Effect of Rod Diameter and Adhesive Thickness to the Pull-out Strength of Threaded Steel Rod Glued in Laminated Bamboo

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Abstract. The purpose of this study was to determine the effect of threaded steel rod diameter and adhesive thickness on pull-out strength, shear strength, slip modulus, and damage patterns of glued-in rod embedded in laminated bamboo. The shape of the specimen is a cube with the dimensions of 100mm x 100mm x 100mm made of laminated Asian Bamboo (Dendrocalamus asper). The threaded steel rod diameter consists of three sizes, namely 8mm, 10mm, and 12mm. Each threaded steel rod is embedded in laminated bamboo to a 40mm length. The epoxy brand Sikadur 372 is used as an adhesive between laminated bamboo and threaded steel rods with three variations of adhesive thickness, namely 2mm, 3mm, and 4mm. Each variation of the test object was repeated five times. The results showed that the rod diameter and adhesive thickness affect the pull-out strength, shear strength, and slip modulus.

1. Introduction
Laminated bamboo can be used as a substitute for wood construction materials. This idea is supported by the mechanical properties of laminated bamboo, which resemble wood. A literature review on engineered bamboo and found that laminated bamboo has a compressive strength parallel to the grain of 63-64MPa, a compressive strength perpendicular to the grain of 20MPa, a tensile strength parallel to the grain of 102-191 MPa, a tensile strength perpendicular to the grain of 3- 4 MPa, the shear strength parallel to the grain is 4 MPa, MOR 78-88 MPa, and MOE 1-12 GPa [1].

Many studies on the application of laminated bamboo for structural elements have been carried out. Most of the studies included beams from laminated bamboo [2, 3], columns from laminated bamboo [4, 5], and boards from laminated bamboo [6, 7]. Structural elements such as beams and columns need to be combined to become an integral part of the structure. Joints are needed as a consequence of the size limitations of the beam/column or to meet the geometric shape of the structure. The joints must be constructed in such a way that they are as strong as the structural elements. Various connecting tools have been developed by previous researchers, ranging from nails, bolts, screws, and recently glued-in rods that have been successfully used in wooden joints. These studies were conducted by [8, 9, 10].

Surprisingly, the glued-in rod joint has never been applied to the structure of the bamboo laminate. This is because the characteristics of the connecting device are not widely known. Research conducted only provides information on the strength of pulling-out the glued-in rod in the direction of the laminated bamboo grain based on the rod diameter and the anchor length on the bamboo laminate [11]. Meanwhile, research only provides information about the pulling-out strength of glued-in rods that are embedded
parallel to laminated bamboo grains with variations in rod distance to the edge of laminated bamboo [12]. These two studies only examined several parameters that affected the characteristics of the glued-in rod, while many other parameters had not been studied. For this reason, the present study examines other parameters that are predicted to affect the characteristics of glued-in rods in laminated bamboo, namely the effect of rod diameter and adhesive thickness on the pull-out strength of rod embedded on laminated bamboo.

In a similar vein, various studies have been conducted to obtain formulas for calculating the pull-out strength of rods embedded in wood. A formula used to calculate the pull-out resistance of rods embedded in wood or laminated bamboo with an edge distance greater than or equal to the minimum distance allowed [13, 14, 15]. Furthermore, Stepinac et al [15] found three main parameters that determine the pull-out strength of the rods embedded in the wood, namely rod diameter, anchor length, and shear strength of the interfacial layer between the wood and adhesive or between adhesive and rod. In line with the findings [15], a formula (1) to calculate the pull-out strength of rods embedded in laminated bamboo [11], namely,

\[ F = L_a \times \pi \times d_a \times f_v \]  

(1)

where F: pull-out strength (kN), La: anchor length (mm), da: rod diameter (mm), fv: interface shear strength (MPa), and \( \pi \): mathematical constant.

In contrast, who used rod diameter to calculate the pull-out strength of rods embedded in laminated bamboo [11], used the diameter of the drilling hole to calculate the pull-out strength in wood [10] with the formula,

\[ f_{v,mean} = \frac{F}{\pi \phi_h \ell} \]  

(2)

with \( f_{v,mean} \): average shear stress (MPa), F: pull-out strength (kN), \( \phi_h \): drilling hole diameter (mm), and, \( \ell \): anchor length (mm).

The two formulas are used in different failure states. If failure caused by the pull-out strength occurs at the interface between the adhesive and the rod, formula (1) is used. Conversely, if the failure caused by the pull-out strength occurs at the interface between the adhesive and wood or bamboo, formula (2) is used.

Other researchers entered the adhesive thickness parameter as a variable and examined the effect of adhesive thickness on the pull-out strength of rods embedded in wood [16, 17]. None of the researchers have examined this on laminated bamboo.

During the pull-out test, a slip will occur at the interfacial between the rod and the adhesive or between adhesive and laminated bamboo. The amount of slip is calculated by the formula (3) and (4),

\[ \Delta S = Y - \Delta L \]  

(3)

\[ \Delta L = \frac{F \cdot L_o}{\Delta E} \]  

(4)

In formulas (3) and (4), \( \Delta S \): Slip (mm), Y: Increased total length (mm), E: Modulus of Elasticity of threaded steel rod (MPa), \( \Delta L \): Increased length of threaded steel rod (mm), F: Load (kN), A: Cross-section area of threaded steel rod (mm²), Lo: Initial length of threaded steel rod (mm).

The slip magnitude is used as the basis for calculating the joint stiffness. Joint stiffness is expressed in slip modulus (Ks) which is calculated by the formula (5) [18],

\[ K_s = \frac{0.4 F_{\text{max}}}{d_{04} - d_{01}} \]  

(5)

with \( K_s \): slip modulus (kN/mm), \( F_{\text{max}} \): maximum load (kN), \( d_{04} \): slip at 40% \( F_{\text{max}} \), \( d_{01} \): slip at 10% \( F_{\text{max}} \).

2. Materials and Methods

This study employed Asian Bamboo (Dendrocalamus asper) taken from Malang City, East Java, Indonesia, aged between 3 and 5 years old. This bamboo was sliced into strips 5 mm in width, 20 mm in thickness, and 1000 mm in length. To obtain uniform physical and mechanical properties from the
sliced bamboo, we used the bamboo parts that are close to the skin. Furthermore, the sliced bamboos were soaked for 4 hours in a solution mixed with the composition of 1kg Boric Acid (H₃BO₃), 1kg Borax (Na₂B₄O₇), and 100 liters of water, then dried until the moisture content is less than 12%.

The shape of specimens for laminated bamboo was a cube in 100mm width, 100mm thick, and 100mm length. It was engineered by gluing sliced bamboo using Urea Formaldehyde adhesive with a spreading of 268gram/m². During the gluing process, the laminated bamboos were pressed at 2MPa for 4 hours. From this procedure, we obtained bamboo lamination with a density of 0.684 grams/cm³ at a moisture content of 15.56%, compressive strength 59.08MPa, and shear strength parallel to grain 9.20MPa.

The steel threaded rods having a diameter of 8mm, 10mm, and 12mm were used in this study. The steel rods yield stress (fy) between 357MPa to 470MPa, ultimate stress (fu) between 402MPa to 534MPa, and an elastic modulus (MOE) between 123,051MPa to 231,324MPa and threads per inch (tpi) ranging from 15 to 21. Data on the steel threaded rods that were obtained from testing each of the three samples are listed in Table 1.

| Diameter (mm) | fy (MPa) | fu (MPa) | MOE (MPa) | tpi |
|--------------|---------|---------|-----------|-----|
| 8            | 357(28) | 465(20) | 123,051(17,431) | 21  |
| 10           | 353(15) | 402(9)  | 196,432(21,231)  | 18  |
| 12           | 470(2)  | 534(8)  | 231,324(23,253)  | 15  |

Remark: numbers in the bracket on 2, 3 and 4 columns are deviation standard

The steel rod was embedded on the bamboo laminate specimens in the direction of the grain which had previously been drilled on an anchored length of 400mm (figure 1). The Sikadur 732 adhesive produced by PT Sika Indonesia was used to glue between steel rods and bamboo laminates on 2mm, 3mm, and 4mm thicknesses. Sikadur 732 adhesive is an adhesive that has two components of epoxy resin, namely Solvent-free and thixotropic. The adhesive had a compressive strength of 63N/mm² and tensile adhesion strength of 12N/mm², respectively, at the age of 28 days.

The pull-out strength test was carried out within 28 days after the gluing process. A pull-compression configuration testing (figure 2) was carried out using a Universal Testing Machine on a 1000kN capacity and an 0.1kN accuracy. The slip measurements were carried out using a dial gauge on
a 50mm capacity and an 0.01mm accuracy. Load and slip readings were carried out in stages with an increase in the load of 0.5kN.

![Testing configuration](image1) ![Photo of testing](image2)

**Figure 2.** Pull-compression load configuration.

3. Results and Discussion

The tests conducted on the specimens yield three important data, namely pull-out strength, slip, and damage patterns. The analysis shows that all the specimens have the same pattern of relationship between load and slip, starting with the load and slip, both of which are zero, then the load is increased gradually by 0.5kN. This is done until the maximum load is reached, which describes the pull-out strength of the glued-in rod. The slope of the graph of the relationship between load and slip shows the magnitude of the modulus of slip, which is the amount of load required for the slip to be a unit length. An example of a graph of the relationship between load and slip as in figure 3 is obtained from the specimen coding 10-2B, namely the specimen with a rod diameter of 10mm, an adhesive thickness of 2mm, and the order of the B or 2nd order of 5 specimens.

![Graph](image3)

**Figure 3.** Typical relationship between load and slip.

3.1. Pull-out Strength and Shear Strength of Glued in Rod

The pull-out test gives the results of pull-out strength, as listed in Table 2 column 7. The pull-out strength is indicated by the maximum load that the glued-in rod can withstand. These results are the average of the five specimens for each treatment.
Table 2. The average pull-out strength of glued in rod

| Specimen Code | Diameter of Rod (d) | Thickness of Adhesive (mm) | Anchored Length (L) | Drilling Hole Area (As) mm$^2$ | Number of Specimen | Average of Pull-out strength kN | Average of Shear Strength MPa |
|---------------|---------------------|----------------------------|---------------------|-------------------------------|-------------------|-----------------------------|-----------------------------|
| 1             | 8                   | 2                          | 40                  | 1,256.0                       | 5                 | 15.64(2.21)                 | 12.45(1.76)                 |
| 8-2           | 8                   | 3                          | 40                  | 1,381.6                       | 5                 | 16.94(0.91)                 | 12.26(0.66)                 |
| 8-3           | 8                   | 4                          | 40                  | 1,507.2                       | 5                 | 18.00(1.74)                 | 11.94(1.15)                 |
| 8-4           | 10                  | 2                          | 40                  | 1,507.2                       | 5                 | 17.30(2.60)                 | 11.48(1.73)                 |
| 10-2          | 10                  | 3                          | 40                  | 1,632.8                       | 5                 | 18.02(1.12)                 | 11.04(0.69)                 |
| 10-3          | 10                  | 4                          | 40                  | 1,758.4                       | 5                 | 18.64(1.79)                 | 10.60(1.02)                 |
| 10-4          | 12                  | 4                          | 40                  | 1,758.4                       | 5                 | 19.74(3.55)                 | 11.23(2.02)                 |
| 12-2          | 12                  | 2                          | 40                  | 1,758.4                       | 5                 | 20.00(2.29)                 | 10.62(1.22)                 |
| 12-3          | 12                  | 3                          | 40                  | 1,884.0                       | 5                 | 21.17(2.73)                 | 10.54(1.36)                 |
| 12-4          | 12                  | 4                          | 40                  | 2,009.6                       | 5                 |                            |                            |

Remark: number in the bracket on 7 and 8 columns are standard deviation

Table 2 and Figure 4 indicate that the magnitude of the pull-out strength is influenced by the diameter of the rod and the thickness of the adhesive. Larger rod diameter and thicker adhesive lead to a greater pull-out strength of the glued-in rod. This can be understood from equation 2, which states that the pull-out strength is a function of the shifted area, namely the area of the interfacial between laminated bamboo and adhesive. The area is a function of rod diameter and adhesive thickness.

![Figure 4](image.png)

Figure 4. Relationship between pull-out strength, rod diameter, and adhesive thickness.

Furthermore, based on the damage pattern that occurs, the interfacial shear stress between the adhesive and the laminated bamboo is calculated using equation 2 and the results are listed in Table 2 column 8. The shear stress in the range of 10.54MPa to 12.45MPa has similar results to the previous study [11], which obtained the shear stress in the range of 10.18MPa to 10.54MPa. The shear stress in their research is similar to shear stress found in the present study, that is 10.63MPa to 11.21MPa for glued-in rod embedded in laminated bamboo with edge distance more than or equal to 3d, where d is rod diameter [12]. Based on the graph in Figure 5, it can be seen that the magnitude of the shear stress is influenced by the rod diameter and the thickness of the adhesive. The smaller the rod diameter and the thinner the adhesive, the greater the shear stress that occurs.
3. 2. Slip and Slip Modulus

From the pull-out test, the slip value was obtained at various stages of loading. The most important result of this test is the slip value at the maximum load calculated by formula (3) and (4). The average values are listed in Table 3 column 7.

### Table 3. The average of slip and slip modulus

| Specimen code | Diameter of Rod (d) | Thickness of Adhesive (mm) | Anchored Length of Rod (L) | Initial Length of Rod (Lo) | Number of Specimen | Average of Slip at Max. Load (mm) | Average of Slip Modulus (kN/mm) |
|---------------|---------------------|-----------------------------|-----------------------------|---------------------------|---------------------|----------------------------------|---------------------------------|
| 1             | 2                   | 3                           | 4                           | 5                         | 6                   | 7                                | 8                               |
| 8-2           | 8                   | 2                           | 40                          | 150.2                     | 5                   | 1.77(0.38)                       | 4.71(0.44)                      |
| 8-3           | 8                   | 3                           | 40                          | 150.2                     | 5                   | 2.20(0.28)                       | 6.63(1.43)                      |
| 8-4           | 8                   | 4                           | 40                          | 150.6                     | 5                   | 2.65(0.77)                       | 6.26(1.76)                      |
| 10-2          | 10                  | 2                           | 40                          | 150.8                     | 5                   | 2.71(0.68)                       | 6.47(1.43)                      |
| 10-3          | 10                  | 3                           | 40                          | 150.2                     | 5                   | 2.88(0.49)                       | 3.98(0.76)                      |
| 10-4          | 10                  | 4                           | 40                          | 150.4                     | 5                   | 3.06(0.77)                       | 5.33(1.56)                      |
| 12-2          | 12                  | 2                           | 40                          | 150.2                     | 5                   | 3.28(0.56)                       | 4.22(0.83)                      |
| 12-3          | 12                  | 3                           | 40                          | 149.8                     | 5                   | 3.40(0.24)                       | 4.35(0.72)                      |
| 12-4          | 12                  | 4                           | 40                          | 149.8                     | 5                   | 3.65(0.34)                       | 4.74(0.68)                      |

Remark: numbers in the bracket on 7 and 8 columns are standard deviation

Based on Table 3, the average slip at the maximum load is between 1.77mm - 3.65mm. Furthermore, based on the graph in Figure 6, it can be seen that the amount of slip is influenced by the diameter of the rod and the thickness of the adhesive. Larger the rod diameter and thicker adhesive lead to a greater slip. This is a direct result of the relationship between the magnitude of the pull-out strength and the slip shown in Figure 3, namely the number of slip increases with the increase of load.

**Figure 5.** Relationship between shear stress, rod diameter, and adhesive thickness
The amount of slip modulus calculated based on formula 5 produces the value as shown in Table 3 column 8. The slip modulus in the range of 3.98 kN/mm to 6.63 kN/mm is close to the slip modulus obtained [12], namely 3.73 kN/mm to 7.77 kN/mm for glued-in rod embedded on laminated bamboo. This is also close to the slip modulus [19], which is 3.28 kN/mm for a glued-in rod in 60 mm anchored length in Douglas Fir Wood. Glued-in rod embedded in glulam made of Black Spruce wood resulted in a slip modulus of 108 kN/mm [20]. Glued-in rod embedded 160 mm in glulam made of Norway Spruce wood and found an initial slip modulus of 94.6 kN/mm [21]. The main parameters that cause variations in the slip modulus of this study and other studies above are the anchor length, the material, and the adhesive used.

Table 3 and the graph in Figure 7 indicate inconsistencies of the relationship between slip modulus and rod diameter and adhesive thickness. However, it can still be seen that the tendency is that the larger the rod diameter, the smaller the slip modulus is. Meanwhile, the adhesive thickness has no relationship with the slip modulus.
3.3. Damage Pattern of Glued in Rod

All specimens were damaged on the interfacial between adhesive and laminated bamboo under the pull-out test (Figure 8a). Figure 8b shows some of the bamboo fibers sticking to the adhesive. This indicates that the bonding strength on the interfacial between the adhesive and bamboo is greater than the internal shear strength of the laminated bamboo. This kind of damage was also found in the previous research [22].

Furthermore, from the graph in Figure 3, it can be seen that the line representing the relationship between load and slip decreases steeply after reaching the maximum load. This shows that a brittle failure occurs on the glued-in rod, which is damaged at the interfacial between the adhesive and the bamboo laminate.

![Glued-in rod damage and bamboo fiber sticking to adhesive](image)

**Figure 8.** Damage on specimen

4. Conclusion

This research concludes that: The pull-out strength of the glued-in rod is affected by rod diameter and adhesive thickness. The larger the rod diameter and the thicker the adhesive, the greater the pulling-out strength of the glued-in rod embedded in laminated bamboo. The shear strength of the glued-in rod is affected by rod diameter and adhesive thickness. Anchored by the smaller rod diameter and the thinner adhesive, the greater shear stress would occur on interfacial between adhesive and laminated bamboo. The slip of the glued-in rod is affected by rod diameter and adhesive thickness. The larger the rod diameter and the thicker the adhesive, the greater the slip that occurs on interfacial between adhesive and laminated bamboo. The slip modulus of the glued-in rod is affected by rod diameter, but it is not affected by adhesive thickness. The larger the rod diameter, the smaller the slip modulus of the glued-in rod embedded in laminated bamboo.

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