Optimum Lamina Configuration of I Glulam Beam

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Abstract

The I glulam beam may have several failure modes, such as failure in bending, wood shear, glue shear or adhesive between glue and wood. This paper presented the analitycal and experimental study of the optimum lamina configuration and dimension. The analytical results of achieving the optimum strength of I beam cross section with the same specific gravity of web and flange showed that the longer the span the smaller the web to flange width ratio needs. The I beam was not optimum when the cross section has a small ratio of span to beam height, the failure mode will be in wood shear. The contribution of shear deflection was small at span to beam height ratio more than 20. The 12 specimens of I glulam beam made from *Acacia mangium* as web with flange variation using *A. mangium*, Meranti and Keruing. The wood specific gravity ratio of flange to web and the shear strength of glue were significant to make the wood and glue achieved the maximum strength. The oilly surface of Keruing flange made the load carrying capacity become low because of the wood-glue adhesive failure.

Key words: deformation, failure mode, lamina configuration, flexural, shear, strength.

Introduction

Since recently difficult to get a large cross section dimension of wood beam, I glulam beam was became one of the alternative as an engineered wood product. In this research, the I glulam beam specimen was made either using lamina of the same wood species or a combination of two wood species with different specific gravity. All web specimens made from Akasia *(Acacia mangium)* and flange variations was made from Akasia, Meranti *(Shorea sp.)* or Keruing *(Dipterocarpus sp.)*. The cross section dimension and flange species variations were shown in Figure 1.

The I glulam beam may have several failure modes, such as failure in bending, wood shear, glue shear or adhesive between glue and wood. This paper presented analytical and experimental study of the optimum lamina configuration and dimension. Since the critical bending stress occured at the top or bottom fiber and the maximum shear stress in the neutral axis, the observation of the width and spesific gravity ratio of flange to web was done. Also the shear strength of the glue cohesion was tested.

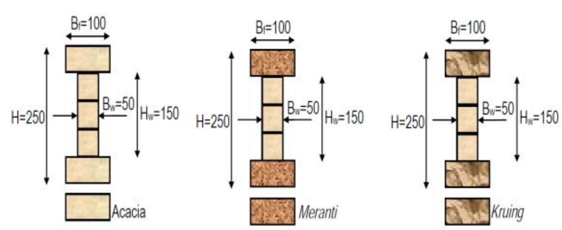

Figure 1 Specimen cross section dimension and flange species variations.

Some analitycal studi was done to find the dimension of the I beam which is make both flexural and shear achieved nearly the maximum strength.

Materials and Methods

Wood material properties test was done for Akasia, Meranti and Keruing, the result as shown in Table 1.

Table 1 Modulus of elasticity, specific gravity and moisture content

No	Species	$E_{Average}$ (MPa)	G	mc (%)
1	Akasia	7741	0.25–0.45	11 - 18
2	Meranti	12367	0.35–0.60	16 - 20
3	Keruing	13326	0.50–0.80	14 - 20

The shear strength of the strong epoxy glue between the lamina was tested using modified shear test method for small clear specimen as in ASTM D 143-94. The lowest glue shear strength was between Akasia-Keruing glue contact surface (see Table 2).

Table 2 Shear strength of strong epoxy glue (F_{gv}) between the lamina

No	web-flange lamina species	F_{gv} range (MPa)	F_{gv} average (MPa)
1	Akasia - Akasia	2.56 – 6.04	3.61
2	Akasia - Meranti	2.88 – 6.63	4.67
3	Akasia - Keruing	1.83 – 3.68	2.46

Analitycal and experimental method

The calculation of bending stress, shear stress, transform section area and deflection based on the common theory of strength of materials, (Gere 2001, Sulistyawati 2008). The possibility of shear and bending stress diagram on the cross section of I glulam beam was shown as in Figure 2.

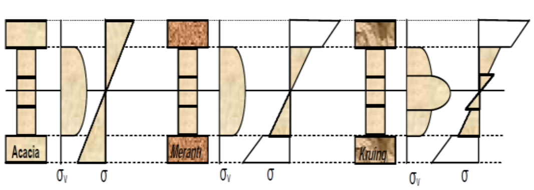

Figure 2 The possibility of shear and bending stress diagram.

The bending and shear stresses calculated by the following basic formula:

$$\sigma = \frac{M.y}{I_x}$$

Where M is bending moment (Nmm), y is distance of fibre from the neutral axis (mm), and I_x is second moment of area (mm^4).

and

$$\tau = \frac{Q.S}{b.I_x}$$

Where Q is shear force (N), S is first moment of area (mm^3), b is width (mm), and I_x is second moment of area (mm^4).

The setting of analitycal and bending test using two points loading was described as in Figure 3 and 4. The Universal Testing Machine, Hung Ta was used to give the loading on the beam.

The mid-span deflection of I beam with span and loading condition for analytical study as in Figure 3 was derived and can be calculated by the following equation (3),

$$\Delta_b = \frac{23.P_{bp}L^3}{1296.EI_x} + \frac{0.1875.P_{bp}L}{F'.G_L}$$

Where Δ_b is elastic midspan deflection (mm), P_{bp} is elastic proportional load (N), I_x is moment of inertia (mm^4), E is elastic modulus (MPa), F' is effective web I beam cross section (mm^2), and G_L is shear modulus (MPa)

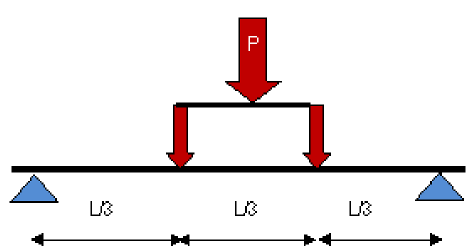

Figure 3 The schematic of beam and loading on the analitycal study.

The deflection for two point loading for experimental study with 1610 mm span described in Figure 4 was,

$$\Delta_b = \frac{81140167.P_{bp}}{EI_x} + \frac{305.P_{bp}}{F'.G_L} \quad (2)$$

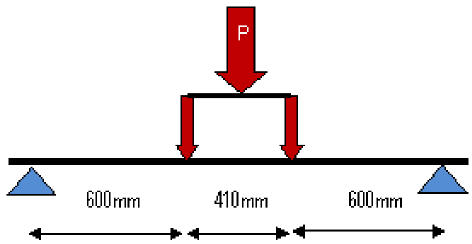

Figure 4 The schematic of beam and loading on the experimental study.

Results and Discussion

Flexural and shear strength

Figure 5 to 7 showed the value of web width (B_w) needed to get the optimum strength in bending and shear of wood. The assumption made was no failure in the glue. The cross section dimension of beam used in this study were total height H = 250 mm, web height H_w = 150 mm, flange width B_f = 100 mm and the span length (L) variation of (1600, 2400, 3200 and 4000) mm.

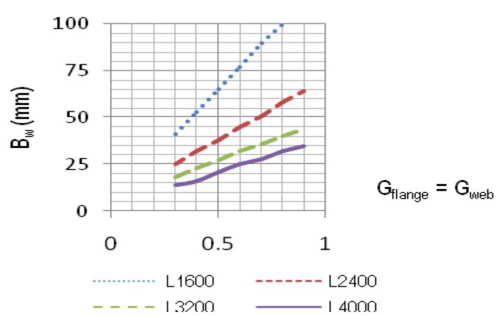

Figure 5 Web width B_w vs spesific gravity G for optimum strength (G_{flange} = G_{web}, H=250mm, H_w=150mm, B_f =100mm).

The calculation of web width (B_w) dimension as variable showed that the shorter the span, the larger width of the web needed to get both the wood materials achieved nearly the maximum shear and flexural strength.

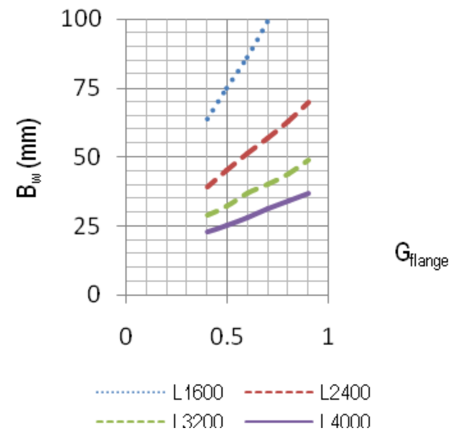

Figure 6 Web width B_w vs spesific gravity G for optimum strength G_{flange}-G_{web} = 0.1, H=250mm, H_w=150mm, B_f =100mm).

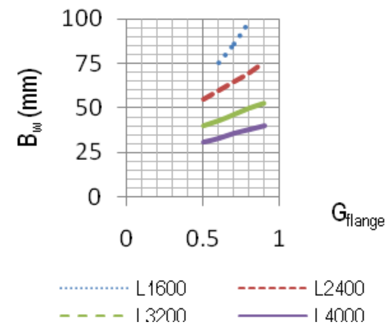

Figure 7 Web width B_w vs spesific gravity G for optimum strength (G_{flange}-G_{web} = 0.2, H=250mm, H_w=150mm, B_f =100mm).

Shear deformation

The contribution of shear deformation to the total deflection (flexural and shear deflection) was shown as in Table 3. The deflection was calculated based on the common theory of the strength of materials (Gere 2001). This study based on some wood properties on the Wood Handbook (FPL 2010).

Table 3 Shear deflection ratio (R) on the I glulam beam (H=250 mm, H_w=150 mm, B_f=100 mm, B_w=50 mm)

Species	E_{sb} (MPa)	G_L (MPa)	G_L/E_{sb}	R For L/H =6.4	L/H for R < 0.10
Akasia+	11034	600	0.054	0.57	22.4
Meranti+	13070	750	0.057	0.56	22.4
Ash	12000	1116	0.093	0.44	17.6
Basswood	10100	516	0.051	0.59	22.4
Fir Subalpine	8900	512	0.058	0.56	20.8
Maple Sugar	12600	1096	0.087	0.46	19.2
Douglas Fir	12150	863	0.071	0.51	20.8
Larch Westrn	12900	852	0.067	0.52	20.8
Pine Sugar	8200	972	0.119	0.38	14.4
Spruce E.	8900	1086	0.122	0.37	14.4

+ based on Tjondro (2007)
Properties data no 3 – 10 from Wood Handbook, 2010.
E_{sb} = modulus of elasticity, G_L = shear modulus,
Δg = shear deformation, Δt = total deformation
R = $\Delta g/\Delta t$. L/H = span-height ratio

The contribution of shear deformation to the total deflection (R) for span-height ratio L/H=6.4 was in between 0.37 to 0.59 and the contribution less than 10% (R=0.10) when L/H was in between 14.4 to 22.4 as was shown in Table 3.

Figure 8 to 10 showed the result of study for other height variations (H = 200, 250, 300 mm) and web width variations (B_w= 30, 40, 50, 60 mm). In this case the spesific gravity was equal and B_f = 100 mm.

The result shows that contribution of shear deflection less than 10% (R=0.10) when the ratio of L/H greater than 20 (average value). This is different with solid beams span height ratio of 15.

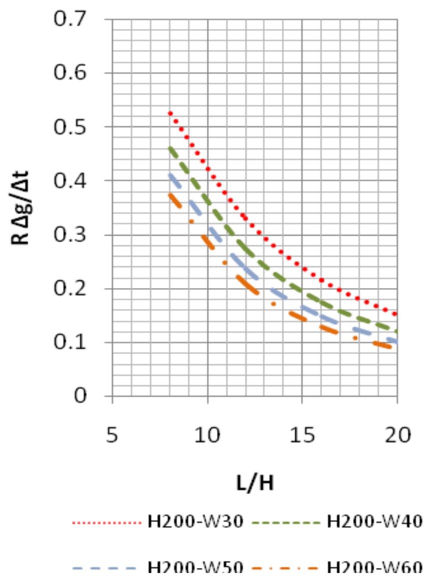

Figure 8 Ratio of shear deformation to the total deflection vs span-height ratio L/H, for H = 200 mm and B_f = 100 mm.

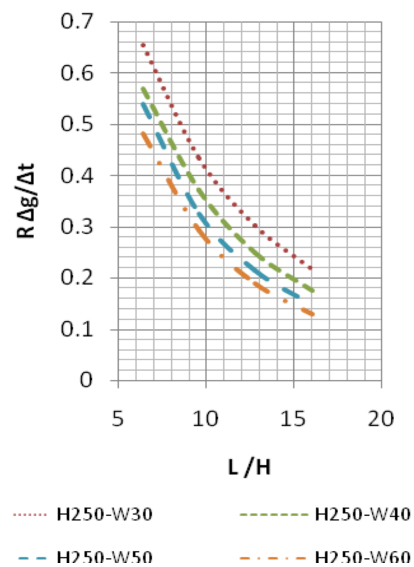

Figure 9 Ratio of shear deformation to the total deflection vs span-height ratio L/H, for H = 250 mm and B_f = 100 mm.

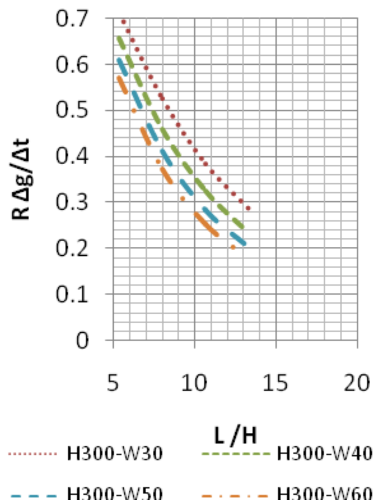

Figure 10 Ratio of shear deformation to the total deflection vs span-height ratio L/H, for H = 300 mm and B_f = 100 mm.

The 12 specimens of I glulam beam with Akasia for all beam web and variation of the flange using Akasia, Meranti or Keruing were tested, as shown in Figure 11 and 12. The results showed that the higher ratio of flange to web specific gravity was not optimum, the failure mode mainly in the glue.

Figure 11 I glulam beam specimens under construction.

Some problem with adhesive of the glue to the surface of Keruing flange species, (Malik 2009) made the load carrying capacity of Keruing-Akasia specimen become low.

Figure 12 I glulam beam specimens and specimen AA4 under loading test.

Load-deflection curve in Figure 13 to 15 shows that the glue works properly and the failure was happened in the wood material. The curve in figure 15 shows some problem with the cohesion of the glue to the surface of Keruing-Akasia specimen KA3 (Buen Sian 2009).

The comparison of the experimental results and design load P_d (calculated by real specific gravity and assumed as a solid cross section) was done. The calculation was made for different two class of wood. The test result of load at proportional limit (P_p) was compared to the load design value (P_d); P_d was choosen from the lowest design value of; P_b (bending), P_{vw} (wood shear) and P_{vg} (glue shear) as in Table 4 and 5. Basic strength value for design comparison was made by considering grade of wood by visual inspection. Generally the wood material was in grade class B. The two assumption was made for calculation. The result showed that for class A as an assumption only specimen AA2, AA3 and MA1 gave good prediction result, For class B assumption; all specimen gave better prediction result, except for KA1, KA2, KA3 and KA4, see Table 4 and 5.

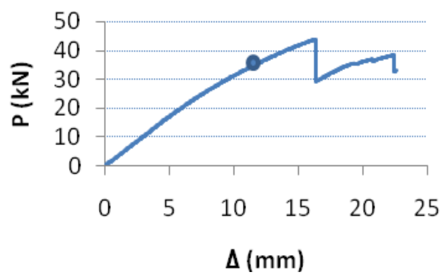

Figure 13 Load – deflection curve of AA1 (Akasia-Akasia) specimen.

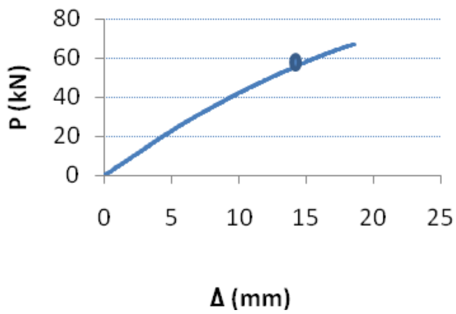

Figure 14 Load – deflection curve of MA1 (Meranti-Akasia) specimen.

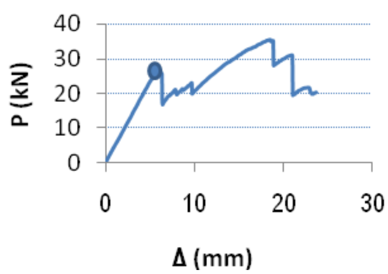

Figure 15 Load – deflection curve of KA3 (Keruing- Akasia) specimen.

The load at proportional limit P_p from bending test of Akasia-Akasia glulam beam is in between 34.7 to 40.6 kN, Meranti-Akasia glulam beam is 53.5 to 57.5 kN, and Keruing-Akasia is 26.6 to 52.8 kN. The average maximum load P_{bu} of Akasia-Akasia glulam is 45 kN, Meranti-Akasia glulam is 65 kN, and Keruing-Akasia is 50 kN. The analytical calculation showed that the rupture of glulam especially because of shear of wood or glue adhesive. Ratio P_p/P_d, between the proportional limit loads from experiment and the design loads are 0.37-0.96.

Table 4 The comparison of the experimental results and design load. (Class A factor, 0.80)

Specimen	P_b* (kN)	P_{vw}* (kN)	P_{vg} (kN)	P_d (kN)	$P_{p\text{-}exp}$ (kN)	$P_{p\text{-}exp}/P_d$
AA1	***61.4***	63.1	74.1	***61.4***	34.7	0.56
AA2	***32.0***	60.5	67.4	***32.0***	30.5	0.95
AA3	***31.3***	58.3	68.6	***31.3***	30.0	0.96
AA4	***51.7***	80.4	71.0	***51.7***	40.6	0.79
MA1	***59.1***	63.9	68.3	***59.1***	53.5	0.91
MA2	77.5	126.5	***71.5***	***71.5***	57.5	0.80
MA3	110.4	77.6	***75.5***	***75.5***	56.9	0.75
KA1	133.3	85.3	***72.8***	***72.8***	33.0	0.45
KA2	193.2	100.5	***73.8***	***73.8***	36.0	0.49
KA3	95.0	95.0	***72.4***	***72.4***	26.6	0.37
KA4	146.4	98.5	***71.0***	***71.0***	52.8	0.74

*) mechanical properties based on Tjondro (2007), AA: Akasia-Akasia, MA: Meranti-Akasia, KA: Keruing- Akasia

Table 5. The comparison of the experimental results and design load. (Class B factor, 0.63)

Specimen	P_b* (kN)	P_{vw}* (kN)	P_{vg} (kN)	P_d (kN)	$P_{p\text{-}exp}$ (kN)	$P_{p\text{-}exp}/P_d$
AA1	***39.6***	52.0	74.1	***39.6***	34.7	0.88
AA2	***20.7***	49.5	67.4	***20.7***	30.5	1.47
AA3	***20.2***	48.9	68.6	***20.2***	30.0	1.48
AA4	***33.3***	65.8	71.0	***33.3***	40.6	1.22
MA1	***38.1***	52.3	68.3	***38.1***	53.5	1.41
MA2	***50.0***	103.5	71.5	***50.0***	57.5	1.15
MA3	71.1	***63.5***	75.5	***63.5***	56.9	0.90
KA1	85.9	***69.8***	72.8	***69.8***	33.0	0.47
KA2	124.5	82.2	***73.8***	***73.8***	36.0	0.49
KA3	***61.3***	77.7	72.4	***61.3***	26.6	0.44
KA4	94.4	80.6	***71.0***	***71.0***	52.8	0.74

*) mechanical properties based on Tjondro (2007)

The failure mode observed for the entire specimen was shown in Table 6. In Figure 16, the MA1 specimen was fail because the small span to beam height ratio made the I beam cross section was not optimum, the failure mode mainly due to shear of wood or glue. Some problem with the cohesion of glue to the surface of Keruing flange made the load carrying capacity become low (Figure 17).

Table 6 Failure modes of I glulam beam (Buen Sian 2009)

Specimen	Failure mode at		Slip at support (mm)
	Wood	**Glue**	
AA1	cross-grain tension at web near load		2.0
AA2	horizontal shear at flange near support	at web	
AA3	cross-grain tension, horizontal shear at midspan web		
AA4	simple tension at flange in tension region		2.0
MA1	horizontal shear at web near support		
MA2	horizontal shear at midspan flange in tension region		
MA3		at web	
KA1		at web	
KA2	horizontal shear		15.0
KA3	cross-grain tension	at web-flange contact	
KA4		at web-flange contact	

Figure 16 Shear failure modes at web near support of Meranti-Akasia MA1 specimen.

Figure 17 Glue shear failure modes at web-flange surface contact of Keruing-Akasia KA4 specimen.

Conclusions

The results showed that the ratio of flange to web specific gravity and the shear strength of glue are significant to make the wood materials and glue achieved the maximum strength.

The analytical results of achieving the optimum strength of I beam cross section with the same specific gravity of web and flange showed that the longer the span the smaller the web to flange width ratio needs.

The small span to beam height ratio made the I beam cross section was not optimum, the failure mode mainly due to shear of wood or glue.
The results showed that the higher specific gravity of flange rather than web specific gravity made the cross section was not optimum, the failure mode mainly in the glue.

Some problem with adhesive of glue to the oilly surface of Keruing flange made the load carrying capacity become low. To prevent the failure at the glue, the glue shear strength must be greater than wood shear strength.

The influence of the shear deflection was small at span length to beam height ratio at the value more than 20.

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