Analysis of the Strength of Timber and Glulam Timber Beams with Steel Reinforcement

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Abstract. Indonesia is a tropical country with abundant tropical timber that can be used as a building material. Wood is a renewable material, thus making it an environmentally friendly construction material. However, the dimensional limitations of solid wood may pose problems in structural constructions. Wood material also has some disadvantages, such as brittle failure. However, the ductility of wood can be increased because of plasticity occurring in the compression zone. Wood material with good ductility can be obtained by reinforcing it in the tensile zone. This study is about the strength of wood material for use as a material for structural elements. Based on the analytical findings, the bending capacity of wood can be improved by adding reinforcements to the tensile zone.

Keywords: *flexural strengthening; glulam wood; reinforcement; solid wood.*

1 Introduction

Wood is a renewable natural resource and is available from a wide range of species in tropical countries such as Indonesia. Its renewable character makes it an environmentally friendly construction material. In addition, wood as a building material also has other advantages compared to materials such as concrete, steel, etc. It is lightweight, easy to work with, can be recycled, and has aesthetic values.

To obtain a good quality of wood, the timber must be cut down at a sufficient age. The optimal age for wood logging depends on the type of wood species. In Indonesia, the age for cutting trees has been set in the decree on selective logging of the Indonesian Directorate General of Forestry, which states that trees can only be harvested when the diameter is over 50 cm, the length of the cutting cycle is 35 years, and the number of trees left with a diameter of over 35 cm is at least 25.

The use of wood as a construction material is limited because its price per m^3 is very high, especially forest wood. The Indonesian government has plans to invigorate industrial forest plantations and public forest plantations so that the local wood supply can be sustained and the wood can be made more affordable,

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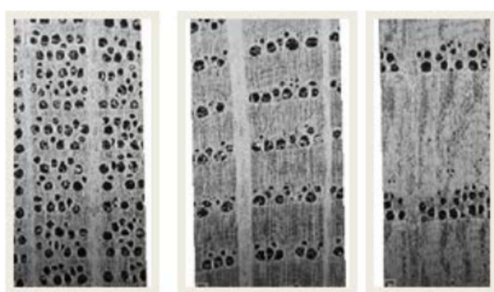
so that industrially produced wooden structural elements such as glulam beams can compete with steel and concrete in simple structures.

When the required span is extended or the load is large, solid wood can be impractical because it takes a long time for a tree to produce timber of sufficiently large dimensions and at some point it also becomes uneconomical. In other cases, there are limits to the dimensions of solid wood, depending on the size of the tree. However, wood of the desired dimensions can be produced using a laminating technique that converts it into a structural material commonly known as glulam wood. Glulam wood is a stress-rated product consisting of two or more layers of wood, glued together in the longitudinal direction of the fibers [1].

In beam bending tests, the part of the beam that fails first is the tensile zone compared to the compression zone. To get a good bending capacity, the tensile zone should be given reinforcement [2-5].

2 Solid Wood

Wood is an anisotropic material because its cells show differences in strength due to defects in the timber, causing difficulties in modeling. The best way to model timber is by using the assumption that the wood is an orthotropic material, which means that it has three orthogonal directions to determine its plane of symmetry.



(a) (b) (c)

Figure 1 Wood density comparison: (a) wood grade I, (b) wood grade II, (c) wood grade III.

Wood cells are usually longer than their width and are specifically oriented to two separate systems in the cell, i.e.the axial system and the radial system. The cells of the axial system have a long axis parallel to that of the tree. The cells in the radial system are oriented lengthwise, perpendicular to the longitudinal axis of the organ. Wood with high density usually has thick cell walls and a small lumen volume. In contrast, low-density wood has thin cell walls and a large lumen volume, as shown in Figure 1.

3 Mapping of Wood

Indonesia's tropical forests are among the largest in the world, after those of Brazil and the Democratic Republic of Congo [6]. According to current estimations, there are about 4,000 species of wood in Indonesia. This estimate is based on herbarium materials collected from various forest areas in Indonesia by the Forest Research Institute. From those 4,000 species, 400 have been estimated to have considerable importance for Indonesia and can be grouped into 120 types of timber for trade.

Table 1 Division of Wood Strength Based on the Density of Wood.

Wood strength	Density(gr/cm^3)
I	> 0.9
II	0.6 - 0.9
III	0.4 - 0.6
IV	0.3 - 0.4
V	< 0.3

Table 2 Reference Strength Value (MPa) based on Mechanical Sorting [7].

Grade Code	Reference value of design (Mpa)					Reference of flexural modulus of elasticity (Mpa)	
	F_b	F_t	F_c	F_v	$F_{c\perp}$	E	E_{min}
E25	26.0	22.9	18.0	3.06	6.11	25000	12500
E24	24.4	21.5	17.4	2.87	5.74	24000	12000
E23	23.2	20.5	16.8	2.73	5.46	23000	11500
E22	22.2	19.4	16.2	2.59	5.19	22000	11000
E21	21.3	18.8	15.6	2.50	5.00	21000	10500
E20	19.7	17.4	15.0	2.31	4.63	20000	10000
E19	18.5	16.3	14.5	2.18	4.35	19000	9500
E18	17.3	15.3	13.8	2.04	4.07	18000	9000
E17	16.5	14.6	13.2	1.94	3.89	17000	8500
E16	15.0	13.2	12.6	1.76	3.52	16000	8000
E15	13.8	12.2	12.0	1.62	3.24	15000	7500
E14	12.6	11.1	11.1	1.48	2.96	14000	7000
E13	11.8	10.4	10.4	1.39	2.78	13000	6500
E12	10.6	9.4	9.4	1.25	2.50	12000	6000
E11	9.1	8.0	8.0	1.06	2.13	11000	5500
E10	7.9	6.9	6.9	0.93	1.85	10000	5000
E9	7.1	6.3	6.3	0.83	1.67	9000	4500
E8	5.5	4.9	4.9	0.65	1.30	8000	4000
E7	4.3	3.8	3.8	0.51	1.02	7000	3500
E6	3.1	2.8	2.8	0.37	0.74	6000	3000
E5	2.0	1.7	1.7	0.23	0.46	5000	2500

All kinds of wood are spread all over Indonesia, including Sumatra, Java, Nusa Tenggara, Kalimantan, Sulawesi, Maluku, and Papua, and have various values of strength. In Indonesia, wood strength is divided into 5 (five) grades, based on the density of the wood (see Table 1).

Based on the flexural modulus of elasticity, other reference strength values of wood are shown in Table 2.

4 Glulam Wood

Glulam wood has several advantages, such as a relatively better strength compared to solid wood because the glulam layers can be arranged to avoid or distribute defective wood to different areas. Glulam layers can also be arranged according to the desired dimensions so that the dimensions do not depend on those of the tree. Glulam timber is also perceived as being more economical than solid wood because it can be composed from avariety of wood qualities [2,8-10].

One of the reasons glulam timber can have better quality when compared to solid wood is that we can select specific lamina to produce the desired quality of timber. Additionally, glulam timber can be optimized by reducing the spread of material defects in the wood, as shown in Figure 2.

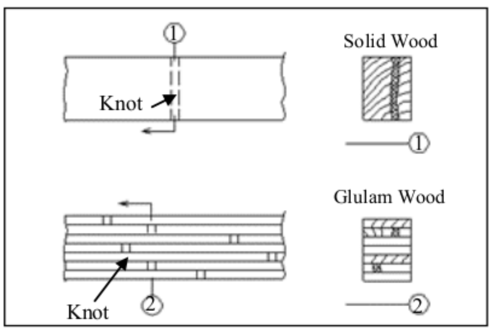


Figure 2 Defect dispersion in wood.

Glulam wood can be produced from laminated layers with the same strength to obtain a homogeneous product, but other combinations, as shown in Figure 3, are frequently used to get more efficient glulam wood.

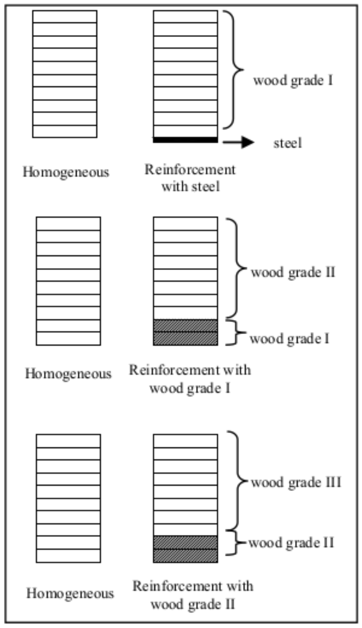


Figure 3 Homogeneous glulam and glulam combinations.

5 Principle of Lamination

Glulam timber lamination can result in good timber because in this process, the defects in the wood such as knots and other defects can be avoided by spreading them. Consequently, glulam timber has better mechanical properties compared to solid wood [3].

Glulam timber can be produced by using one type of quality grade of wood or using different grades of wood, depending on its intended use. The production of glulam timber using variations of wood species is also possible. When the timber element receives a positive moment, the timber must be given reinforcement in the tensile zone. On the other hand, when the timber receives a positive and a negative moment, the reinforcement should be given in the tensile and compression zones.

6 Glulam Beam Reinforcement

Using glulam in larger structures requires it to be reinforced so that the dimensions and deflection of the beams can be controlled. By adding reinforcement, the gains in structural stiffness are affected by the modulus of elasticity and stress tension permission of the reinforcement material. Generally, the higher the strength ratio or stiffness of the reinforcement material, the greater the strength or stiffness obtained.

Reinforcement of glulam can be done by usingwood materials that have better strength or by using steel reinforcement (Figure 3). Steel is the most common metallic reinforcement used for timber. Reinforcing glulam with steel has been a focus of study for a long time and has been applied in practice for decades. Ductile structural elements allow redistribution of internal forces, dissipation of energy from impact or seismic actions, which induces increased structural safety, as well as warning of possible structural failure/overload. The latter is possible because of the presence of large plastic or inelastic deformations before failure. Glulam reinforcement using steel elements imparts ductility to the system, because the steel will yield before the timber. Thus, by using reinforcement with a proper distribution of tension and compression, ductility can be induced in the global behavior of the reinforced beam.

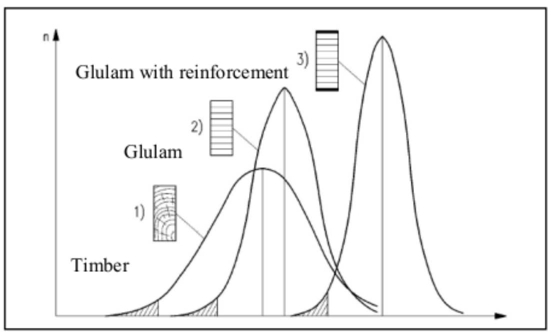


Figure 4 Characteristics of solid wood, glulam wood, and glulam wood with reinforcement [11].

Variability in wood is the biggest problem, making wood very unpredictable in design, due to the fact that each tree grows in a different environment, which has an influence on the reduction factor of the strength of the wood. Figure 4 compares the strength characteristics and strength distribution characteristics of solid wood, glulam timber and glulam timber with reinforcement. It shows that we can expect glulam timber to have less variability in terms of mechanical properties. The design values of glulam timber with reinforcement are also increased so that it can hold greater loads.

7 Reinforcement in Tensile Zone

In flexural beam tests, failure usually occurs in the tensile zone, in areas close to wood defects, at connection points, and in parts that have the maximum stress value. Glulam beams are usually given reinforcement in the tensile areas, which is expected to increase their tensile and flexural strength, consequently providing a good stiffness.

Figure 5 shows a model of linear-elastic and elastic plastic covering nonlinear behavior of compression.

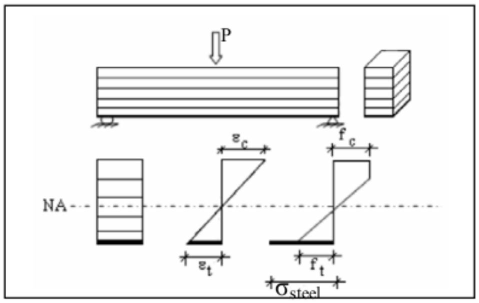


Figure 5 Linear elastic, elastic plastic model [11].

8 Case Studies of Bending Capacity of Glulam Timber with Tensile Reinforcement

The present research started with tests of wood properties in order to determine the strength values on the basis of which glulam timber can be designed using a variation of wood qualities. The results of the bending tests can be seen in Table 3.

Table 3 Test Results from Bending Testof Wood Beams.

Wood species	MOE (MPa)
Bangkirai	22527.19
Kamper	11004.67
Nyatoh	8392.46

The graphic load vs. deflection values from the bending test can be seen in Figure 6, which shows both the experimental test results and the theoretical values.

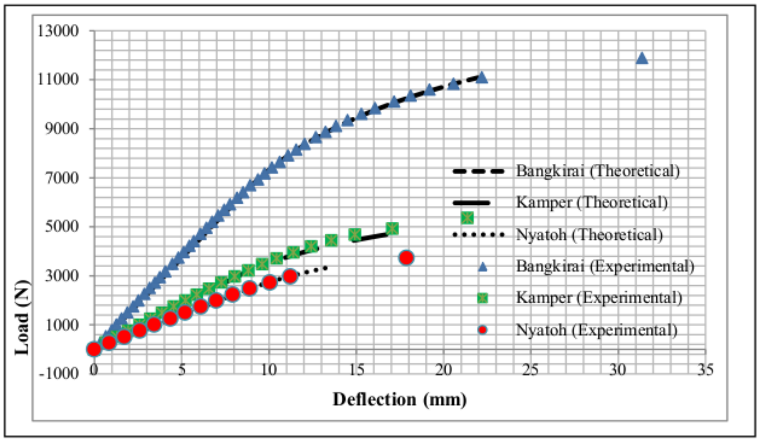


Figure 6 Load vs deflection of wooden beams.

8.1 Effect of Tensile Reinforcement

Unreinforced glulam beams usually fail in tension. Therefore, reinforcement is introduced at the tension side to strengthen this part. This basically increases the tensile capacity of the beam, which results in shifting of the failure mode to the compressive side.

Figure 7 illustrates a typical moment curvature relation for a beam reinforced at the tension side. It can be observed that the moment curvature relation is linear up to the elastic limit and afterwards it is nonlinear due to the compressive plastification up to failure.

Figure 8 illustrates the effect of increasing the tensile reinforcement. It can be seen that the beam behaves in a linear elasticity at very low tensile reinforcement levels, but plasticity comes into the picture as the reinforcement level goes up. However, at this level, failure occurs in tension as indicated in the diagram by ‘ft’ (tensile failure). But as the reinforcement level reaches 5 mm, pure compressive failure occurs (indicated by ‘fc’, compression failure).

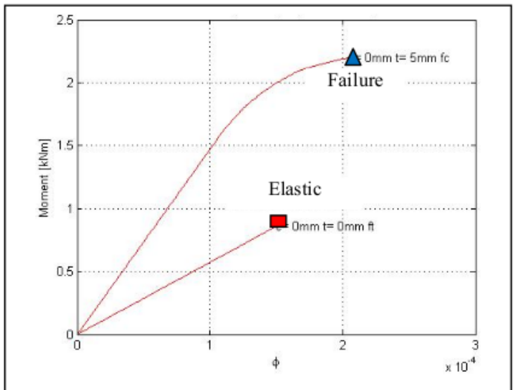


Figure 7 Illustrates a typical moment curvature relation for a beam reinforced at the tension side.

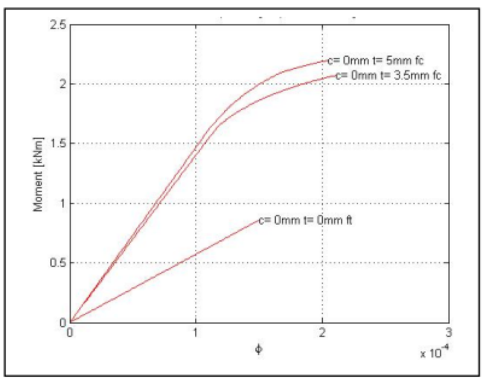


Figure 8 Effect of increasing tensile reinforcement.

9 Conclusion

In this paper discussed about advantages of glulam wood. Solid wood can be impractical when the required span is extended or the load is large, because it takes a long time for a tree to produce timber of sufficiently large dimensions and at some point it also becomes uneconomical. In other cases, the dimensions of solid wood are limited by the size of the tree. Timber of the desired dimensions can be obtained by a laminating technique that can convert wood into a structural material commonly known as glulam. In this study also discussed about the strength of wood material for use as a material for structural elements. The bending capacity of glulam timber is better than that of solid wood. Based on the analytical findings, the bending capacity of wood can be improved by adding reinforcements to the tensile zone. The modulus of elasticity of glulam and glulam with steel reinforcement will considerably strengthen the tensile zone compared to that of solid wood. The increase in value is 13,68% for wood reinforcement and 186% for steel reinforcement which mean reinforcement can optimize the application of glulam timber. In the end of this conclusion, it is desirable to develop the technology of glulam for construction purposes because it is an environmentally friendly building material.

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