The Influence of the use of horizontal pegs at distance of 15 cm to the shear strength of the laminated bamboo beam based on type of adhesive

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Abstract. Laminated bamboo can be used as an alternative elements of building materials. Laminates techniques can be used to form the building materials used as construction in large sizes. Previous studies have extensively covered the beam strength of laminated bamboo, type and crack. The test of the shear strength with the use of 60 MDGL A (Mutilayer Double Glue Line), resulting in shear fracture between bamboo material and not occur in the adhesive. Comparison between high beam size and the width is 120 mm x 60 mm. Further tested the strength of the beam to the shear capacity with four variations of adhesive. Using bamboo outer skin on the surface of the beam and the use of 50 MDGL adhesive variations. The results showed that there was no significant difference in shear strengths between the variations of each adhesive. Beam strength is highest test object is on 50 MDGL C with a value of 24.4 KN load with a deflection of 41.5 mm. The average shear stress laminated beams obtained is on 5.49-6.66 and 4.58 MPa. This strength is still greater than the strength of the wood beams in general, where the wood shear stress is 1.25 MPa class II.

1. Introduction
Bamboo is one of the non-forest resources that is widely used by Indonesian people. Bamboo can be used as an alternative substitute for wood to overcome the scarcity of wood raw material supply for the furniture industry. Bamboo has several advantages such as easy to plant, fast growth rate, does not require special maintenance, easy to obtain, easy to process, and in parallel directions the bamboo fibre has a better mechanical properties than wood.

Previous studies have reviewed the strength of laminated bamboo beams, the type of collapse and crack patterns. Some tests on shear strength with the use of adhesive tape 50 # MDGL (Mutilayer Double Glue Line), obtained that faults occur partially between bamboo materials, and not occur in adhesives. [8]

The results of previous studies, Zulmahdi [16] obtained the use of glue paste 30 # MDGL (Mutilayer Double Glue Line), 40 # MDGL (Mutilayer Double Glue Line) and 60 # MDGL (Mutilayer Double Glue Line) on laminated bamboo beams has no significant differences in shear strength and stiffness.

The results of previous studies, Hanung [17] obtained the use of variations in the spacing of 10cm, 15cm and 20cm on laminated beams has no significant differences between shear strength and stiffness, and the optimum strength was obtained at a distance of 15 cm.

The research that will be proposed is the manufacture of laminated bamboo beams without the use of bamboo outer skin, using variations of 3 types of adhesive tape and pegs with a distance of 15 cm, so the use of the type of adhesive tape that has optimum strength is obtained. The comparison of the size or dimensions of the beam
between the height of the beam and its width is 2:1, measuring (12 cm x 6 cm), with 3 variations of the type of adhesive tape, and then the strength of the beam is tested for shear strength and bending.

Material mechanical properties are properties of a material related to changes in the shape of an object caused by the strength of the object’s resistance to the loads that affect it. This trait is important to determine the usefulness of an item, even for some purposes, this trait can be used as a material selection criteria. [18]

2. Literature Review

Zulmahdi [19], laminated bamboo beam shear capacity with variations of MSGL (Mutilayer Single Glue Line) adhesive tape and horizontal peg use. The results of the study showed that the effect of the use of pegs and adhesives tape 30 # MSGL (Mutilayer Single Glue Line), 40 # MSGL (Mutilayer Single Glue Line), 50 # MSGL (Mutilayer Single Glue Line) and 60 # MSGL (Mutilayer Single Glue Line) on laminated beams on strength and stiffness, there were no significant differences. The highest beam strength is 60 # MSGL (Mutilayer Single Glue Line) with an average value of 20.6 KN. The laminated beam shear stress is averaged 2 Mpa. This strength is still greater than the strength of wood beams in general, where the shear stress of strong wood class II is 1.25 MPa.

Hanung [17] examined the effect of using horizontal pegs with variations in the distance of 10 cm, 15 cm and 20 cm against the strength of laminated bamboo shear. The results of the study showed that the use of pegs and adhesive tape on laminated beams, there were no significant effect on strength and stiffness. The optimum beam strength is on the test object with a spacing of 15 cm, and got an average value of 3.8.

2.1) Water Content

\[ w = \frac{m_1 - m_2}{m_2} \times 100\% \]  

with:

- \( w \) = bamboo’s water content (%),
- \( m \) = mass of bamboo before drying (g),
- \( m_2 \) = oven dry bamboo mass (g).

2.2) Density

\[ \rho_w = \frac{m_w}{V_w} \]

with:

- \( \rho_w \) = the density of bamboo in water content \( w \) (g/cm\(^3\))
- \( m_w \) = bamboo mass at water content \( w \) (g)
- \( V_w \) = the volume of bamboo in water content \( w \) (cm\(^3\)).

2.3) Compressive Strength

\[ \sigma_{sk} = \frac{P_{maks}}{A} \]

with:

- \( \sigma_{sk} \) = Compressive Strength (MPa),
- \( P_{maks} \) = maximum compressive force (N)
- \( A \) = thickness x width = stressed area (mm\(^2\)) of the test object.

2.4) Tensile Strength

\[ \tau_{sk} = \frac{P_{maks}}{A} \]

with:

- \( \tau_{sk} \) = Tensile Strength (MPa),
- \( P_{maks} \) = maximum tensile force (N),
- \( A \) = thickness x width = extracted area (mm\(^2\)) of the test object.

2.5) Shear Strength
\[
\tau_{\text{sk},L} = \frac{P_{\text{maks}}}{A}
\]

with:
- \(\sigma_{\text{sk},L}\) = Shear strength parallel to the fibre (MPa),
- \(P_{\text{maks}}\) = maximum shear force (N)
- \(A\) = thickness \(\times\) width = shifted area (mm\(^2\)) of the test object.

2.5) Curvature

\[
R = \frac{\gamma(n-1)+2\gamma(\gamma(n+1)}{d\Delta x^2}
\]

2.6) Internal Moments

Calculation of internal moments of laminated beams is based on the strip method with the line equation for the compressed area is \(y = -8E + 10x4 + 2E + 09x3 - 3E + 06x2 + 8765,7x - 0,8638\), while the line equation for the extracted area is \(y = 11864x2 + 1143.5x + 11.252\). Next, determining the height of the compressive and tensile area is carried out by the following procedure:

- **a.** Strain = beam curvature \(\times\) Pias distance
- **b.** Stress = line equation from the stress-strain graph with variable \(x\).
- **c.** Area of strip = stress \(\times\) delta strip.
- **d.** The strip distance to the neutral line = \(1/2\) the distance of the new strip delta plus the previous strip delta
- **e.** Static moment = strip distance to neutral line \(\times\) strip area
- **f.** Strip force = strip area \(\times\) beam width.
- **g.** Moment arm distance =
  \[
  d = \frac{\text{total static moment of press area}}{\text{total area of strip press area}} + \frac{\text{total static moment of pull area}}{\text{total area of strip pull area}}
  \]
- **h.** Internal Moment = \(C \cdot d\)

2.7) Flexural strength

\[
MOR = \frac{MYa}{l}
\]

with:
- \(MOR\) = bamboo bending modulus (MPa),
- \(M_{\text{max}}\) = Maximum moment (N mm),
- \(Y_a\) = Upper edge distance to neutral line (mm)
- \(l\) = Beam Inertia (mm\(^4\)).

2.8) Shear strength

\[
f = \frac{M c}{l} \quad \text{and} \quad \nu = \frac{VQ}{lb}
\]

2.9) Modulus of elasticity

\[
MOE = \frac{PL^3}{48,\delta.l}
\]

with:
- \(MOE\) = bamboo elastic modulus (MPa),
- \(L\) = bamboo length (mm)
- \(\delta\) = proportional deflection of bamboo (mm),
2.10) Gluing Process

The gluing of wood using the term glue spread is the amount of adhesive that is sprinkled per unit area of surface adhesion. The unit of fixed surface area is determined by a British unit of a thousand square feet (1000 square feet) as MSGL (Multilayer Single Glue Line) or pounds (Lbs). If the two surface areas are covered, it is called MDGL (Multilayer Double Glue Line) or two-sided investment (Prayitno, 1996), in laboratories the adhesive units are converted into simpler ones called GPU (gram pick up) with Equation 9:

\[ GPU = \frac{S \cdot A}{317.5} \]  
(11)

Information:
GPU = Gram Pick Up (in grams)
S = amount of adhesive which is sprinkled in pounds / MSGL (Multilayer Single Glue Line) or pounds / MDGL (Multilayer Double Glue Line)
A = area to be glued (in square)

Adhesive fields are calculated in units of square centimeters Equation 9 becomes:

\[ GPU = \frac{S \cdot A}{2048.3} \]  
(12)

2.11) Laminated beam

Laminate beams are made of relatively thin layers of wood which can be combined and bonded in such a way as to produce wood beams of various sizes and lengths (Breyer, 1988). Some of the advantages owned by the laminate structure include: sizes can be made higher, longer spans, curved shapes and oval shape configurations can be easily fabricated, can be reduced form changes and reduced strength by wood defects can be made more random (Blass et al, 1995). In addition, the material used in the beam can be selected from the supply of good quality laminates and natural characteristics, that limit the capacity of solid wood to be ignored in the glulam beam (Breyer. 1988).

Based on the material used, there are beams with one type of material / constituent material and beams with two kinds of constituent material where the stronger material is on the outside, while the weaker one is in the inner part (core). By following the concept on bamboo lamination obtained from the processing of bamboo bars starting from cutting, gluing, and pressing, to obtain the desired laminate shape. For some things, the properties of lamination do not differ greatly from the nature of the original bamboo. The final properties will be much influenced by the number of nodia / segments on one stem and the adhesive used. [20]

3. Research Methods

This research will be carried out by making laminated bamboo without using outer skin with variations of 3 types of glue adhesive including adhesive B, C and D, the results of this study obtained the type of adhesive with optimum shear strength. The following are some of the supports in the study, including:

3.1) Research Materials

The materials used in this study are as follows:
1) Bamboo Petung

Bamboo is used for laminated beam material and the making of pegs is taken in the middle of the stem and without the use of outer skin,
2) Adhesive

The adhesive material used is 3 types of adhesive with adhesive B, C and D

3.2) Research Equipment

The research equipment is divided into two, namely equipment for making test objects and equipment for testing specimens, both physical and mechanical properties
1) Test Item Equipment
The tools used for making test objects are:

a) Circular Panel Saw.
b) Planner Machine.

2) Other complementary tools, including: Measuring / crossing meter, wire, balance / scales, clamping clamps, channel steel (C), adhesive containers along with stirrers (sticks), vise pliers, bolt locks, axes, saws and KNives cutter.

3) Physical and mechanical testing equipment:

a) The mechanical testing machine UTM (Universal Testing Machine) is used to test the mechanical properties of lamina beams.

b) Tools for bending and shear testing of laminated beams of the E brand include a frame loading and load controller tool and are added with Dial to read deflection during testing.

3.3) Test Object

1) Preliminary Test Objects

The behavior of bamboo mechanics in the place and season has an effect, so in the first and second years it needs preliminary testing. The size of the specimen for testing the physical properties and mechanical properties of bamboo follows the ISO (International Standard Organization) standard 3129-1975. The number of test specimens for preliminary petung bamboo is presented in Table 3.1 and each preliminary material test material is made in quantities as below.

| No | Type of Testing | Number of Test Items | Testing Standard |
|----|----------------|----------------------|-----------------|
| 1  | Density        | 3 pieces             | ISO 3130-3131-1975(E) |
| 2  | Water content  | 3 pieces             | ISO 3130-3131-1975(E) |
|    | Total          | 6 Pieces             |                  |

The laminated shear block test object is made using 50 # MDGL (Mutilayer Double Glue Line) adhesive tape. Each Test Item can be seen in Table 3.2.

| No | Types of Test Objects                                           | Total  |
|----|----------------------------------------------------------------|--------|
| 1  | Laminated bamboo shear 50 # MDGL (Mutilayer Double Glue Line) with 3 types of adhesive tape | 9 pieces |
|    | Total                                                           | 9 pieces |

3.4) Test Item

The laminated beam specimens were made as many as 9 blocks measuring 6 cm x 12 cm with variations of 3 types of adhesive tape including B, C and D, each with 3 replications using the spacing resulting from previous research.

| Test Item Name                               | Adhesive Type | Total (pieces) |
|----------------------------------------------|---------------|----------------|
| 50#MDGL (Mutilayer Double Glue Line) A       | B             | 3              |
| 50#MDGL (Mutilayer Double Glue Line) B       | D             | 3              |
| 50#MDGL (Mutilayer Double Glue Line) C       | C             | 3              |
|                                              | Total         | 9              |

3.5) Laminate Beam Testing

The laminated beam testing is carried out on a simple support (joints) with two loading points. Lateral restraints are provided to prevent the influence of lateral torsional buckling. From this setting it is expected to have a flexible collapse. The first loading frame is prepared with two supports and one
lateral restraint between the load and roller points. After that the test beam is placed on the pedestal, along with the profile beam that is used as the loading point. And the load cell on it. Load cell is connected with hydraulic jack and digital indicator transducer to find out the amount of load that works. After that a dial gauge is installed in the middle of the pointer range, set to zero. The loading process is carried out in stages and recording deflection occurs. During loading, damage was observed to the test object.

In general, the implementation of the research follows the flow chart as follows

![Flowchart of Research Implementation](image)

**Picture 1. Flowchart of Research Implementation**

4. **Analysis Method**
Analysis is done by connecting the results data from the literature study with its application into the structure of building construction. Data were analysed by considering the reciprocal relationship between the properties of bamboo and the structure of the construction that occurred, so that a conclusion occurred.

5. **Expected Output**
The success of this research is measured based on the achievement of the success indicators as follows:
1. The ideal and economical type of adhesive is used to obtain a balance between the strength of bamboo material and the strength of the adhesive.
2. The technique of making laminated bamboo beams.

6. **Analysis and Study**
   a. **Preliminary Test Results**
Table 4.1 Moisture Test Results Data [21]

| Test Item   | Average   |
|-------------|-----------|
| End Section | 11.4405%  |
| Middle Section | 14.2217%  |
| Base Section | 13.9263%  |

Based on the table above, it is obtained that the moisture content of bamboo exceeds the water content required by the PT. C Specialty adhesive, the gluing process is 8% to 12%. The water content of the material does not meet the requirements, so before starting gluing, the bamboo must be dried by drying it for about 5 days or until it meets the 12% requirement.

b. Density

Table 4.2 Density Test Result [21]

| Test Item   | Average |
|-------------|---------|
| End Section | 0.66%   |
| Middle Section | 0.60%   |
| Base Section | 0.50%   |

Prayitno (1996: 46) states that for the classification of wood density less than 0.4 g / cm³ including light wood, wood density is less than 0.55% g / cm³ including medium wood and wood density less than 0.72 g / cm³ including heavy wood.

c. Strain Test

d. Stress Test
e. Strength of Laminated Bamboo Beams

1. Laminated Bamboo Beams with Type B Adhesive

The beam with the largest force load is on the 50 # MDGL (Mutilayer Double Glue Line) B1 beam with a style of 23.3 KN and deflection that occurs at 41 mm with a moment of 5850.0 KNmm and curvature of 05.83E-04.

2. Laminated Bamboo Beams with Type C Adhesive

The beam with the largest force load is on the 50 # MDGL (Mutilayer Double Glue Line) B1 beam with a style of 23.3 KN and deflection that occurs at 41 mm with a moment of 5850.0 KNmm and curvature of 05.83E-04.
Laminated Bamboo Beams with Type C Adhesive

The beam with the greatest force load is in the 50 # MDGL (Mutilayer Double Glue Line) C1 beam with a force of 24.4 KN and deflection that occurs at 41.5 mm with a moment of 6100.0 KNmm and curvature of 05.90E-04

Laminated Bamboo Beams with Type D Adhesive

The beam with the greatest load force is on the 50 # MDGL (Mutilayer Double Glue Line) R1 beam with a style of 22.3 KN and the deflection that occurs is 40.5 mm with a moment of 5575.0 KNmm and curvature of 05.76E-0

Table 4.3 Laminated Beam Stiffness [21]

| Test Item | Loads | Deflection | Stiffness | Average |
|-----------|-------|------------|-----------|---------|
|            |       |            |           |         |

Picture 4.4 Graphic of the Relation between Moment and Curvature with Type C Adhesive

Picture 4.5 Graphic of the Relation between Loads and Deflection with Type D Adhesive

Picture 4.6 Graphic of the Relation between Moment and Curvature with Type D Adhesive
The table above shows variations in the type of glue adhesive did not significantly affect the stiffness of the beam and the maximum beam stiffness value was in the Test Item with Type B adhesive.

### f. Internal and External Moment

#### Table 4.4 Internal and External Moment of Laminated Beams

| Test Item | Moment External | Moment Internal | Ratio |
|-----------|-----------------|-----------------|-------|
|           | KNmm            | Average         | KNmm  | Average |
| B1        | 4850            | 4133.333        | 9596.57 | 9079.25 |
| B2        | 4500            | 10412.67        | 7228.501 | 14078.01 |
| B3        | 3050            | 8593.46         | 14078.01 | 7964.18 |
| C1        | 5325            | 4533.333        | 11168.03 | 2463537 |
| C2        | 3050            | 8593.46         | 14078.01 | 7964.18 |
| C3        | 5225            | 4533.333        | 11168.03 | 2463537 |
| D1        | 2675            | 3441.667        | 6467.07 | 2314048 |
| D2        | 4300            | 10004.65        | 7964.18 | 2314048 |
| D3        | 3350            | 7420.83         | 7964.18 | 2314048 |

The results obtained from the analysis process show that the value of the external moment is greater than the value of the internal moment, but not too significant, and has met the equilibrium requirements of the structure, ie the internal force must be the same as the external force. The difference in value that occurs is probably caused by factors during testing.

### g. Shear Stress

#### Table 4.5 Shear Stress of Petung Bamboo Laminated Beams

| Test Item          | Shear Stress (Mpa) | Average | Wood Classification |
|--------------------|--------------------|---------|---------------------|
| 50# MDGL (Mutilayer Double Glue Line) | 5.78               | 5.49    | II                  |
| B1                 | 6.25               |         |                     |
| B2                 |                    |         |                     |
As a comparison, Adi's research results show a pattern of damage that occurs at the closest connection with placement, so that connections placed at bending stresses of both smaller and larger bending stresses have no effect on shear strength. The beam used in this study uses MDGL (Mutilayer Double Glue Line) # 60 glue adhesive with dimensions of 60 mm in width, 120 mm in height and a span length of 90 cm.

Table 4.6 Comparative Shear Strength [21]

| Test Item | Shear Stress Mpa | Average |
|-----------|------------------|---------|
| 60#MDGL (Mutilayer Double Glue Line) | | |
| 30A | 3.17 | 3.24 |
| 30B | 3.44 | |
| 30C | 3.1 | |
| 40A | 3.17 | 3.24 |
| 40B | 3.45 | |
| 40C | 3.1 | |
| 50A | 3.52 | |
| 50B | 3.32 | |
| 50C | 3.4 | |
| 60A | 4.45 | |
| 60B | 3.07 | 3.67 |
| 60C | 3.48 | |

h. Difficulties During Research

During the Research there were several difficulties experienced, including:

a. Limitations of skilled human resources during work.
b. Changing weather conditions greatly affect the length of drying of bamboo blades.
c. Wood cutting machines that often experience problems cause the length of the process cutting and making bamboo blades.

7. Conclusions And Suggestions

A. Conclusions

Based on the discussion and objectives of the research that has been conducted, some conclusions can be drawn, including the following: The average value of sequential shear blocks of 50 # MDGL (Mutilayer Double Glue Line) based on Table is 5.49 MPa, 6.66 Mpa and 4.85 Mpa. The results of this test did not obtain a significant difference. The testing behavior of the shear strength of the laminated beam is observed when it reaches the first crack the load experiences stuck or stopping but the deflection continues. Beams resist with deflection so that the load rises slowly to the maximum load. Without the use of bamboo outer skin reduces the cavities in the layers of the Test Item blades. Judging from the results of testing of shear strength, wood was obtained above class II.

B. Suggestion

Some suggestions to consider in bamboo research:

1. This research can be continued, namely by replacing the type of adhesive tape used.
2. Fabrication of Laminated beams should be carried out during the dry season, to obtain the optimum moisture content of bamboo according to the recommendations of the adhesive factory so that maximum bonding between the laminated bamboo occurs, where the water content limit is very difficult to achieve and when in the rainy season.

3. In bamboo processing, the bamboo should be placed indirectly in contact with the floor or soil to avoid water that stagnates and causes corrosion of the bamboo.

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