The Effect of Using PVAc (Polyvinyl Acetate) & Epoxy Resin Adhesives on the Shear Strength of Laminated Bamboo

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ABSTRACT

Wood is a common construction material in Indonesia, but its widespread use has led to increased prices and threatened rainforests and their ecosystems. Bamboo, a sustainable and affordable alternative, is proposed. However, its hollow interior presents challenges for utilization. To address this, bamboo lamination technology is introduced, facilitating the manufacture of construction components.The study aims to determine the shear strength of bamboo laminations using two adhesives: PVAc and epoxy resin, and to understand the damage patterns after shear strength testing. The tests adhered to SNI 03-3400-1994 standards, using laminated bamboo beams. The results showed that beams using epoxy resin adhesive had higher shear strength (average 6.7206 MPa) than those using PVAc adhesive (average 2.7949 MPa).
The damage patterns revealed that the adhesive part was damaged under maximum load, with bamboo slats detaching from the adhesive. This occurred with both types of adhesives, where the glue part was lifted.

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1. INTRODUCTION

The use of wood as a construction material is common throughout Indonesia, this is due to Indonesia's geographical conditions which are located on the equator with high sunlight intensity and rainfall throughout the year supporting the formation of many rainforests scattered throughout Indonesia. Based on this, wood material is easy to obtain and wood material itself can make buildings look more attractive [1]. However, the use of wood as a source of material for both construction and non-construction has increased the price of wood and also made rainforests that function to protect the environment threatened with loss as well as the ecosystem in it. One material that is suitable for replacing wood is bamboo [2].

Bamboo is recorded worldwide in more than 75 countries and 1250 species. The quantity of bamboo distributed in South and Southeast Asia is estimated at 80% of the total bamboo in the world [3]. Bamboo has the advantage of being a multi-functional material, fast plant growth (3-5 years), and has tensile strength properties that are almost close to steel [4]. Bamboo is easy to plant, breed, fast in growth, and has a relatively low price. Apart from the factors mentioned, bamboo also has the disadvantage that the size of bamboo is relatively small when compared to wood produced from trees such as teak, mahogany, pine and so on [5]. The hollow or empty interior of bamboo is also something that often makes it difficult for users to utilise bamboo. Therefore, bamboo lamination technology is applied to facilitate the manufacture of building construction components [6]. Bamboo lamination technology is developed not in the form of a whole non-wood structure but a laminated component made through gluing or commonly referred to as a laminated bamboo beam [7]. Lamination technology is a technique of combining materials with the help of adhesives, small building materials can be glued together to form material components as needed. The lamination technique is also a way of combining raw materials that are not uniform or of varying quality [8].

The use of bamboo as a laminated beam has been developed through previous testing. In a study entitled "The Effect of Using Pegs with Distance Variations (10 cm, 15 cm, 20 cm) on the Flexural Strength of Bamboo Laminated Beams (Dendrocalamus Asper)" it was found that testing flexural beams with peg spacings of 10 cm, 15 cm, and 20 cm produced an average flexural strength of 25.739 Mpa, 35.041 Mpa, and 28.027 Mpa respectively. The results of this test showed a significant difference, namely the effect of using variations in peg spacing on the flexural strength of laminated bamboo beams. The average damage to laminated beams is in the connection part of the laminated beam pegs where some pegs are detached from the laminated bamboo beam slats [2]. Another study with the title "Analysis of the flexural strength of curved laminated beams with epoxy adhesive" found that the flexural strength of curved laminated beams with reinforced epoxy adhesive was able to withstand an average load of 85.45 kg and an average deflection of 23.510 mm. Overall the load resulting from this test meets the requirements for structural materials. From the test results it can be concluded that the higher the curvature the greater the load obtained while the shorter the curvature the greater the deflection obtained [7]. The last research with the title "The effect of using horizontal pegs with a distance variation of 25 cm, 30 cm, 40 cm, 50 cm on the bending shear strength of laminated bamboo" found that the average value of 60#MDGL shear beam testing sequentially is 3.00 Mpa, 2.41 Mpa, 2.26 Mpa, 3.21 Mpa. The results of this test cannot be significantly different. The testing behaviour of the shear strength of laminated beams was observed when reaching the first crack the load decreased. The beam resisted with deflection so that the load rose slowly to the maximum load. The use of the outer skin on the surface of the laminated beam adds stiffness to the laminated bamboo beam. Judging from the test results on shear strength, it was found that the wood strength was above 2nd quality [9].

Based on the description above, this study has the aim of knowing the shear strength value of the bamboo laminate used when using PVAc adhesive and when using Epoxy Resin adhesive and knowing the damage pattern on the Betung Bamboo laminated beam after shear strength testing when using PVAc adhesive and when using Epoxy Resin adhesive.

2. METHODS

This research was conducted by the Civil Engineering Laboratory of Sultan Ageng Tirtayasa University. Making test objects is done by cutting bamboo using a cutting wheel to get the desired bamboo length. bamboo is peeled off the outer skin using a knife or machete and cleaned of dirt that may still be attached. After washing, the bamboo culms are sorted for defects such as bending or breaking. After sorting, the bamboo slats are then shaved using a planer until the bamboo slats have a flat surface. For preliminary testing, bamboo culms that have been stripped of their skin are cut into the desired bamboo slats according to the reference used.

2.1 Physical and Mechanical Properties of Bamboo

Examination of the physical and mechanical properties of bamboo is carried out with the aim of knowing the value of water content, density, and shrinkage growth, compressive strength, tensile strength, and shear strength in bamboo [10]-[11]. This examination was carried out at the Untirta Civil Engineering Laboratory.

Table 1. Physical and Mechanical Properties of Bamboo

Test Type	Standard	Spesification
1. Physical Properties		
Water Content (%)	ISO 22157[12]	-
Density (g/cm^3)	ISO 22157[12]	< 0,4 (Light Wood) < 0,55 (Medium Wood) < 0,7 (Heavy Wood)
Shrinkage Growth (%)	ISO 22157[12]	-
2. Mechanical Properties		
Compressive Strength	SNI 03-3958-1995[13]	-
Tensile Strength	ISO 22157[14]	-
Shear Strength (Adhesive)	SNI 03-3400-1994[15]	-

Figure 1. Bamboo Physical and Mechanical Testing Object

Table 1 shows the tests conducted to determine the physical and mechanical properties of bamboo, and Figure 1 shows the form of the test object for the physical and mechanical properties of bamboo.

2.2 Bending Strength Testing of Laminated Bamboo Beams

Inspection of laminated bamboo beams made with 2 variations of adhesive, namely PVAc and epoxy resin. This examination was carried out at the Untirta Civil Engineering Laboratory. For the flexural strength test, the peeled bamboo stems were cut into bamboo slats and after that they were cleaned from the broken bamboo segments that were still attached to the inner side of the bamboo and cleaned from the inner skin of the bamboo. After that, the bamboo is cut to the desired size and the stem is smoothed with a planner and then cleaned of any remaining dirt. After cleaning, the bamboo slats enter the curing process. After the curing process, the bamboo slats are glued together using adhesives or go into the lamination process.

Figure 2. Gluing Process of Laminated Bamboo Beams

Figure 2 represents the process of laminating bamboo slats into a laminated bamboo beam using a cold compression process carried out at room temperature.

3. RESULTS AND DISCUSSION

3.1 Bamboo Physical Properties Test Results

Testing of aggregate characteristics was carried out using laboratory equipment available at the Untirta Civil Engineering Laboratory. The test was conducted using bamboo specimens that had been made in accordance with the requirements.

Table 2. Bamboo Physical Properties Test Results

Jenis Pengujian	Results	Standard	Spesification
Water Content (%)	9,32	ISO 22157	-
Density (g/cm^3)	0,6255	ISO 22157	< 0,4 (Light Wood) < 0,55 (Medium Wood) < 0,7 (Heavy Wood)
Shrinkage Growth (%)	19,336	ISO 22157	-

Water content testing is a test to obtain the value of water content in bamboo and water content is how much water content is in bamboo, in this test it is carried out on three parts of the bamboo, namely the base, middle and top of the bamboo. From the tests that have been carried out, the average water content in the base, middle and top of the bamboo stem is 9.32%. Moisture content is one of the physical properties that must be considered in the gluing process because moisture content that is too high and too low can cause low adhesive firmness and even bonding failure. In density testing, the results of the betung bamboo density study have an average value of 0.6255 g/cm^3, including heavyweight wood. The classification of wood density less than 0.4 g/cm3 includes light wood, wood density less than 0.55 g/cm^3 includes medium wood and wood density less than 0.72 g/cm^3 includes heavy wood. In the shrinkage growth test, the results obtained at the base of 7.64%, in the middle of 6.96% and the top of 8.94% with an average volume shrinkage average of 7.85%.

3.2 Bamboo Mechanical Properties Test Results

3.2.1 Bamboo Compressive Strength

Compressive strength testing was carried out to determine the compressive strength of betung bamboo culms (Dendrocalamus asper). Tests were carried out with 3 variations of test specimens, namely base bamboo, middle bamboo, and top bamboo.

Table 3. Bamboo Compressive Strength Results

Sections	Results (MPa)	Average (MPa)	Standard
Base	40,172		
Middle	42,034	49,163	SNI 03-3958-1995
Top	65,282		

Figure 3. Compressive Strength Test

The results of the compressive strength of the segment at the base obtained a value of 40.172 Mpa, the middle of 42.034 Mpa, the top of 65.282 Mpa and with an average of 49.163 Mpa, based on the Indonesian Wood Construction Regulations (PKKI) the compressive strength of betung bamboo that has been done is classified into wood class II [16].

3.2.2 Bamboo Tensile Strength

Tensile strength testing was carried out to determine the tensile strength value of betung bamboo (Dendrocalamus asper).

Figure 4. Tensile Strength Test

Table 4. Bamboo Tensile Strength Results

Sections	Strain (ε)	Stress (MPa)	Standard
Base	0	0,000	ISO 22157

	0,0029	652,002
	0,0055	720,634
	0,0055	754,950
	0,0060	789,266
	0,0060	823,582
	0,0060	892,214
	0,0060	926,530
	0,0060	995,161
	0,0060	0,000
Middle	0	0,000
	0,0026	604,918
	0,0050	640,501
	0,0050	676,084
	0,0050	747,251
	0,0050	782,835
	0,0068	818,418
	0,0085	854,001
	0,0085	925,168
	0,0085	0,000
Top	0	0,000
	0,0014	482,905
	0,0020	547,293
	0,0022	547,293
	0,0042	547,293
	0,0042	579,486
	0,0054	579,486
	0,0076	579,486
	0,0076	611,680
	0,0076	0,000

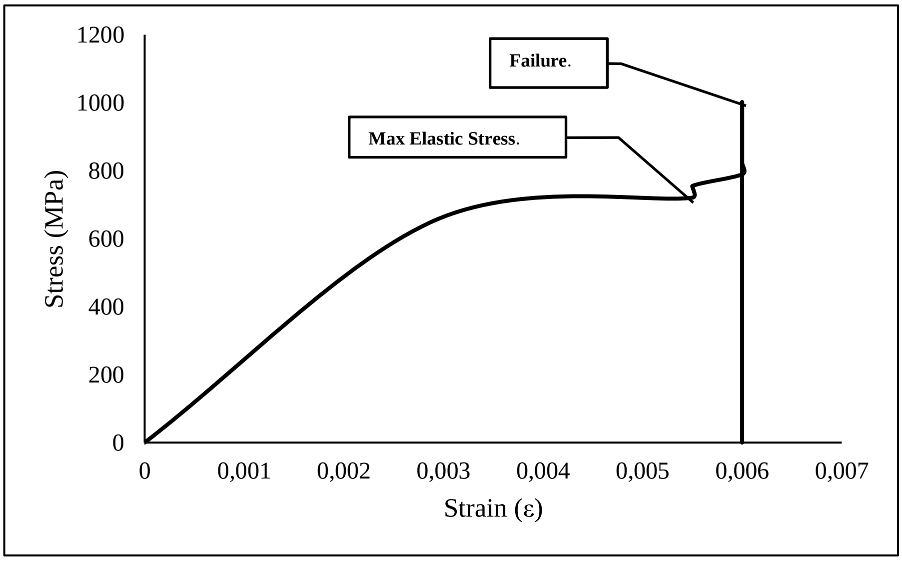

Figure 5. Stress-strain Graph of the Base of the Bamboo

The tensile strength test at the base of the bamboo found that the maximum elastic stress was at a strength of 720.634 MPa with a strain (ε) of 0.0055 and failure occurred at a maximum stress of 995.161 MPa with a strain (ε) of 0.0060.

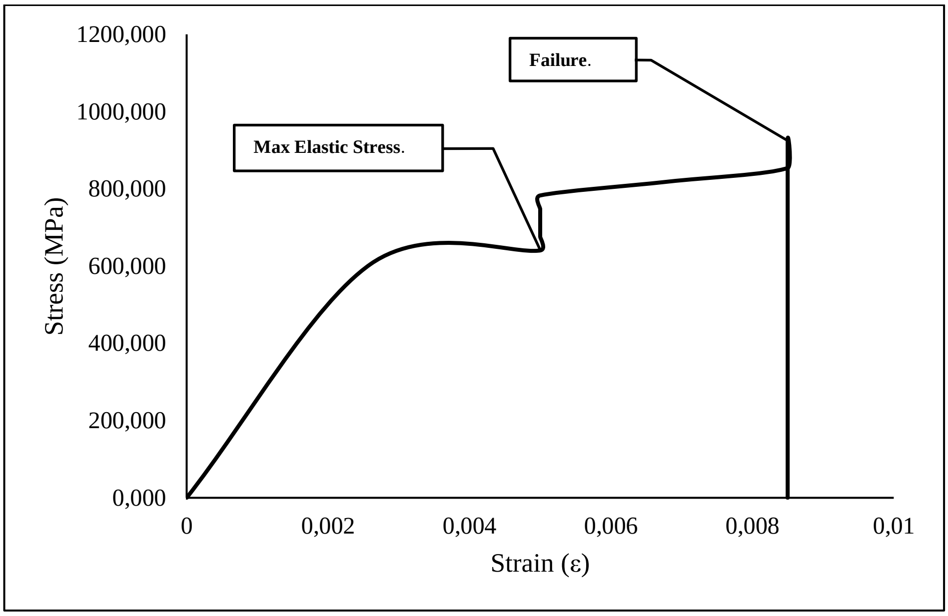

Figure 6. Stress-strain Graph of the Middle of the Bamboo

The tensile strength test at the base of the bamboo found that the maximum elastic stress was at a strength of 640.501 MPa with a strain (ε) of 0.0050 and failure occurred at a maximum stress of 925.168 MPa with a strain (ε) of 0.0085.

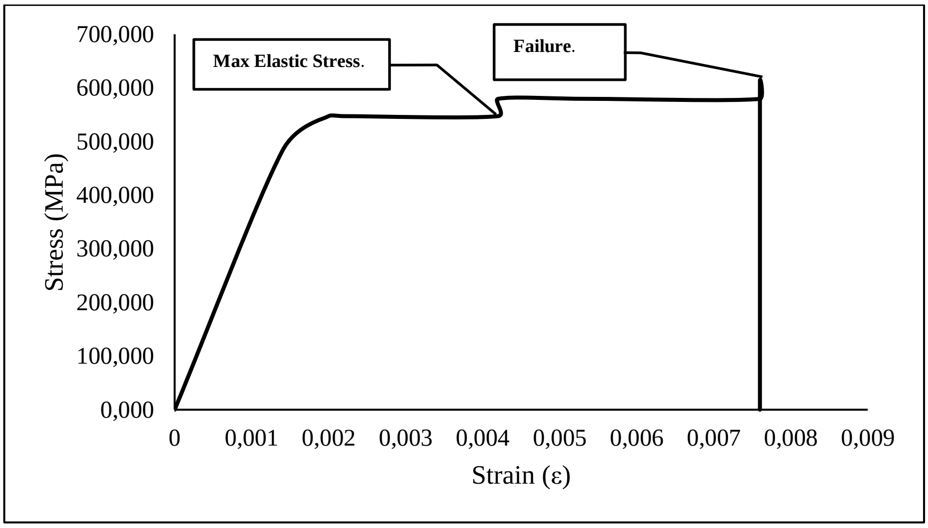

Figure 7. Stress-strain Graph of the Top of the Bamboo

The tensile strength test at the base of the bamboo found that the maximum elastic stress was at a strength of 547.293 MPa with a strain (ε) of 0.0042 and failure occurred at a maximum stress of 611.680 MPa with a strain (ε) of 0.0076.

3.2.3 Shear Strength of Bamboo (Adhesive)

Tensile strength testing was carried out to find the shear strength value of laminated bamboo. Tests were carried out with 2 adhesive variations, namely with PVAc adhesive and epoxy resin.

Table 5. Shear Strength of Bamboo (Adhesive) Results

Type of Adhesive	Results (MPa)	Standard
PVAc	2,7949	SNI 03-3400-1994
Epoxy Resin	6,7206	

Figure 8. Shear Strength Test

The results of the shear strength test on the PVAc type adhesive produced an average shear strength value of 2.7949 Mpa. The shear strength value of PVAc adhesive has a smaller value than the shear strength value with epoxy resin adhesive with a value of 6.7206 MPa.

3.3 Bending Strength of Laminated Bamboo Beams Test Results

The research was conducted at the Untirta Civil Engineering Laboratory to determine the flexural strength value of bamboo beams that have been laminated with 2 adhesive variations. Testing was carried out using a Universal Testing Machine (UTM). The test specimens used were pre-made test specimens using PVAc adhesive and epoxy resin. The data obtained in the flexural strength test is the maximum load and deflection that occurs in laminated beams.

In laminated beams with PVAc adhesive, the first test specimen with the test specimen code BUPA-G1 has a maximum load of 20.3 kN, a deflection of 27.5 mm, a stiffness of 0.73818 and a moment of 2030 kNmm. The second specimen with the code BUPA-G2 had a maximum load of 15.2 kN, a deflection of 26.5 mm, a stiffness of 0.57358 and a moment of 1520 kNmm. The test specimen with the code BUPA-G3 had a maximum load of 16.5 kN, a deflection of 28 mm, a stiffness of 0.58929 and a moment of 1650 kNmm.

Figure 5. BUPA-G1, BUPA-G2, and BUPA-G3 Laminated Bamboo Beams

In laminated beams with epoxy resin adhesive, the first test specimen with the code BUER-G1 obtained the maximum load of 22.4 kN, deflection of 23 mm, stiffness of 0.97391 and internal moment of 2240 kNmm. The test specimen with code BUER-G2 obtained the maximum load of 37.7 kN, deflection of 19.5 mm, stiffness of 1.93333 and internal moment of 3770 kNmm and the last test specimen with code BUER-G3 with a maximum load of 35.7 kN, deflection of 21.5 mm, stiffness of 1.66047 and internal moment of 3570 kNmm.

Figure 6. BUER-G1, BUER-G2, and BUER-G3 Laminated Bamboo Beam

4. CONCLUSION

From the research that has been done, the shear strength of epoxy resin adhesive is stronger with an average value of 6.7206 MPa compared to PVAc adhesive of 2.7949 MPa. In the damage pattern that occurs, the gluing part experiences scuffing when the maximum load occurs with the bamboo slats detached from the adhesive on the epoxy resin adhesive and on the PVAc adhesive the glue part is lifted.

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