The Study on Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) of Lamina Beams on The Lime Wood (*dryobalanops* spp.)

J Suryono and S O W Bhakti  
Department of Civil Engineering, Samarinda State Polytechnic – Indonesia  
Corresponding author: jokosuryono55@gmail.com

**Abstract.** The aims of this study are to determine the stiffness, flexural strength of lamina beam of lime wood by using both of adhesive Dovebond 30 and Synteko 1909. The testing was conducted based on standard ASTM D 143-05. Data was processed and analyzed by factorial design. The board made by using a log wood with a diameter of more than 40 cm and display 1 m which then split into several pieces of sheet board with 2; 1; 2 cm, thickness 5 cm. The board sheet was cut to a width of 5 cm, 2; 1; 2 cm thick and 71 cm long to make multiple walking joints and types. The entire adhesive resurfacing system was carried out using a cape/brush. Both lamina (double spread) surfaces was sprinkled with 200-220 g/m2 melting weight. The adhesion sliding strength of lime beam used 1.03 kN /cm2 of adhesive Synteko 1909 and 0.84 kN/cm2 of adhesive Dovebond 30. The measured three-layer lamina beam was the measurement results of lime wood that provides the stiffness efficiency (MoE) of 38.91% of solid beam stiffness (MoE) and the flexure strength (MoR) of 10.26% of the flexure strength of the solid beam. Three-layer lamina beam with five finger joints was the measurement result for the highest MoE stiffness of 1,321 kN /cm2 using the adhesive Dovebond 30, and the highest flexure strength of 80.6 kN /cm2 using the adhesive Synteko 1909.  

**Keyword:** MoE, MoR, lamina beams

1. **Introduction**  
The beam lamina is as an effort in providing an alternative to the stiffness (MoE), flexural strength (MoR) with a solid beam so that it can overcome the use of large beams. In Indonesia, the lamina beam is interested by the society to meet the availability of structural components with the desired size of the beam, it is necessary to develop the structural shape instead of solid beam but lamina component made by gluing or commonly called lamina or glulam (glued laminated) beam. East Kutai Regency is a growing area of lime forest plantations (figure 1-2). Some people around Muara Wahau use the wood for use as building material because it is easy to obtain. To meet the availability of structural components with dimensions that are independent of the diameter of the wood, a non-wooden structure is developed but the laminate component is made by sticking or called laminated beams.  

The lamina beam is a composition of several layers of wood glued together perfectly into one unity without any displacement. According to [8] the finger joints at the ends of wood cuts are very effective because they are most porous so that it allows the adhesives to flow into the wood to form stronger adhesive bonds than edge-to-edge joints and edge-to-end joint. A well-made finger joint will easily achieve a joint strength of about 85% of solid wood.
2. Research Methods

2.1. The location
The location of the research was conducted at the Laboratory of the Faculty of Forestry Mulawarman University of Samarinda. The manufacture of test samples in lamina wood industry company PT. Light Samtraco Utama Samarinda. PT. Cahaya Samtraco Utama is located on Economic Road of Loa Buah Village Kunjang River Subdistrict of Samarinda, East Kalimantan Province.

2.2. The object of the research
The object of the research was the Cretaceous Tree (Dryobalanops spp.,) felled from the forest growing in Muara Wahau area of East Kutai Regency with > 40 cm diameter.

2.3. The materials
The materials used in the research were as follows: Lime wood, Polyvinyl acetate white glue type adhesive with adhesive Dovebond 30, Polyester resin type adhesives, Vinyl ester resin and Acrylate with adhesive Synteko 1909.

2.4. The instruments
The instruments used for the research test were as follows: measuring instruments (micrometer), electric balance, oven, caliper, constant room, testing machine (Universal Testing Machine 100 kN), with type OTTO WOLLPERT 10 TUZ 745, WOLLPERT PW 15 S type pendulum, stationery, calculator and computer.

2.5. Research Procedures
Research Procedure include the manufacture of beams; the manufacture of lamina beams; and form and size formation test sample. In the beam making procedure, the beam material is made of Lime wood. The beam making includes log woods with diameter more than 40 cm and display 1 m split into several sections of beam with square size, then plotted to remove the fibers and smoothed the surface. In the manufacture of lamina beams, lamina beam materials were made of lime wood. The making of the lamina beam includes the making of boards; the making of a joint; and gluing process. Making the board is done by using a log wood with a diameter of more than 40 cm and display 1 m which then split into several pieces of sheet board with 2.5 cm thick, 5 cm, and then it was planned to remove the fibers and smooth the surface. In the making of the walking joints, the board sheet is cut
to a width of 5 cm, 2.5 cm thick and 71 cm long. And some pieces were made of the jaw joints as the material to make into multiple joints and types. In the gluing process, it included the using the adhesive Dovebond30 and the adhesive Synteko 1909. Before the gluing process, the lamina surface was smoothed, cleaned of any dirt. The entire adhesive resurfacing system was carried out using a cape / brush, and is sprinkled on both lamina (double spread) surfaces with 200-220 g / m² melting weight. The gluing begins on the bottom lamina lining, followed by the upper layer. The finished lamina laminated throughout the gluing process was placed between 2 (two) square iron profiles fitted with an iron plate, followed by clamping at a distance of 30 cm for ± 45 minutes. Before re-aligning the entire lamina surface and testing of the flexure strength, the lamina beam needs to be conditioned first for at least 7 (seven) days to ensure the adhesion maturation process. The measurement of the cross-sectional dimension consists of the width and thickness of the wood on all solid beams, lamina beams and lamina junction connecting beams.

![The Research Flow](image)

In the procedure of making the form and size of test examples, the test sample for the measurement of moisture content, density, solid beam, and the sliding strength lamina beams were made each with the size of 5 cm x 5 cm x 5 cm and lamina beam 5 cm x 5 cm x 7, 5 cm as many as 6 replicates of lime wood. Similarly, a sample test for the measurement of MoE stiffness and the strength of the solid beam MoR mole was made in each test of 3 replicates of lime wood, measuring 5 cm x 5 cm x 71 cm (Figure 4 – Figure 10). Test samples for the measurement of MoE stiffness and the flexure strength of lamina beam and lamina beam joints of lime wood each with 2.5 cm thick, 2.5 cm thick and 5 cm thick as many as 3 replications.
The lamina wood is glued with adhesive resurfacing on the side of the joint. Adhesives are sprinkled from 200-220 g / m² using a brush evenly, and ensuring all of the gluing layers are smeared. Further soon the arrangement of lamina wood in the clamps because of the hardening bonding occurs quite quickly. This clamp is carried out for 1 (one) day until the hardening occurs perfectly.

3. Discussion

3.1. The Physical and Mechanical Characteristics of solid wood

The average value of physical and solid mechanical characteristics of lime wood that has a diameter of more than 35 cm can be seen in Table 1.

| Wood Characteristics | Lime Wood | Average | coefficient of variation (%) |
|----------------------|-----------|---------|-----------------------------|

Figure 4. Solid Beams
Figure 5. Lamina Beams 2 Layer
Figure 6. Lamina Beams 3 Layer
Figure 7. Lamina 2 Layer 2 Joints
Figure 8. Lamina 2 Layer 3 Joints
Figure 9. Lamina Beams 3 Layer 3 Joints
Figure 10. Lamina Beams 3 Layer 5 Joints
According to [10], density is an important feature of wood and needs to be known. With the forging and the process of penetrating the adhesive into the wood, the density value will increase. The average value of normal density of Lime wood is 0.61 g/cm$^3$. The sliding strength is a measure of the strength of wood in terms of its ability to withstand forces that make a part of the wood shift to another in the parallel plane of fiber [4]. Lime wood sliding strength was 1150 N/cm$^2$.

The stiffness is the ability to resist form changes or arches and Modulus of Elasticity (MoE) wood is an indication of stiffness [7], states that MoE is the proportional slope of the linear line and the stress and strain curves. Modulus of Rupture (MoR) is a fiber strength that occurs at the maximum load that is when the object fails and is said to be maximum strength. The lime wood MoE stiffness was 951 kN/cm$^2$ while the lime wood bending strength was 7.31 kN/cm$^2$. From Table 1 above shows both the physical and mechanical properties of wood. Based on the classification of Indonesian hardwood class by [3] lime wood including strong class II.

3.2. Adhesion Sliding strength of Lamina Beams

The average value of adhesion sliding strength of lime wood lamina beam by using adhesive Dovebond 30 and Synteko 1909 used in this study can be seen in Table 2.

| Wood Type | Glue     | Adhesion Sliding Strength (N/cm$^2$) | Wood Failure (%) |
|-----------|----------|--------------------------------------|------------------|
| Lime wood | Dovebond 30 | 873,6                                | 29,65            |
|           | Synteko 1909 | 1030                                | 13,51            |

The unevenness of the adhesive sliding strength measurements of lamina is due to the strong adhesive differences of each adhesive quality. The failure occurs in each type of adhesive, used as observation of the difference in the value of the maximum load that can be withheld and the value of sliding strength.

The result of measurement of parallel sliding compressive fiber in the laboratory was seen from the number of test samples failure on both surface of the adhesive Synteko 1909 layer of wood crushing value and the adhesion sliding strength was bigger than adhesive Dovebond 30. According [7], on wood with low density, high adhesion strength, this is due to the adhesion strength of the wood so that the damage occurs when the measurement occurs only in the wood. High density woods generally have concentrations that beam the adhesive constraint when the lamina beam cross section is a unity between the lamina beam and the use of adhesive material. No unifying layers of the lamina beam surface were caused the unevenness of the gluing process.

The ANOVA Sliding strength values of lamina beam by using the adhesive Dovebond 30 and Synteko 1909 used in this study are shown in Table 3.

| Source of Diversity | Free degree | Sums of Squares | Mean Squares | F-count | F table |
|---------------------|-------------|----------------|--------------|---------|---------|
| SD                  | Fd          | SS             | MS           | F-count | 5 %     | 1 %     |
4.402 & 1.467 & 5.05 & 3.10 & 4.94 \\
4.94 & 3.10 & 4.35 & 8.10 \\
5.05 & 3.10 & 4.35 & 8.10 \\
9.04 & 9.04 & 9.04 & 9.04 \\
20 & 5.816 & 291 & 291 \\
23 & 10.217 & 10.217 & 10.217 \\

Note: * = significant ** = very significant ; ns = non-significant

Analysis of sliding strength of lamina lime beam with 95% confidence interval, F-count > F-table (α) = 5% > F-table (α) = 1%, where F-count = 9.03, F-table (α) = 4.35 and F-tables (α) = 8.10 was significant which the value of sliding strength strongly influenced by lamina type. The F-count value> F-table (α) = 5%, where F-count = 6.08 and F-table (α) = 4.35 was significant which the value of the adhesion sliding strength is influenced by the type of adhesive. It was indicated that there were influences of lamina type and adhesive type. Therefore, the type of lamina and adhesive type of sliding strength was followed by further tests. To see significant differences in each type of adhesive, it was necessary to have further test on the adhesion sliding strength of the Dovebond 30 and Synteko 1909 as we can see in Table 4 as follows:

### Table 4. The Further Test on LSD on the Adhesion Sliding Strength

| Adhesive       | Average (N/cm²) | LSD 5% | LSD 1% |
|----------------|-----------------|--------|--------|
| Dovebond 30    | 762.9           | 0      | 15     |
| Synteko 1909   | 934.5           | 0      | 28     |

Note: * = significant

From Table 4 above, it shows that the adhesion sliding strength of the lamina beam using 934.5 N/cm² of adhesive Synteko 1909 was better than the adhesion sliding strength of the lamina beam using 762.9 N/cm² adhesive Dovebond 30. Further testing of LSD showed that the adhesion sliding strength of the lamina beam was significantly different between the adhesive Dovebond 30 and the adhesive Synteko 1909, in which the adhesive Synteko 1909 had better adhesion sliding strength than the adhesive Dovebond 30. This is because the adhesive Synteko 1909 is a synthetic adhesive with a base material of Polyester resin, Vinyl ester resin and acrylate plus Hardener 1999. While adhesive Dovebond30 is a white glue polyvinyl acetate. Thus, the results of lamina beam testing measurements with parallel loading of fiber show that the adhesive Synteko 1909 is better than the adhesive Dovebond 30.

### 3.3. Modulus of Elasticity (MoE), Modulus of Rupture (MoR) on Lamina Beams

The stiffness of MoE of each type of solid wood beams, 2-layer lamina beams, and 3-layer lamina beam by using both adhesive Dovebond 30 and Synteko 1909 can be seen in Figure 11-14 below.
The measurements of MoE stiffness on solid beams and lamina lime beams with centralized loads in the middle of the spans in Figure 13 show the maximum MoE stiffness occurring in three-layer lamina beams with five joints using both adhesive Dovebond 30 and Synteko 1909 greater than the stiffness of MoE of solid beams. From both lamina beams, it can be seen that a five-layer lamina beam with five joints using adhesive Dovebond 30 retains the largest MoE stiffness of 22.54% larger than a three-layer with three joints and a three-layer lamina beam with five joint using Synteko 1909 holds the MoE stiffness of 9.13% larger than a three-layer lamina beam without any joints.

Moreover, Solid beam retains MoE stiffness of 951 kN / cm². Thus, it can be seen that both of three-layer with five joints and three joints lamina beams using adhesive Dovebond 30 experienced a 38.89%, 7.58% MoE stiffness and both of three-layer lamina blocks with five joints and without any joints using Synteko 1909 experienced efficiency of stiffness as much 16.79%, 6.13% of MoE stiffness of solid beams. This shows that a three-layer lamina beam with five joints of a MoE stiffness
value of 1.321 kN / cm\(^2\) was a three-layer lamina beam with five joints providing a larger increase of solid beam MoE stiffness using adhesive Dovebond 30.

The flexural strength of MoR of each type of lime wood solid beam, two-layer lamina beam, three-layer lamina beam using adhesive Dovebond 30 and Synteko 1909 can be seen in Figure 14 below:

![Figure 14. MoR of Solid beams and lime wood lamina beams](image)

The results of the measurements of the flexure strength MoR of solid beams and lime wood lamina beam centralized load in the middle of the span in the figure 14, shows that the maximum flexure strength MoR of solid beam was 7.31 kN/cm\(^2\), the flexural strength MoR of a three-layer lamina beam without any joints was greater than a two-layer lamina beam with two joints using adhesive Dovebond 30 and a three-layer lamina beam with five joints was greater than the flexural strength MoR of a two-layer lamina beam without any joints using adhesive Synteko 1909. From the observation of both lamina beams, a three-layer lamina beam without any joints using adhesive Dovebond 30 was a lamina beam that could retain flexural strength 0.79\% greater than a two-layer lamina beam with two joints and a three-layer lamina beam with five joints using adhesive Synteko 1909 could retain the flexural strength MoR as much as 22, 68\% greater than a two-layer lamina beam without any joints could.

A solid beam could retain flexural strength MoR as much as 7.31 kN/cm\(^2\). Thus, both of a three-layer without any joint and a two-layer lamina beam with two joints using adhesive Dovebond 30 experienced the efficiency of the flexure strength MoR as much 4, 32\%. Furthermore, a three-layer lamina beam with five joint using Synteko 1909 experienced 10.26\% of the flexure strength MoR while a two-layer lamina beam without any joint experienced the weakening of the flexure strength as much 2.05\% of the flexure strength MoR of the solid beam.

The measurements of the solid beam and the lamina beam that measured on the static position with the load centralized on two locations was symmetric so that the maximum of the stiffness MoE and the flexure strength MoR was not equal, the compressive strength occurred on the upper fiber and the tensile strength occurred on the lower fiber. The greatest stiffness MoE and flexure strength MoR was in the center of the span. At the loading time, lamina beam experienced a slip that occurred among the layers in the pulling area. The imperfection of the gluing process caused the efficiency and weakening of the stiffness MoE as well as the flexure strength MoR.

The measurement results of the mean score showed that the influence of the wood density on the adhesion strength, the stiffness MoE, the flexure strength MoR as well as the wood finger joint
efficiency was uneven, except on the lime wood. It was because the lime wood has the low density, more porous than the other woods which have bigger sticky surface, thus, its gluing strength as well as its joint becomes higher [8].

4. Conclusion
The sliding strength of lamina beam using Synteko 1909 was 89.57% of the solid beam. Based on both physics and mechanics characteristics, it was classified into the strong class II which can be used as construction materials. Besides that, the adhesion sliding strength of lamina beam using 1.03 kN/cm² Synteko 1909 higher with adhesive Dovebond 30 was 17.90%, the failure lamina beam using adhesive Synteko 1909 was higher than when it used adhesive Dovebond 30. Thus, the big failure gives strength. The three-layer type 2 lamina beam (Figure 10 dan Figure 13) MoE was 38.91% and MoR was 10.26% higher than solid beam’s (Figure 10 and Figure 14). The best design was the three-layer lime wood with five finger joints that had the highest MoE as much 1.321 kN/cm² glued together with adhesive Dovebond 30 and the highest MoR as much 8.06 kN/cm² glued together with adhesive Synteko 1909.

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