WOOD RESEARCH doi.org/10.37763/wr.1336-4561/69.4.721729
e-ISSN 2729-8906
69(4): 2024 721-729 pp.

Short notes

EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOR OF RED MERANTI (*SHOREA SPP.*) GLULAM BEAM OF VARIOUS NUMBER OF LAMINAE

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(RECEIVED OCTOBER 2024)

ABSTRACT

This research aims to study flexural behavior of Red Meranti (*Shorea spp.*) glulam beam of various number of laminae by carrying out testing beams made from four, six, and eight laminae. Four points bending test method according to ASTM 198-22 was applied. The research results show that glulam composed of a smaller number of laminas reaches a smaller flexural rigidity. The empirical equations for flexural strength ratio and modulus of rupture ratio, and the trend of flexural rigidity between glulam and solid proposed in this study can be used in designing the flexural members of timber buildings, timber bridges, and in calculating the deflection of timber beams.

KEYWORDS: Flexural rigidity, flexural strength, modulus of rupture, glulam, red meranti.

INTRODUCTION

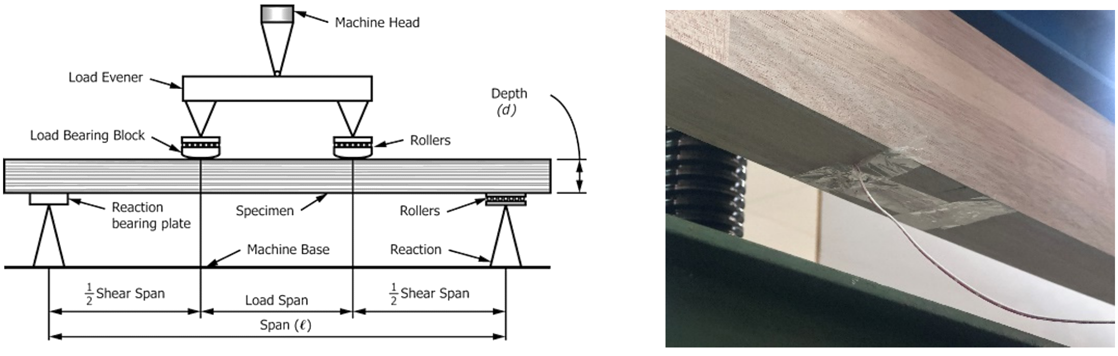
Several previous studies dedicated to establishing mechanical properties, especially flexural strength and modulus of rupture, of various wood species have been carried out, including research to study the flexural behavior of solid red Meranti wood (*Shorea spp.*) by Noh and Ahmad (2017). The flexural strength, modulus of rupture, and the flexural modulus of elasticity obtained experimentally in the study were 23.06 MPa, 56.87 MPa, and 9160.00 MPa, respectively. Baharin et al. (2020) measured the flexural strength, the modulus of rupture, and the flexural modulus of elasticity of solid red Meranti wood at 31.83 MPa, 52.23 MPa, and 12790.55 MPa, respectively. Dayadi (2022) resulted in the modulus of rupture and the flexural modulus of elasticity of solid red Meranti wood of 76.24 MPa and 9801.36 MPa, respectively. Lee et al. (2024) obtained the modulus of rupture and flexural modulus of elasticity of red Meranti wood of 81.08 MPa and 12169.00 MPa, respectively.

Study of flexural behavior of glulam beams have also been carried out. Research on the effect of lamina thickness on the flexural strength and flexural modulus of elasticity of glulam beams was carried out by Pulngern et al. (2020). The results indicated that the lamina thickness had little effect on flexural performance of Douglas fir glulam beam.

The objective of this research is to study the flexural behavior of glulam beams made of red meranti (*Shorea spp.*). Experimental tests of such beams were performed to obtain empirical equations, namely flexural strength ratio, modulus of rupture ratio, and flexural rigidity. The term ratio herein means the ratio between the property of glulam and the property of solid beam. The scope of this research are as follows. Glulam beams are made from four laminae (90 mm x 164 mm), six laminae (90 mm x 246 mm), and eight laminae (90 mm x 328 mm), each consisting of 3 test specimens. The thickness of each lamina is 41 mm. Flexural testing uses the four points bending test according to ASTM 198-22 (2022a). Flexural rigidity (EI), flexural strength (F_b) in terms of proportional or yield load, and the modulus of rupture (MoR) were studied.

MATERIAL AND METHODS

Glulam meranti products were produced by Woodlam Indonesia. In this research, the four points bending test method was used, referring to ASTM D198: 2022 (Fig. 1). A similar test method based on the EN 408 was used in previous research to study the flexural strength and the modulus of elasticity of wood by Herda et al. (2024).



a) b)

Fig. 1: a) A schematic of the bending test according to ASTM D198: 2022, b) strain gauge placed at tension surface.

Destructive experimental testing of glulam beams has been conducted with a total of 9 test specimens with total length 2000 mm and clear span 1600 mm. Tab. 1 shows the test specifications and the number of test specimens. Destructive tests were performed using Electro-hydraulic servo universal testing machine HT-9501 with maximum load capacity of

1000 kN (Hung Ta 2008). The relationship between the load obtained from the machine head and mid-span deflection of the beam were obtained for each test specimen.

Tab. 1: Specimens identity.

N^o	Specimen ID	b (mm)	d (mm)	Number of laminae
1	BGM.90.126.1	90	164	4
2	BGM.90.126.2			
3	BGM.90.126.3			
4	BGM.90.210.1		246	6
5	BGM.90.210.2			
6	BGM.90.210.3			
7	BGM.90.294.1		328	8
8	BGM.90.294.2			
9	BGM.90.294.3			

Determining the yield point

To calculate the flexural strength, the proportional or the yield point must be determined. This point indicates when plastic deformation begins. To obtain the yield point, the Yasumura and Kawai method (Munoz 2010) was used. The first step is to calculate the initial stiffness (straight line) between 10% and 40% of the maximum load that can be obtained from the load-displacement (P-Δ) curve from the experimental tests. The second step is to connect two points with 40% and 90% of the maximum load. The third step is to calculate a tangent-line to the load-displacement curve, parallel to the 40%-90% line generated in the second step. This last line represents the post-elastic condition. The intersection between the 40%-90% line with the tangent-line was projected horizontally towards the load-displacement curve to obtain the point called yield or proportional load and displacement. This method was used to calculate the yield load (P_y) and the P-Δ curves are results of experimental tests (Pranata and Suryoatmono 2013).

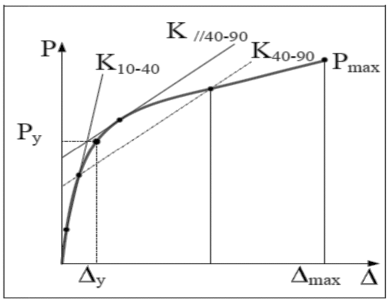


Fig. 2: Yasumura and Kawai yield point method (Munoz 2010).

Polynomial regression analysis

An assumed relationship between a response, which is dependent variable, and an input variable (in term of independent variable) implies a constant rate of change. The straight-line model involving one independent variable is the second-order polynomial or quadratic model (Rawlings et.al. 2013). The quadratic model includes the term x^2 in addition to x. This model is a case of the multiple regression model where $x_1 = x$ and $x_2 = x^2$:

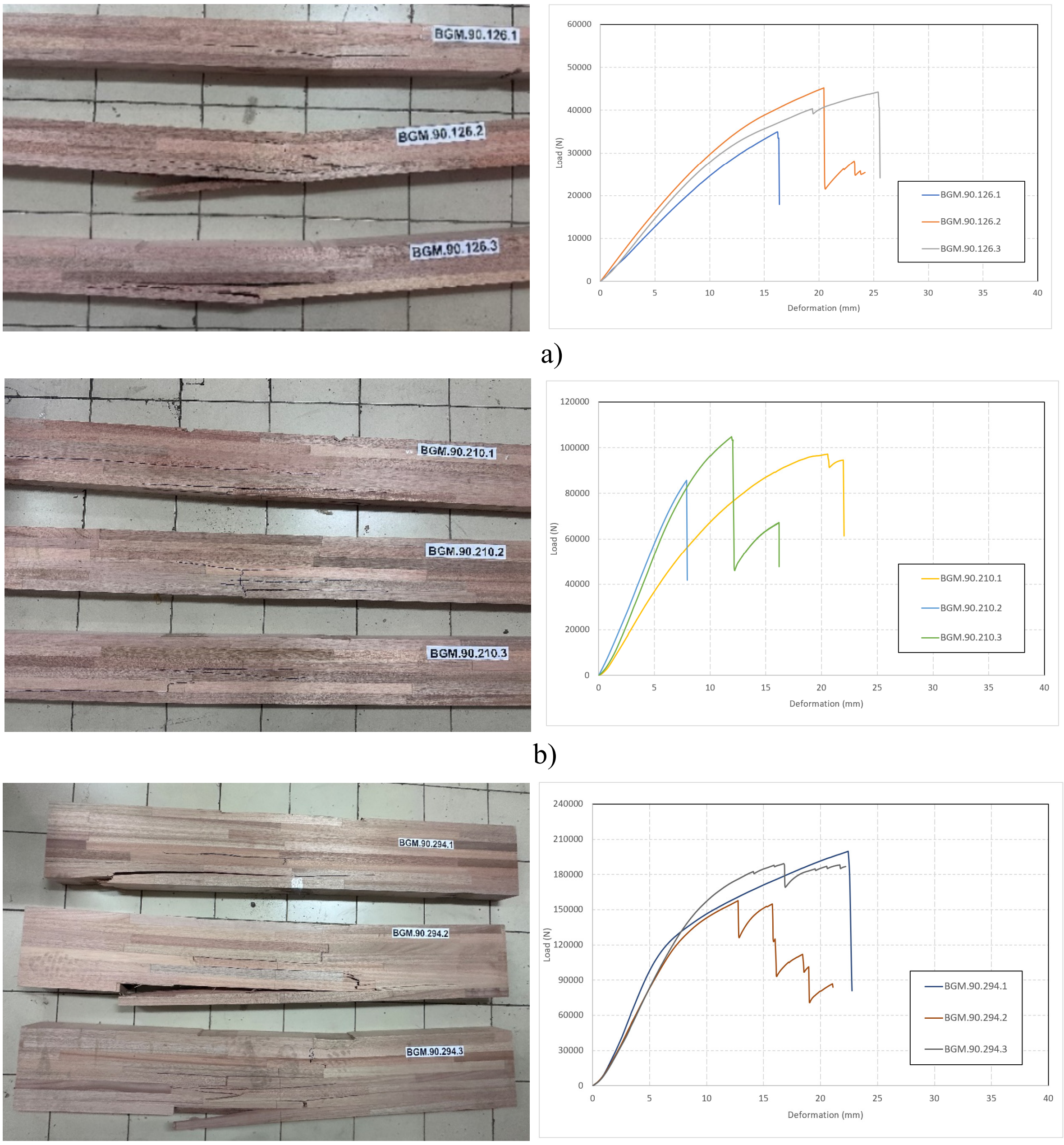
$$\varepsilon_{(Y)} = \beta_0 + \beta_1 . x + \beta_1 . x^2 \qquad \text{quadratic model} \qquad (1)$$

$$\varepsilon_{(Y)} = \beta_0 + \beta_1.x + \beta_1.x^2 + ... + \beta_p.x^p \qquad \text{polynomial model} \qquad (2)$$

Higher order polynomials in Eq. 2 allow increasing flexibility of the response relationship and are cases of the multiple regression models.

RESULTS AND DISCUSSION

Fig. 3 shows the destructive experimental testing of glulam beams using four points bending test method. The tests were displacement controlled with a constant displacement speed of 2.5 mm/min. This was in accordance with ASTM D198-22 (2022a).



a)

b)

c)

Fig. 3: The failure mode and load versus deformation relationship curve of four (a), six (b) and eight (c) laminae glulam beams.

The result of flexural strength as shown in Tab. 2 is calculated using flexure formula in beam theory (Hibbeler 2023). The flexural strength of solid wood is obtained from previous research (Baharin et.al. 2020). The modulus of rupture of solid wood is obtained from previous research as well (Lee et al. 2024). The flexural rigidity ratio is calculated using beam deflection theory (Goodno and Gere 2021). The presence of adhesive in glulam beams causes less ductile behavior compared to solid beams. This is proven by the results of the study. As seen in Tab. 2, the average displacement ductility (μ) of the tested glulam beams are quite small, namely 1.29 (glulam with four laminae), 1.16 (glulam with six laminae), and 1.56 (glulam with eight laminae). Note that one glulam specimen with eight laminae had ductility of 2.15, a value of which was much higher than the other two specimens. Therefore, if this specimen is considered as outlier, the average ductility of the other two specimens is 1.26. On the other hand, the average displacement ductility of Red Meranti solid beams is 1.56 (Pranata et al. 2011).

Tab. 2: Results of flexural strength (F_b) and modulus of rupture (MoR) of glulam beams.

Specimen	P_y (N)	P_{ult} (N)	D_y (mm)	D_{ult} (mm)	μ (mm/mm)	F_b (MPa)	MoR (MPa)
Four laminae							
BGM.90.126.1	31994.76	34959.32	15.54	16.22	1.23	36.95	40.37
BGM.90.126.2	40023.16	45183.17	15.43	20.45	1.33	46.22	52.18
BGM.90.126.3	40333.68	44196.06	19.43	25.48	1.31	46.58	51.04
Average	37450.53	41446.18	16.80	20.72	1.29	43.25	47.86
Six laminae							
BGM.90.210.1	93214.86	97131.20	17.72	20.50	1.16	38.75	40.38
BGM.90.210.2	76032.61	85613.67	7.10	8.19	1.15	31.61	35.59
BGM.90.210.3	98602.62	104762.84	10.14	11.95	1.18	40.99	43.55
Average	89283.36	95835.90	11.65	13.55	1.16	37.12	39.84
Eight laminae							
BGM.90.294.1	146595.82	199839.92	10.43	22.39	2.15	31.09	42.39
BGM.90.294.2	143954.00	157765.81	10.30	12.76	1.24	30.53	33.46
BGM.90.294.3	177334.83	189117.58	12.86	16.73	1.30	37.61	40.11
Average	155961.55	182241.10	11.20	17.29	1.56	33.08	38.65

P_v is the proportional or yield load calculated using Yasumura and Kawai method, P_{ult} is the ultimate load, D_v is the deformation at proportional or yield point, and D_{ult} is the deformation at ultimate point, μ is displacement ductility (D_u/D_y).

The glulam-to-solid ratios of F_b and MoR obtained in this study (Tab. 3) show that for beams with the same cross-sectional size made of more laminae have glulam-to-solid ratios of both F_b and MoR. This should be the case because for same cross-sectional size the more laminae glulam has, the less structural integrity it has, and therefore F_b and MoR are lower.

Tab. 3: Results of glulam-to-solid ratios of flexural strength and modulus of rupture.

Specimen	F_b (MPa)	Ratio of F_b (glulam-to-solid ratio)	MoR (MPa)	Ratio of MoR (glulam-to-solid ratio)
Solid	55.08	-	81.08	-
Glulam with four laminae	43.25	0.79	47.86	0.59
Glulam with six laminae	37.12	0.67	39.84	0.49
Glulam with eight laminae	33.08	0.60	38.65	0.48

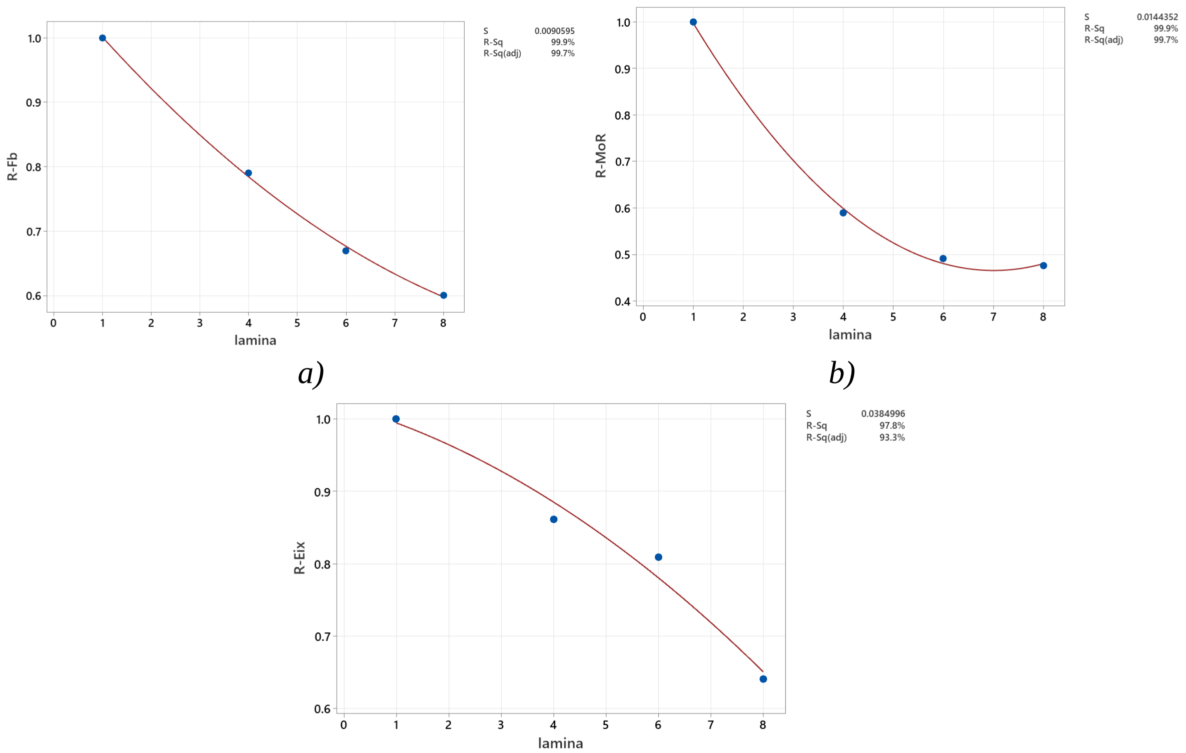
Regarding the glulam-to-solid ratio of flexural rigidity (EI), Tab. 4, shows that for glulam beam of the same cross-sectional size with more laminae, the ratio is lower. This should be the case because glulam with more laminae has more possibility of experiencing post-elastic behavior and slip in the adhesive layers and por.

Tab. 4: Results of flexural rigidity of glulam beams.

Specimen	b (mm)	d (mm)	EI_x (solid)	EI_x (glulam)	Ratio of EI_x (glulam-to-solid)
Glulam with four laminae	90	164	403005898560	347265677707.51	0.86
Glulam with six laminae	90	246	1360144907640	1100171788734.74	0.81
Glulam with eight laminae	90	328	3224047188480	2065306548358.89	0.64

Furthermore, by using polynomial regression analysis, an empirical equation can be prepared to obtain a prediction of the ratio of flexural strength (rF_b) of glulam-to-solid with the number of lamina parameters as shown in Fig. 4a as follows:

$$rF_b = 1.088 + 0.0906.n + 0.00367.n^2 \qquad R_{\text{-}square} = 99{,}9\% \qquad (3)$$



a) *b)*

c)

Fig. 4: Ratio of the flexural strength (a), modulus of rupture (b), and flexural rigidity (c) between glulam and solid.

In the same way, an empirical equation for the modulus of rupture ratio (*rMoR*) can be prepared as shown in Fig. 4b as follows:

$$rMoR = 1.19 + 0.207.n + 0.0148.n^2 \qquad R_{\text{-}square} = 99{,}8\% \qquad (4)$$

Eqs. 3-4 can be used in design of the flexural structural components of timber buildings, timber bridges, and calculating the stiffness (deflection) of timber beams. Results obtained from Tab. 4 and Fig. 4c indicate that the flexural rigidity EI of glulam beams are not the same as solid beam. Glulam beams with smaller number of laminae produce larger glulam-to-solid ratios of flexural rigidity because they behave closer to those of solid beams.

CONCLUSIONS

The research results show that red Meranti (*Shorea spp.*) glulam beams with smaller number of laminae produces larger glulam-to-solid ratios of flexural rigidity, flexural strength and modulus of rupture. This is because the glulam beam with the smaller number of laminae is closer to the beam with solid cross-section. The proposed empirical equations for glulam-to-solid ratios of flexural strength, ratios of modulus of rupture, and flexural rigidity can be used in design of the flexural structural components of timber buildings, timber bridges, and calculating the stiffness (deflection) of timber beams. If the flexural strength of the solid beam made of Red Meranti is known, the flexural strength of the glulam beam made of Red Meranti of the same dimension (width and depth) with certain number of laminae can be estimated using the proposed equation. The other proposed equation can be used to estimate modulus of rupture of the glulam beam made of Red Meranti in a similar way.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support from Universitas Kristen Maranatha (Research: collaboration schemes with domestic partners, Fiscal Year 2022). The authors also gratefully acknowledge the support from Woodlam Indonesia and all staffs and technicians of Structures and Concrete Laboratory of Universitas Kristen Maranatha for facilitating successful experimental tests results.

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