shown in Table 2. Calculation of the elastic section modulus and bending stress is carried out using Equation 2 and Equation 3.

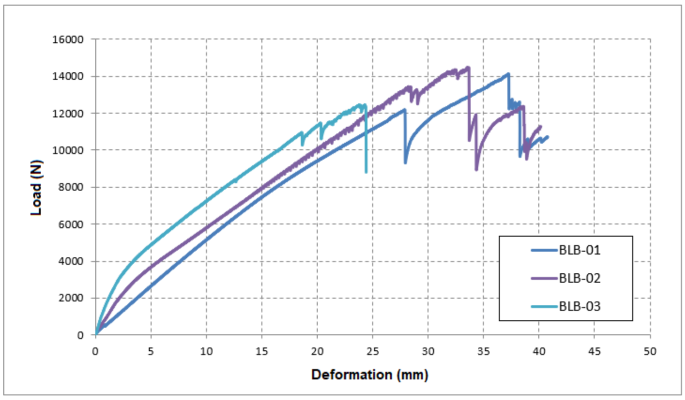

Figure 5. Load vs Deformation curves of the bolt-laminated timber beams.

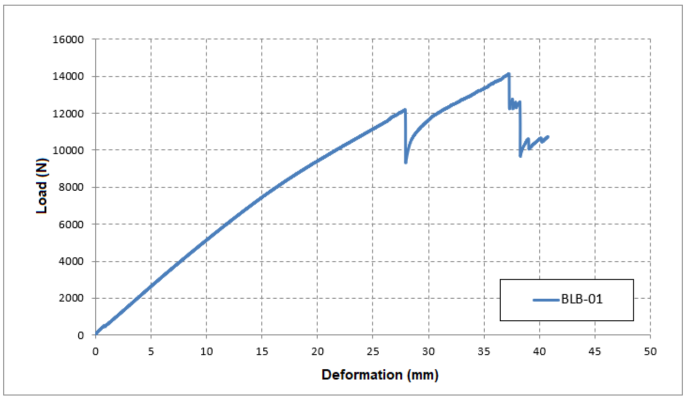

Figure 6. Calculation of proportional and ultimate points for specimen BLB-01.

Table 1. Proportional point, ultimate point, deformation at proportional point, deformation at ultimate point, and displacement-ductility results.

Specimen	P_y (N)	d_y (mm)	P_u (N)	d_u (mm)	μ
BLB-01	12001.91	23.83	12280.28	24.32	1.02
BLB-02	13074.70	28.46	14330.85	33.58	1.18
BLB-03	12137.70	27.78	14127.15	37.27	1.34
Average	12404.77	26.69	13579.43	31.72	1.18

Table 2. Results of flexural rigidity ratio of bolt-laminated timber beams.

Specimen	M_y (kN.mm)	$f_{b\text{-}lam}$ (MPa)	f_b (MPa)	k_S
BLB-01	3000.478	11.72	37.96	0.31
BLB-02	3268.675	12.77	37.96	0.34
BLB-03	3034.425	11.85	37.96	0.31
Average	3101.193	12.11	37.96	0.32

The bending strength of bolt-laminated timber beams obtained from an experimental test is 12.11 MPa (average) in the term of proportional limit load, while the bending strength of a solid timber beam is 37.96 MPa (secondary data from Atlas elastic cross-section modulus, timber, beam, bolt-laminated, Jabon Indonesia). The results showed that the elastic cross-section modulus and the flexural stress of the bolt-laminated timber beams were lower with a ratio of 0.32 than the solid timber beam, and the ductility ratio of the bolt-laminated timber beams was 1.18 so that they were categorized in the limited ductility criteria. The test results indicate that the failure of bolt-laminated Jabon timber beams are a failure of bending. The elastic modulus cross-section parameters of laminated timber beams are useful for the design of beam structure components in buildings, especially in the calculation of beam strength and beam stiffness as a serviceability requirement.

4. Conclusion
The load-deflection curve of bolt-laminated timber beams shows a bilinear trend. The presence of a bolt gives the beam a ductile impact. Changes in the behavior of beams from elastic to plastic

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conditions are due to the effective stress that occurs in some parts of the timber material that has exceeded the yield limit criteria. When the proportional limit load is reached, the bolt has not yielded, so that after the beam has post-elastic behavior the bolt still functions as a shear transfer between laminae, likewise the normal stress that occurs on each of the outer edge fibres has not exceeded the ultimate limit criteria so that the beam is still capable, endure the bending moment. The failure behavior of bolted-laminated timber beam occurs due to bending failure.

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