Potential of Reinforced Indonesian Glulam Beams Using Grade I (Bengkirai), Grade II (Kamper), Grade III (Nyatoh) Woods for Use in Structural Wood Design

Saptahari Sugiri[1,*], Eka Mulya Alamsyah[2] & Arie Putra Usman[1]

[1]Structural Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
[2]Forestry Technology Research Group, School of Life Sciences and Technology, Institut Teknologi Bandung, Jalan Ganesa No. 10, Bandung 40132, Indonesia
*E-mail: saptahari@si.itb.ac.id

Abstract. Wood is a natural resource that is renewable and available in various species in tropical countries. Its abundancy in nature makes it easy to obtain, thus making it a nature friendly material for use in construction. Indonesia is the most important source of tropical wood in the world after Brazil, making the use of wood for structural elements very desirable. It is estimated that 4000 different varieties of wood exist in Indonesia. This estimate is based on the herbarium species collected by the Forestry Research Institute, currently counting nearly 4000 types of trees with a diameter of more than 40 cm. In the Indonesian wood structure code, the strength of woods is divided into 3 grades (grade I, II and III). This paper presents an evaluation of the mechanical properties of glulam wood sourced from native Indonesian timber: Bengkirai wood (grade I), Kamper wood (grade II), and Nyatoh wood (grade III), thus proving the potential for Indonesian wood as industrial structural elements in wooden constructions.

1   Introduction

Glulam technology consists mainly of assembling structural elements from layers of wood by gluing them together with durable, moisture-resistant structural adhesives, hence the name glulam wood. The advantage of glulam technology is the freedom with which the glulam wood can be formed into the specific dimensions required by a structural element. The strength of the glulam wood can be increased by enlarging the surface dimension of the wooden structure and also by reinforcement of the glulam wood. Hence glulam wood can be utilized as a structural component for housing construction or as a light structural component in building, replacing solid wood products from the natural forest, which have become limited in supply due to extensive illegal logging, forest fires and other factors.

In an effort to sustain the supply of wood and fibers for industry and to maintain the tropical forest environment, Indonesia initiated a commercial program of plantation forest development called the Industrial Wood Estate (HTI) program in 1986. This is meant to ensure the sustainability of these forests and prevent illegal logging of wood. Various trees from both slow- and fast-growing species have priority in the establishment of the plantations.

According to the Indonesian Wood Code, there are 3 grades of wood for structural design [1], as shown in Table 1.

Table 1   Grades of wood for structural design.

| No | Wood Species/ Grade | | |
	I	II	III
1	Bangkirai (*ShorealaevisRidl*)	Kamper (*Dryobalanopsspp*)	Nyatoh (*Ganuaspp*)
2	Banjar	Mahoni (*Swieteniaspp*)	Pinus (*PinusmerkusiiJungh*)
3	Borneo	Keruing (*D. borneensis V.SI*)	Sengon (*Paraserianthesfalcataria*)
4	Merbau (*Inisiaspp*)	Medang (*Alseodaphnespp*)	Albasia
5	Jati (*TectonagrandisL.f*)	Rengas (*Glutaspp*)	Surian (*ToonasureniMerr*)
…	…	…	…

2   Glulam Wood

Glulam wood is one of the ways to process wood so that its dimensions can be made according to required specifications [2-4]. In this research, Bengkirai wood (grade I), Kamper wood (grade II), and Nyatoh wood (grade III) were used to make glulam wood. The dimensions of glulam wood are shown in Figure 1.
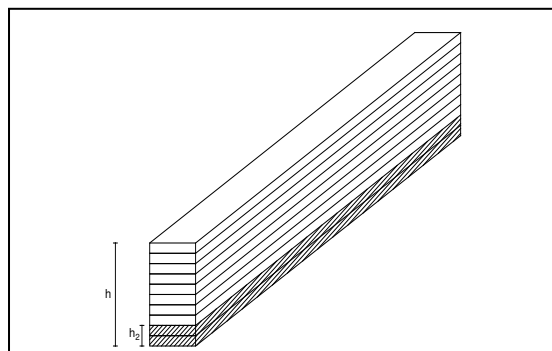

Figure 1   Glulam wood structure.

Wood in general is found in limited dimensions, so that a joint construction is needed. One of the reasons that it is better to use glulam wood than solid wood is due to the fact that the quality of the wood laminate can be customized, thus enabling that the best glulam wood properties can be obtained. Also, the quality of the glulam wood can be optimized by decreasing the distribution of the wood's defects [5-7].

Glulam wood can be made from one grade or several grades of wood with different quality grades, depending on the purpose of its intended application. The production of glulam wood combining several variations of wood quality grades is also possible. When a wooden element receives axial loading or the flexural element receives a parallel load in the same plane as the width of the wooden beam, then the use of only one grade of wood quality is recommended. On the other hand, the use of glulam wood made of several different quality grades is better and more effective if the glulam wooden element is a flexural element that will be loaded perpendicularly to the width of the laminated wood beam [8].

3   Thickness of Glulam Wood Reinforcement

3.1   Theoretical Consideration

The moment capacity for glulam beams with reinforcement is calculated such that the thickness of the reinforcement of the glulam wood has an optimal value of 0.2 h. Figure 2 shows the calculation of moment capacity M_{el} for a composite beam comprising of three moments, M_1, M_2 and M_v [9]. M_{el} is the external bending moment applied to the composite beam. M_1 and M_2 are the bending moments proportional to their stiffnesses. M_v is the composite moment ($M_v = N.a$), where N is the flexible shear connection that induces the compressive force and a is the distance between compressive forces N_1 and N_2.
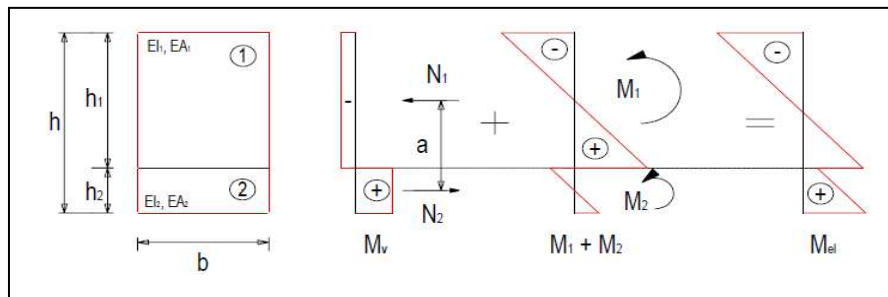

Figure 2 The gamma method for a bipartite beam composed of two sections that are connected together by a flexible adhesive layer.

The total moment M_{el}, which is the sum of the partial moments M_1, M_2 and M_v (shown in Eq. (1)), is a function of (h_2/h).

$$M_{el} = M_v + M_1 + M_2 = \frac{f_{m,u}.b.h^2}{6} \cdot g\left(\frac{h_2}{h}\right) \tag{1}$$

$f_{m,u}$ is the bending strength of the glulam beam, h is the total height of the bipartite beam, while h_2 is the height of the smaller of the two members.

By adjusting the height (h_2), the optimal height can be determined as h_2/h = 0,2 [9]. Figure 3 shows that in comparison to a conventional glulam beam, an increase of up to 20% in the bending strength of the bipartite beam is possible.
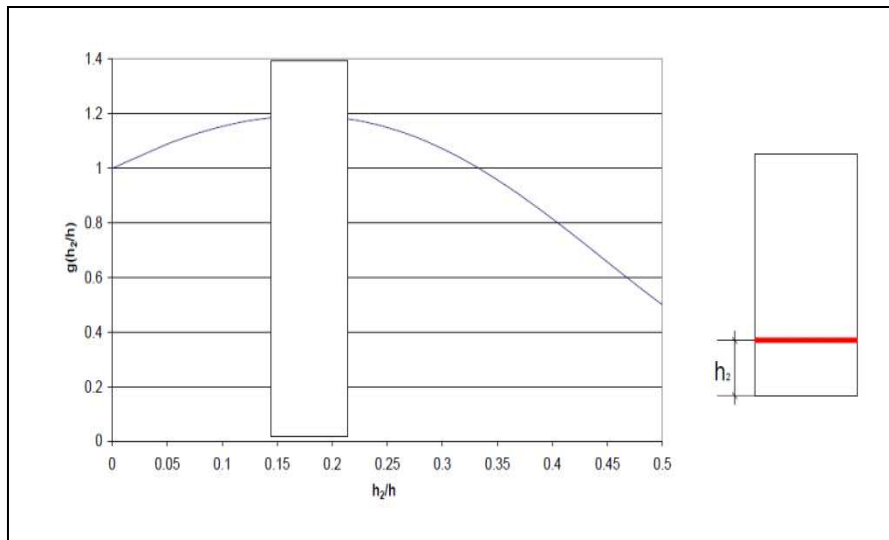

Figure 3 Increment factor g of the bending strength of the bipartite beam as a function of the position of the flexible adhesive layer in the beam cross section.

3.2   Numerical Consideration

By considering the elastoplastic condition of the glulam material, the moment capacity for the glulam beam section can be calculated by varying the reinforcement thickness. Figure 4 shows the increase in moment capacity of the glulam when the reinforcement thickness is at 0% h, 1% h, 5% h, 10% h, 17% h, 20% h, and 30% h of reinforcement. It can be seen that the increase in moment capacity for reinforcement thicknesses above 20% h (0.2 h) becomes insignificant.
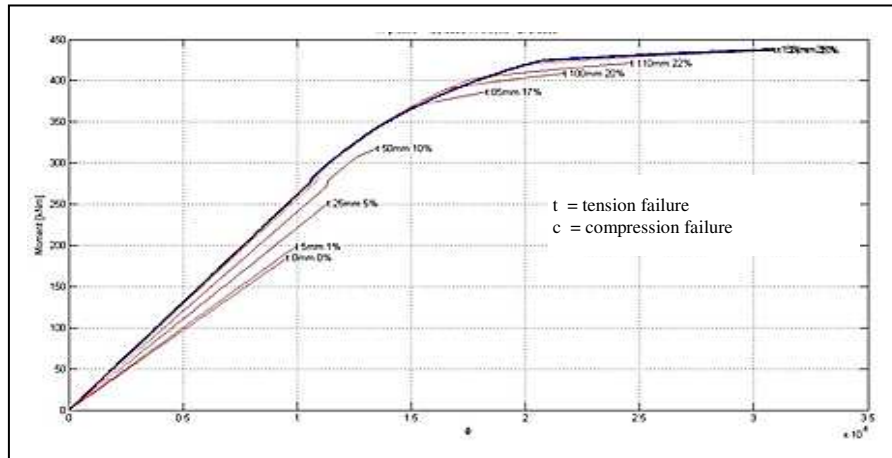
Figure 4 Moment capacity vs. curvature, with function of height (h_2) for Kamper wood.

4 Mechanical Properties of Glulam Wood

In designing glulam wood, the mechanical strength can be made according to the wood's original strength by using the following Eurocode equation (Table 2):

Table 2 Some mechanical properties of glued laminated wood [10].

Property		Equation According to prEN 1194
Bending strength	(N/mm^2)	$f_{m,g,k}$ = 7 + 1,15 $f_{t,0,1,k}$
Tension strength	(N/mm^2)	
– *parallel to fiber*		$f_{t,0,g,k}$ = 5 + 0,8 $f_{t,0,1,k}$
– *perpendicular to fiber*		$f_{t,90,g,k}$ = 0,2 + 0,015 $f_{t,0,1,k}$
Compression strength	(N/mm^2)	
– *parallel to fiber*		$f_{c,0,g,k}$ = 7,2 $f_{t,0,l,k}^{0,45}$

Note: $f_{0,g,k}$ = parallel to fiber, $f_{90,g,k}$ = perpendicular to fiber.

In the elastoplastic behaviour of wood, the tensile zone will start failing as the wood wears out; plasticity will fail to occur because the wood also undergoes failure. Whereas for the compressive zone, wood can still demonstrate plastic behaviour under compression.

For the plastic capacity of wood, we can take k = 3, where k is the ratio of plastic strain to elasticity (k = $\varepsilon_p/\varepsilon_e$) [11].

5   Capacity of Reinforced Glulam Wood

To increase the glulam wood's strength, the glulam wood layer can be made from several wood qualities of different strengths and can also be made by combining it with other stronger materials such as steel, FRP (fiber-reinforced polymer), etc. For example, glulam wood grade III can be reinforced with glulam wood grade II or grade I, and glulam wood grade II can be reinforced with glulam wood grade I or steel, and glulam wood grade I can in turn be reinforced with steel.
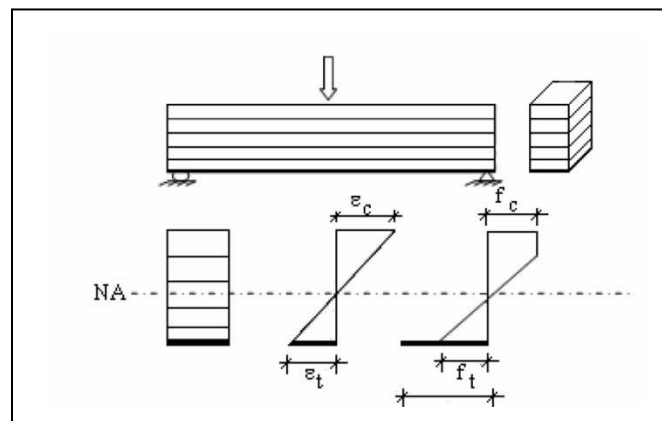

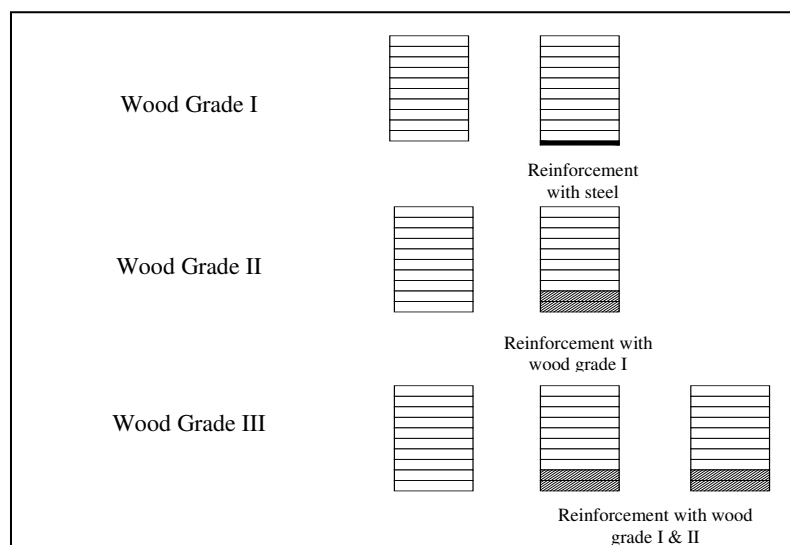**Figure 5** Linear elastic, elastoplastic model, Hernandez, *et al.* [12]

Figure 6 Reinforcement for glulam beam, with steel reinforcement and wood grade I and grade II reinforcement.

Glulam wood made from several quality grades can be produced using equal reinforcement (top and bottom side reinforcement) or unequal reinforcement combinations (only bottom side reinforcement), depending on the geometrical composition of the laminated wood. For an unequal combination where the reinforcement is only on the bottom side (Figure 5), the critical zone of the glulam wood's flexural zone that must be controlled is the outer tensile zone.

6   Case Study of Glulam Wood Surface

A glulam wooden beam with 2 simple supports, spanning 8 m, was reinforced with a grade above the glulam wood's own quality, while the grade I wood was reinforced with steel (see Figure 6).

The modulus of elasticity and the strength of Bengkirai wood (grade I), Kamper wood (grade II), and Nyatoh wood (grade III) are shown in Table 3. For steel reinforcement, the following parameters were used: yield strength (fy) = 240 MPa and modulus of elasticity (Es) = 200 GPa.

Table 3   Strength reference value (MPa) based on mechanical sorting at 15% moisture content [1].

Wood species	Flexural Modulus of Elasticity E_w	Bending strength f_b	Tensile strength parallel to fiber f_t	Compressive strength parallel to fiber f_c	Shear Strength f_v	Compressive strength perpendicular to fiber $f_{c\perp}$
Bengkirai	23000	59	56	45	6.4	22
Kamper	11000	23	22	37	4.6	11
Nyatoh	9000	18	17	24	4.3	9

Table 4   Moment capacity of wood with and without reinforcement.

Wood Species	Moment		Capacity Increase (%)
	Elastic (kNm)	Plastic (kNm)	
Bengkirai	162[1]	950[2]	486
Kamper	77[1]	101[3]	32
Nyatoh	62[1]	67[4]	7
		91[5]	47

Notes:
1. Value for elastic moment of Bengkirai wood (grade I), Kamper wood (grade II), and Nyatoh wood (grade III).
2. Value for plastic moment of Bengkirai wood (grade I) reinforced with steel.

3. Value for plastic moment of Kamper wood (grade II) reinforced with Bengkirai wood (grade I).
4. Value for plastic moment of Nyatoh wood (grade III) reinforced with Kamper wood (grade II).
5. Value for plastic moment of Nyatoh wood (grade III) reinforced with Bengkirai wood (grade I).
6. Elastic moment is the moment capacity of the section where the tensile zone and the compression zone are in the elastic condition.
7. Plastic moment is the moment capacity of the section where the tensile zone is in the elastic condition and the compression zone is in the plastic condition

The capacity of the glulam beams was calculated in 2 stages: the elastic capacity for glulam beams without reinforcement and the elastoplastic capacity for glulam beams with reinforcement. The plastic moment capacity of Bengkirai glulam beam reinforced with steel showed a considerable increase (486%), when compared to the elastic moment capacity without reinforcement. Meanwhile, the Nyatoh glulam beam when reinforced with Bengkirai showed a satisfactory increase (47%) compared to the elastic moment capacity. The moment capacity of glulam beams with and without reinforcement is shown in Table 4.

7   Conclusion

Indonesian wood can be categorized into grade I, grade II, and grade III and made into glulam wood with and without reinforcement. Reinforcement of glulam wood by using a grade from a higher strength will increase the beam's section capacity.

The elastoplastic calculation on the glulam beam's section capacity show that reinforcement of grade III wood (Nyatoh) with grade I wood (Bengkirai) can significantly increase the capacity by 47%.

Reinforcement of the glulam beam with steel will considerably increase its capacity, for which our calculation showed a remarkable increase of 486%. Hence, the reinforcement of grade I glulam beam with steel is very effective.

Indonesia being one of the worlds' major resources for tropical wood has the potential to develop glulam wood for structural beams. By making glulam from grade I, grade II, and grade III wood and adding reinforcement using superior grades of wood or combining it with steel, various beam strength capacities can be tailor-made to meet specific requirements. Consequently, the development of glulam wood for the construction industry will be able to boost Indonesia's wood industry.

References

[1] Ministry of Public Work, *Regulation of the Indonesian Wood Construction* (PKKI), 1961.

[2] Breyer, D.E., *Design of Wood Structures – ASD*, Fifth Edition. McGraw-Hill, 2004.

[3] Sugiri, S. & Usman, A.P, *Experimental Study on Bending of Solid Timber Beam and Bending of Glulam Timber Beam*, ASIA-OCEANIA Top University League on Engineering (AOTULE), 2010.

[4] Usman, A.P., *Experimental Study on Bending of Solid Timber Beam and Bending of Glulam Timber Beam*, Master Thesis, Civil Engineering Study Program, Institut Teknologi Bandung, 2011.

[5] Sugiri, S., *The Standard of Using Wood for Construction Materials*, Exposure Research Scope Research and Development Engineering Center of Forestry and Forest Products Processing, Bogor, 2012.

[6] Sugiri, S., *Using Wood as Construction Materials*, Workshop Role of Wood As A Construction Material and Decorative Products, School of Life Sciences, Institut Teknologi Bandung, 2012

[7] Usman, A.P., *Behavior of Glulam with Flexural Strengthening*, The Second International Conference on Sustainable Infrastructure and Built Environment – Bandung 19-20 November 2013.

[8] Sugiri, S., Alamsyah, E.M, & Usman, A.P, *Mapping of Indonesian Timber: Potential of Glulam Wooden Beams without Reinforcement and with Reinforcement for Timber Structures*, The Second International Conference on Sustainable Infrastructure and Built Environment – Bandung 19-20 November 2013.

[9] Brunner, M. & Donzé, M., *Glulam Reborn: A Flexible Adhesive Interface to Increase the Bending Resistance of Glulam*, 10th World Conference on Timber Engineering, 2008.

[10] Leonardo da Vinci Pilot Project, *Educational Materials for Designing and Testing of Timber Structures*, Handbook 2-Design of Timber Structures According to EC 5, 2008.

[11] Jacob, J. & Barragan, O.L.G., *Flexural Strengthening of Glued Laminated Timber Beams with Steel and Carbon Fiber Reinforced Polymers*, Master's Thesis in the International Master's Program Structural Engineering, Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden, 2007.

[12] Hernandez, R., Davalos, J.F., Sonti, S.S., Kim, Y. & Moody, R.C., *Strength and Stiffness of Reinforced Yellow-Poplar Glued-Laminated Beams*, US Department of Agriculture, Forest Service, Forest Product Laboratory, 1997.