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STRUCTURAL EFFICIENCY AND FLEXURE STRENGTH OF MIX-GLULAM TIMBER BEAMS ARE COMPOSED OF SENGON AND COCONUT WOOD AS GREEN MATERIAL CONSTRUCTIONS

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Abstract

Wood is a green materials that has a low level of embodied energy. Production of sawn timber is very efficient because it can reduce; reuse and recycling. Two species of wood that could be developed is sengon and coconut wood. The problem is that sengon wood have not an adequate mechanical performance. On the other hand, coconut wood has a good mechanical properties, but the heavy weight becoming an obstacle. Therefore, it is necessary to increase the performance of them. The improvement is achieved by a mix-glulam system that will be produced a lightweight structural timber beams. This research was conducted through a three and four point bending test according to ASTM:D 198 – 02. The coconut wood was placed as the outer zone of glulam. The beams size is 55mm in width, 155 mm in depth and 1740 mm in span. As a control parameter used the mechanic behavior of clear specimen as initial strength. The experimental results showed that the mix-glulam system can increase the flexure strength and stiffness by 6.1% and 8.4% respectively. In addition, the lamination process could be to improve the flexure strength and modulus of elasticity sengon-wood by 8.4% and 26% respectively. On the other hand the lamination process causes a decrease in ductility of 14%, so the glulam beams failure that occurred tend to be more brittle. In terms of structural efficiency, mix glulam has a level much better than concrete and almost equivalent to steel.

Keywords: Coconut Wood, Mix-glulam, Sengon-wood, Timber Beam.

INTRODUCTIONS

Wood is naturally renewable building material that one of the oldest known materials of construction. Simplicity in fabrication, lightness, reusability, and environmental compatibility, have made this material one of the most popular in light construction. Today wood remains important to the engineer by reason of improved technology. Modern technology has increased the durability of wood. Although many construction products using wood as the raw material have been introduced into the construction market in the last 20 or more years and are presently being used extensively the dominant use of wood is still in the form of lumber which are pieces of wood cut from tree trunks (Issa & Ziad, 2005)..

Using more wood in construction has the potential to store more carbon in the building materials than is emitted. The manufacture of wood products results in low emissions compared with other materials. In addition, the carbon stored in wood products is substantially greater than the emissions from their initial manufacture. The carbon stored in wood products as an offset to emissions was shown to be significant. Comparison of various building materials wood, steel, and concrete showed that wood was more environmentally friendly (Lippke et. al, 2010). Table 1 shows that the use of wood as a construction material to produce environmental impact index is smaller than steel and concrete (Perez-Garcia et. al, 2005).

Table 1. Environmental Performance Indices for Residential Construction

Mineapolis Design	*Wood*	*Steel*	*Difference*	*% Change*
Embodied Energy (GJ)	651	764	113	17%
Global Warming Potential (CO_2 kg)	37047	46826	9779	26%
Solid Waste (total kg)	13766	13641	-125	-0.9%
Atlanta Design	*Wood*	*Concrete*	*Difference*	*% Change*
Embodied Energy (GJ)	398	461	63	16%
Global Warming Potential (CO_2 kg)	21367	28004	6637	31%
Solid Waste (total kg)	7442	11269	3827	51%

Source: Data adapted from Perez-Garcia et.al (2005:12)

In addition to having an index lower environmental impact, wood also has a good level of structural-efficiency. Based on the structure capacity and mass ratio, the structural-efficiency level of timber is almost equivalent to the steel. Table 2 presents a comparison of the structural-efficiency level of wood, steel and concrete as building material (Thelandersson & Hans, 2003).

Table 2. Strength and Density Rasio of Building Construction Materials

Material	Density (kg/m^3)	Strength (MPa)	Strength /density (10^{-3} $MPa.m^3/kg$)
Structural steel	7800	400-1000	50-130
Aluminium	2700	100-300	40–110
Concrete, compression	2300	30-120	13-50
Clear softwood, tension	400-600	40-200	100-300
Clear softwood, compression	400-600	30-90	70-150
Structural timber, tension	400-600	15-40	30-80

Source: Data Adapted from Thelandersson & Hans (2003:16)

Two species of wood that potential to be developed as a construction material is sengon and coconut wood, although both has disadvantages in terms of mechanic properties and achievement dimensions. The availability of two types of wood is perfectly adequate and does not depend on the logging of natural forests. The low performance of sengon wood and achievements of dimensions can be overcome by applying a mix glue laminated timber systems. Glued laminated timber beams is one of derivative product from wood. The glulam manufacturing process consists in the gluing of overlaid lamellae of timber.

In compare with sawn solid beams, glulams have more advantageous. When the span becomes long, the use of sawn lumber may become impractical. Glued laminated timber can be a good choice for use in this kind of situations. Glued laminated timber beams are highly engineering components manufactured specially selected and positioned lumber laminations of varying strength and stiffness properties (Homas & Williamson, 1976). High quality lumber is required only for the outer laminations and lower quality lumber can be used in the core laminations (Van-Green & Jean, 2001).

In this research, the mixed-glulam system is applied through the placement of coconut wood as the outer lamina to obtain an increase in the flexural strength of the beam. In addition, the limited dimensions can also be solved with this system. Thus will be obtained laminated timber beam structure that is lightweight with an adequate flexural strength. However, note the flexure strength generated by the application of the system. Likewise with flexural behavior changes when compared with solid beams. Therefore, in this paper will discuss about comparisons bending strength and ductility of the mix-glue laminated timber beams with sengon-solid wood beams. In addition, also discussed the structural-efficiency level of the glue laminated timber beams compared to concrete and steel.

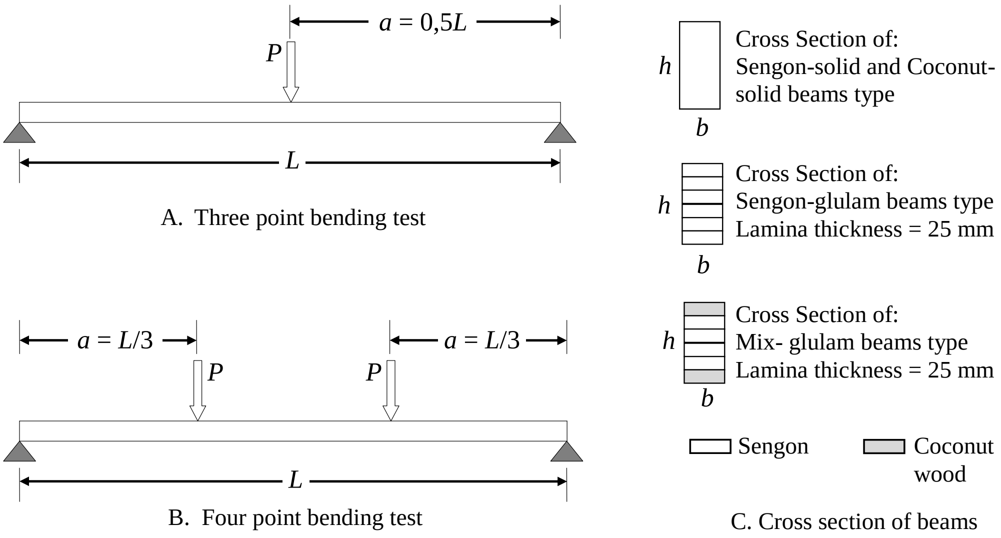
In order to predict the behavior of glulam, it is essential to understand the effect of the strength increase of laminations as a result of bonding them, the so-called laminating effect. This is a formal definition linked to the assumption that the load-bearing capacity of a glulam beam is essentially governed by the tensile strength of its outer laminations. Furthermore it is assumed that the stiffness and the strength of the laminations are positively correlated (Falk & Colling, 1995).

Material and Methods

The materials used in this study are sheets of board from sengon wood (*Albizia falcatara*) and coconut wood (*Cocos nucifera*). The size of the boards is the thickness = 3 cm, width = 6 cm and length = 200 cm. Before being used as a laminate material, both dried naturally so as to achieve ± 12% moisture content. Sengon wood density used is 320 kg/m^3 and coconut wood density is 551 kg/m^3. The sheets of the board was then leveled using knives planner-machine, in order to reach net dimensions thickness = 2.5 cm, width = 6 cm and length = 200 cm. Then do the manufacturing of wooden beams (solid and glulam) as a specimen, according to the type and dimensions of which are presented in Table 3 and Figure 1.C. Especially for laminated beams, the adhesive used is a urea formaldehyde resin powder (UF-100) which is mixed with water. Its composition is water: UF-100 = 1: 2. Pressure force applied is 2 MPa with a duration of clamping for 24 hours.

Table 3. Geometry and Dimensions of Timber Beam Specimens

Beam Type	Method	Load Type	*b* mm	*h* mm	*L* mm	Repe tition	Density (kg/m^3)
Sengon-Solid	ASTM: D143–2000	Three point bending	25	25	360	3	320
Sengon-Glulam	ASTM: D198 – 02		55	155	1740	3	-
Mix-Glulam (sengon-coconut wood)			55	155	1740	3	-
Coconut-Solid		Four point bending	45	90	1350	3	551



A. Three point bending test

B. Four point bending test

C. Cross section of beams

Figure 1. Setting Up of Bending Test and Beams Geometry

Load-deflection data collection is carried out through a static bending test against three types of beams, as Table 3 and Figures 1A and 1B. For each type of laminated beams used uniform lamina thickness of 25mm. Lamina thickness does not make any statistically significant difference in the flexural properties. Laminated beam with the same lamina thickness have no significant difference in the flexural properties. The wood adhesive bond strength and the wood failure percentage are appreciable (Nadir & Praveen, 2014).

The test results is then processed and analyzed to determine the mechanical properties and performance of timber beams. The beam performance criteria determined by the modulus of rupture (MOR), modulus of elasticity (MOE), ductility (D_u) and structural efficiency (ρ / MOR). All parameters were determined by Equation 1 to Equation 5 (ASTM D198-02, 2002).

$$MOE = \frac{P_e L^3}{48 \delta_e I} \quad \text{(for three point bending test)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$MOR = \frac{1{,}5\, P_u L}{b h^2} \quad \text{(for three point bending test)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

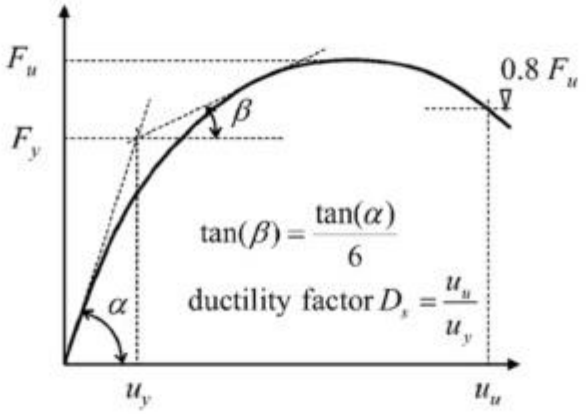
$$MOE = \frac{P_e a}{24\, \delta_e\, I}\left(3L^2 - 4a^2\right) \quad \text{(for four point bending test)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$MOR = \frac{1{,}5\, P_u L}{b\, h^2} \quad \text{(for four point bending test)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$D_u = \frac{\delta_u}{\delta_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where:
MOE = modulus of elasticity (MPa)
MOR = modulus of rupture (MPa)
P_e, P_u = elastic and ultimit load (N)
δ_e, δ_y, δ_u = elastic, yield and ultimate deflection respectively (mm)
L = span of beam (mm)
a = load distance to the supported (mm)
I = moment of inertia (mm^4)
D_u = ductility index

Because the determination of the yield point of the load-deflection curve is difficult, then used the approach as Figure 2 (SIA 265, 2003). Most timber structures are not able to develop full plastic mechanisms at failure. The plasticization only develops in timber under compression. In this case, the currently relative definitions of ductility, as a ratio between an ultimate deformation/displacement and the corresponding yield quantity (Jorissen & Massimo, 2011).



Source(s): SIA 265. 2003

Figure 2. Definition of Ductility Factor, Yield and Ultimate Deformation

RESULTS AND DISCUSSIONS

Flexure Strength and Stiffness of Glue Laminated Timber Beams

The results of the three-point bending test on laminated timber beams are presented in Figure 3. There are two phases to the load-deflection curve of each beam, namely the phase of linear and non-linear phase. Mix glue laminated timber beams by compose sengon-coconut wood (type II.11) has a linear phase firmer and longer. The maximum load is reached after all laminated beams through a non-linear phase. Based on Figure 3, the apparent decrease in the maximum deflection is achieved due to the placement coconut wood on the outer lamina. Bending strength and stiffness changes also occur due to the placement of coconut wood on the outermost lamina (mix-glulam method).

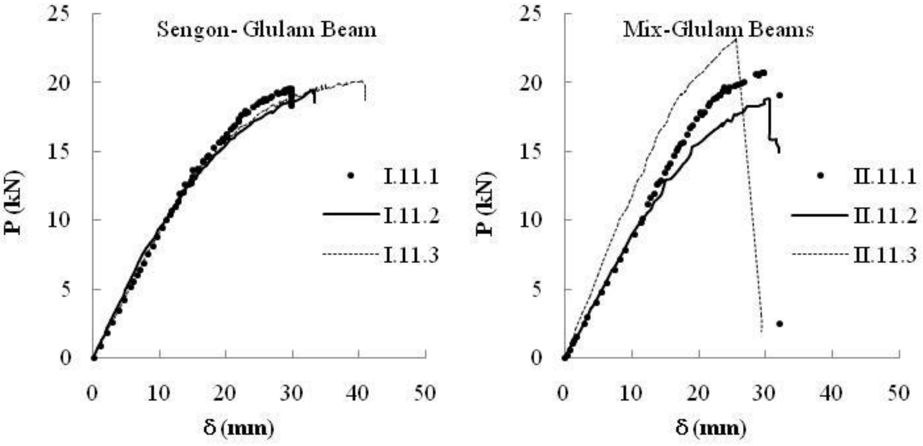


Figure 3. Load-Deflection at Mid Span of Glue Laminated Timber Beams

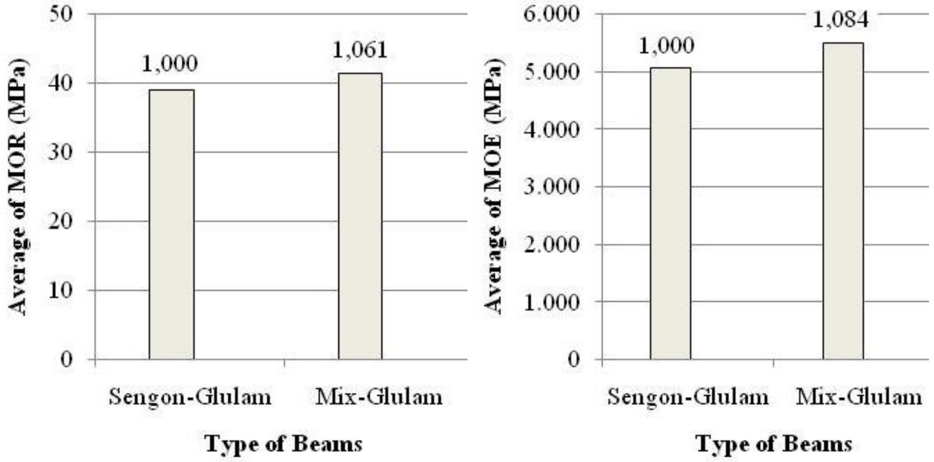


Figure 4. Flexure Strength and Stiffness of Sengon-Glulam and Mix-Glulam Beams

In this case, the mix glulam method produce flexural strength and modulus of elasticity which is higher than the uniform laminated timber beams (uniform glulam method). Figure 4 shows an increase in flexure strength and stiffness by application of the mix glulam method is 6.1% and 8.4% respectively. Both occurred because of the strength increased in the outermost lamina (laminating effect). In this case the tensile strength of coconut wood is higher than the tensile-strength of sengon wood. This is in line with the statement that the bending strength of laminated timber beams is determined by the strength of the outermost lamina (Falk & Colling, 1995).

The laminating effect are shown in Figure 5. By comparison of flexure strength (MOR) and modulus of elasticity (MOE) of the sengon-solid beams and sengon-glulam beams showed an increase. The increase in flexural strength of 8.4% caused by the lamination process applied to sengon wood. Likewise, the modulus of elasticity of sengon-wood increased by 26%. This increase occurred due to the densification effect of the lamination process. There is also a weak zone deployment of the lamina. In solid timber beam, the weak-zone concentrated in one location. But in laminated beams, the weak zone (wood defect) will be spread along the beam.

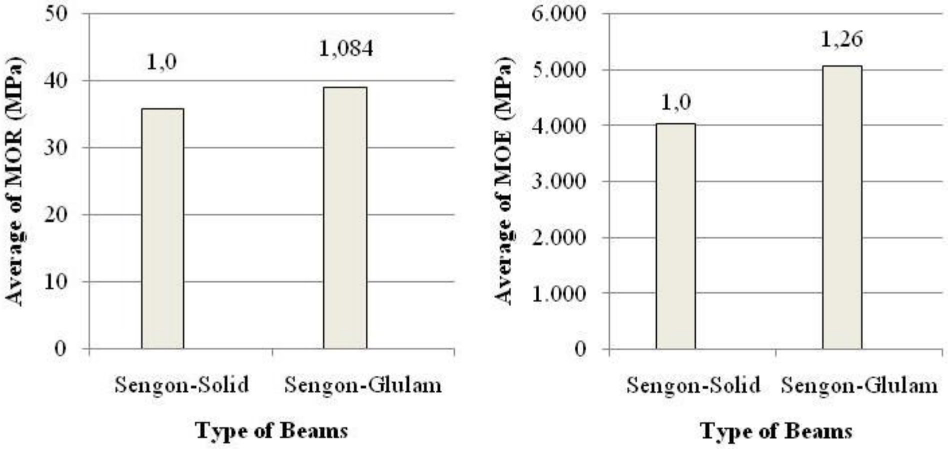


Figure 5. Flexure Strength and Stiffness of Sengon Solid and Glulam Beams

Ductility and Structural Efficisy of Beams

In terms of ductility, the lamination process and placement of coconut wood in the outer zone of glulam beams produces the ductility index smaller than the sengon-solid beam as Figure 6. Its means a solid beam (sengon-solid beam) is more ductile than laminated timber beams (sengon-glulam beam).

The decrease of ductility index is 14% and 27%, respectively for sengon-glulam beams and mix-glulam beams. The ductility index is closely associated with the failure mode of the beam. If the beam ductility index is smaller, so the beams failure that occurred tend to be more brittle. In this research, the application of lamination methods contribute to an increase in flexural strength (MOR) and modulus of elasticity (MOE) of the beam, while also contributing to changes the failure mode from ductile to more brittle, as shown in Figure 7.

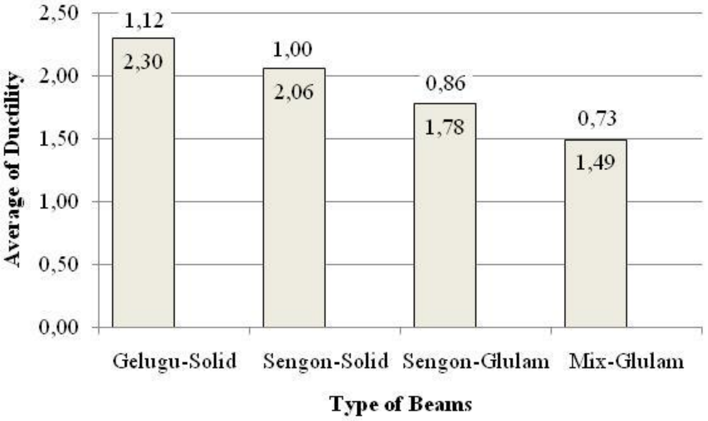


Figure 6. The Ductility Factor of Solid and Glulam Beams

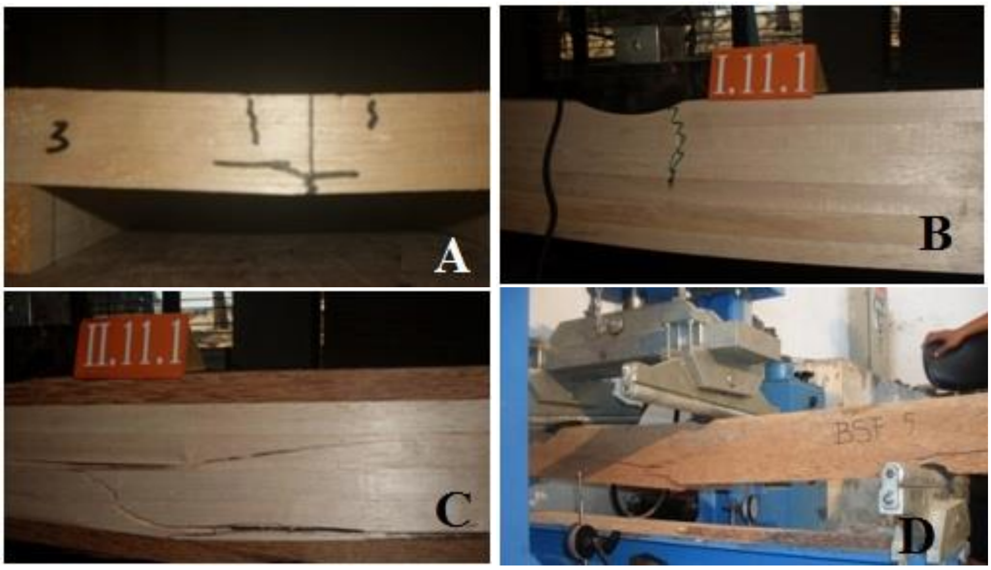


Figure 7. Failure Mode of Solid and Glue Laminated Timber Beams
Where: A. Ductile failure of sengon-solid beam
B. Ductile failure of sengon-glulam beam
C. Brittle failure of mix-glulam beam
D. Brittle failure of coconut wood-solid beam

The brittle failure is one of the shortcomings of building construction if it is associated with ductility requirements on the earthquake structural design. Therefore need to be treated in addition to the glue laminated timber beam structure to improve the ductility, for example by application the external reinforced. However, when viewed in terms of strength and structural-efficiency, then the glue laminated timber beam structure of are still very good.

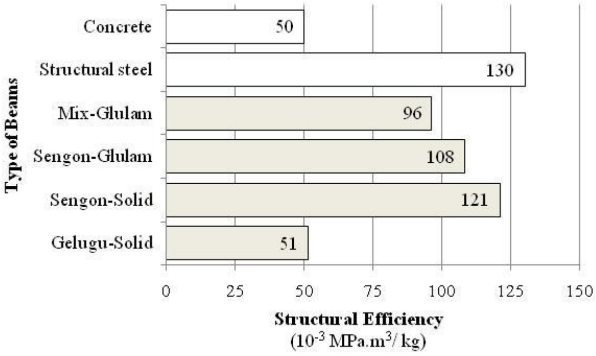


Figure 8. The Comparison of Structural-Efficiency of Wood with Steel and Concrete as Constructions Materials

The use of wood as a construction material has an structural-efficiency level is very adequate. In this case, the system of laminated beams (sengon-glulam, mix-glulam) have a level of structural-efficiency approximately two times better than concrete, and almost equivalent to steel (Figure 8). So with a combination of flexure strength and structural-efficiency, the glue laminated timber beam system are viable to developed. Furthermore, if the environmental impact factors involved included as a consideration in the selection of construction materials, the use of laminated timber beam structure would provide benefits. By compared with concrete and steel, as presented in Table 1, the mix-glulam system is very suitable to be applied for green-construction.

CONCLUSIONS

The mix-glulam method can increase flexure strength and stiffness of glue laminated timber beams by 6.1% and 8.4% respectively. This increase occurred due to laminating effect and strengthening the outer zone by placement of coconut wood. The lamination process resulted in increased bending strength and modulus of elasticity wooden beams sengon 8.4% and 26% respectively.

The lamination process and placement of coconut wood in the outer zone of laminated beams causes a decrease in ductility of 14% and 27%, respectively for laminated beams-sengon and mix-glulam. This means that the solid beam sengon more ductile than laminated beams. Thus, the increase in flexural strength and modulus of elasticity of the beam actually causes changes in the pattern of collapse ductile (solid beam) into a brittle failure (laminated beams). Therefore, the external reinforcement in laminated timber beams was needed to improve the ductility.

Nevertheless, the laminated timber beams structure have a structural-efficiency level that approximately two times better than concrete and almost equivalent to steel. Therefore, the glue laminated timber beams structure could be developed as green-material construction purposes, especially in terms of the carbon emissions and storage.

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