



Influence of Epoxy Resin on the Compressive Strength of Laminated Bamboo Short Columns

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Abstract. *The use of laminated bamboo columns as alternative building materials has attracted increasing attention, particularly as a substitute for wood in construction. Bamboo lamination techniques enable the production of structural materials with tailored mechanical properties. Numerous previous studies have investigated the compressive strength of laminated bamboo short columns subjected to various treatments. This study aims to evaluate the compressive strength and failure patterns of laminated bamboo short columns under compression loading. The experimental program included physical and mechanical characterization of bamboo, followed by compression testing of laminated bamboo short columns with dimensions of 10 cm × 10 cm × 30 cm. Three treatment variations were examined: untreated laminated columns, epoxy resin-coated columns, and steel plate-reinforced columns. The results indicate that untreated laminated bamboo columns exhibited an average compressive strength of 28.044 MPa, with cracking concentrated at the top of the column. Epoxy resin-coated laminated bamboo columns achieved an average compressive strength of 28.774 MPa, showing crack formation distributed across several regions of the column. Steel plate-reinforced columns demonstrated the highest average compressive strength of 31.138 MPa, with failure localized in the region between the steel plates. These findings provide valuable insights into the effectiveness of different treatment methods in enhancing the compressive performance and failure characteristics of laminated bamboo columns.*

Keywords: *Compressive Strength; Epoxy; Laminated Bamboo; Resin; Short Columns.*

1. INTRODUCTION

Rapid population growth has resulted in a significant increase in the demand for building materials, especially wood. This increase in demand leads to massive exploitation of forests, which reduces the availability of timber and potentially causes environmental disasters. Alternatively, bamboo emerged as a promising building material. (Alkalah, 2016).

Bamboo is one of the alternatives that can replace the role of wood as a building material because bamboo is a plant that grows faster than wood. The high strength of bamboo and the good quality of bamboo make bamboo an alternative as a substitute for wood both as a building material and building furniture.

Bamboo plants are plants that have economic value and are easy to cultivate. Bamboo can grow in dry to wet climates, from lowlands to mountainous areas and usually in open places where areas are free from waterlogging. This plant is known for its rapid growth, where bamboo with good quality can be obtained between the ages of 3.5 – 5 years. While most forest timber is only ready to be cut after more than 30 years. (ASTM E8/E8M, 2010)

Several studies have explored the potential of laminated bamboo in construction. Zhou et al. Axial compression test was performed on short columns of basalt fiber-reinforced laminated bamboo (BFRP), using 12 columns with dimensions of 10 cm × 10 cm × 30 cm and

four variations in basal fiber content (1.2%, 1.8%, 2.3%, and 2.9%). The results of the axial compressive strength test on laminated bamboo short columns were obtained by increasing the strength ratio when reinforced with basal fibers with each variation experiencing an increase in compressive strength of 3.5%, 8.5%, 15.9%, and 17.0% for laminated bamboo short columns without basal fiber reinforcement (BFRP).

Li et al. Examine the load-strain relationship, axial compressive strength, and failure pattern in laminated bamboo columns by comparing three growth parts of bamboo (tip, middle, and base). The study involved 24 columns of the same dimensions and found a maximum stress of 52 MPa, with a failure pattern that varied from material failure and shear at the top to bending failure at the center of the column. (Badan Standardisasi Nasional [BSN], 1995).

Wu et al. Exploring laminated bamboo columns coated with steel tubes, with layer thicknesses of 4.5 mm and 6.5 mm and varying diameters of 5 specimens (68 mm, 83 mm, 95 mm, 114 mm, and 133 mm). The result of the research of the short column of laminated bamboo coated steel tube is that the influence of the thickness of the steel tube has a very large influence on the ultimate stress and ultimate strain of the test piece. The pattern of damage changes from shear failure to split failure due to the failure of laminated bamboo material.

The proposed study aims to evaluate the compressive strength of laminated bamboo short columns and analyze the damage pattern after the compression test. The experiment will involve laminated bamboo columns with dimensions of 10 cm × 10 cm × 30 cm, which will be tested in three treatment variations: normal columns, columns with *epoxy resin* coatings, and columns reinforced with steel plates. The main objective is to obtain data on the compressive strength and damage patterns that occur, as well as to determine the effectiveness of various treatments in improving the performance of laminated bamboo columns.

2. METHODS

This research was conducted at the Civil Engineering Laboratory, Sultan Ageng Tirtayasa University. The materials used in the study include several main components as follows: (1) Petung Bamboo: The petung bamboo used comes from Pandeglang; (2) Sodium Tetraborate: Used as a bamboo preservative before the lamination process to improve the durability of the material; (3) Steel Plate: It has a thickness of 2 mm, used to reinforce the structure of bamboo columns; and (4) *Epoxy Resin*: Serves as an adhesive in the bamboo lamination process. The use of this material aims to evaluate the compressive strength and damage patterns of laminated bamboo columns that have been treated with various treatments.

The stages of the research are carried out as follows: (1) bamboo material design for testing (2) testing the physical and mechanical properties of bamboo materials; (3) design of laminated bamboo short column test piece; (4) testing the physical and mechanical properties of laminated bamboo short column test pieces; (5) analysis of the results of testing the physical and mechanical properties of the test piece; (6) comparison of the results of testing the physical and mechanical properties of the test piece; and (7) conclusions and recommendations for further research. The explanation for each stage of the research will be explained in the results and discussion section.

Physical and Mechanical Properties Test Pieces

The laminated bamboo to be designed as a test piece must have good material standards that meet certain bamboo quality standards. For this reason, it is necessary to carry out physical and mechanical property testing, which is a preliminary test to determine the quality of the materials used. Physical property testing consists of bamboo moisture content testing, bamboo density testing and bamboo shrinkage testing. The quality of bamboo can be influenced by the value of bamboo's physical properties, the higher the quality of bamboo will be shown by high specific gravity value, low moisture content and low shrinkage. Mechanical properties are the main indicator in bamboo design design, this indicator determines whether or not bamboo is strong and suitable for use in a certain position in a construction. The mechanical properties test consists of cylindrical bamboo compressive strength and steel tensile strength. Some of the things that affect the physical properties of bamboo include the age of the bamboo, the position of the height of the bamboo, the diameter of the bamboo, the thickness of the bamboo flesh and the position of the load (on the book or segment). (Darwis & Riyadi, 2024).

Each test of physical and mechanical properties of bamboo has 3 (three) specimens, each part of bamboo (base, middle, end). Testing the mechanical properties of steel in the form of tensile test with 3 specimens with a thickness of 2 mm. The design of bamboo materials for testing physical and mechanical properties can be seen in Figure 1. Details of bamboo materials for testing physical and mechanical properties in this study can be seen in table 1.

Table 1. Physical and Mechanical Properties Test Specimen Details.

Bamboo Parts	Physical Properties			Mechanical Properties	
	Moisture Content	Density	Shrinkage	Cylinder Compressive Strength	Strong Tensile Steel
Pangkal	3	3	3	3	-
Tengah	3	3	3	3	-
Ujung	3	3	3	3	-
Jumlah	9	9	9	9	3



Figure 1. Physical and Mechanical Properties Test Piece Design.

Laminated Bamboo Short Column Test Pieces

Testing of laminated bamboo short column test pieces is carried out by the fiber parallel compressive strength method. This test aims to determine the compressive strength value of the laminated bamboo short-column test piece and the damage pattern that occurs after the compressive strength test is carried out. The laminated bamboo short column test piece has 3 (three) treatments, namely: (1) normal test pieces are only ordinary laminates; (2) laminated bamboo test pieces coated *with epoxy resin*; and (3) laminated bamboo test pieces given steel plate reinforcement. Normal test pieces are laminated bamboo short columns without treatment (plain), laminated bamboo short column test pieces coated *with epoxy resin* are treated on the entire surface of the test piece coated *with epoxy resin*, laminated bamboo short column test pieces reinforced with steel plates are treated with steel plate reinforcement with a thickness of 2 mm on the top, middle and bottom of the laminated bamboo short column. In full, the design of laminated bamboo short columns in this study can be seen in Figure 2. Details of test pieces and the number of laminated bamboo short column test pieces in this study can be seen in Table 1. (Ghozali, 2011).

Table 1. Details of Laminated Bamboo Short Column Test Specimen.

Test Specimen	Type of Treatment	Specimen Code	Number of Specimen	Total
Laminated Bamboo Short Column	Normal	KN-L	3	9
	<i>Epoxy Resin</i>	KE-L	3	
	Reinforced Steel Plate	KP-L	3	



Figure 2. Design of Laminated Bamboo Short Column Test Pieces.

3. RESULTS AND DISCUSSION

Results of Bamboo Physical and Mechanical Properties Testing

Testing the physical and mechanical properties of bamboo was carried out at the Civil Engineering Laboratory of Sultan Ageng Tirtayasa University. The results of the physical and mechanical properties of bamboo can be seen in Table 2. (HIS, 2004a).

Table 2. Physical and Mechanical Properties Test Results.

Types of Testing	Spesimen			Average
	Tip	Middle	Bottom	
Moisture Content (%)	15,38	14,17	16,77	15,44
Density (g/cm ³)	0,77	0,74	0,78	0,77
Shrinkage (%)	8,18	11,38	8,10	9,22
Cylinder Compressive Strength (MPa)	43,75	41,47	36,12	40,45
Strong Tensile Steel (MPa)	460	465	460	461,67



Figure 3. Physical and Mechanical Properties Test Results.

Figure 3 shows the results of the tests that have been carried out, the average moisture content of bamboo is 15.44%. The recommended moisture content is 8-12%. Moisture content is one of the things that must be considered in the adhesive process, if the moisture content value is too high or too low it can affect adhesion to cause adhesion failure. The results of the bamboo density test were obtained with an average of 0.77 g/cm³. Density testing is included in the density classification of the heavy wood category. The higher the type of wood, the better the strength of the wood will be. The results of the shrinkage test at the end, middle and base were obtained with an average score of 9.22%. The main cause of shrinkage is the loss of water in the bamboo fiber network, as a result of which the shrinkage of bamboo is higher in direct proportion to the amount of water released. The results of the cylinder compressive strength test were obtained on average 40.45 MPa. The compressive strength test results of bamboo cylinders are included in the density classification of the Class III category. The class III wood category is a wood material that is suitable for use in heavy construction that is protected under the roof and is not related to wet soil. The results of the steel tensile strength test obtained an average maximum tensile value of 461.67 MPa, an average strain of 0.002 and an average elasticity value of 21805.556 N/mm². The graph of the steel tensile strength test results can be

seen in Figure 4. The results of the physical and mechanical properties test can be seen in Figure 3. (Zhou et al., 2022).

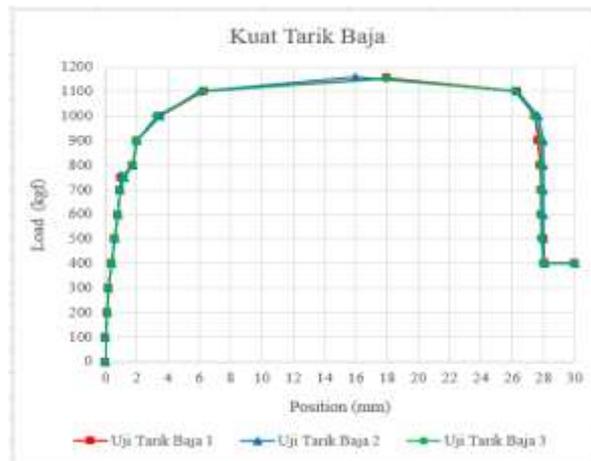


Figure 4. Steel Tensile Strength Testing Chart.

Laminated Bamboo Short Column Test Results

Normal Laminated Bamboo Short Column (KN-L)

The results of the KN-L compressive strength can be seen in **Table 3** where the compressive strength values of the KN-L 1, KN-L 2 and KN-L 3 test pieces are 276.2 kN, 276.7 kN and 261.2 kN, respectively, so that the average value of KN-L compressive strength is 271.4 kN. The pattern of damage that occurred in KN-L 1 was material failure resulting in cracks at the top of the column and sliding failure in the adhesive between bamboo slats. The pattern of damage that occurs in KN-L 2 is a material failure that results in cracks at the top of the column. The pattern of damage that occurs in KN-L 3 is a material failure that results in a crack failure at the top of the column. The KN-L damage pattern can be seen in **Figure 5**. (HIS, 2004b).



Figure 5. KN-L Damage Pattern.

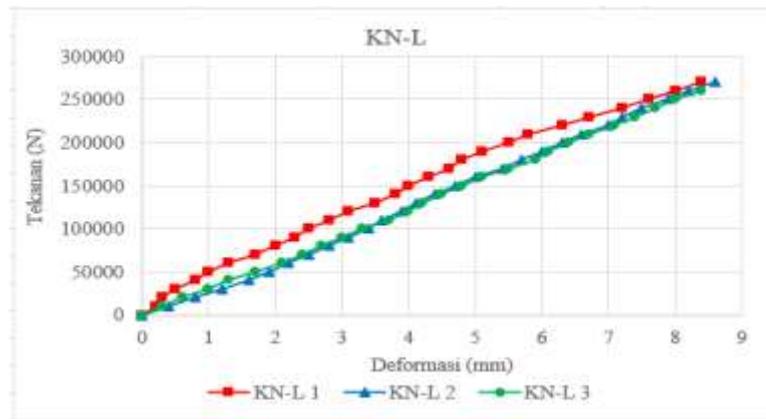


Figure 6. KN-L Pressure-Deformation Relationship Graph.

The deformation that occurred in the KN-L 1, KN-L 2 and KN-L 3 test pieces was 8.4 mm, 8.6 mm and 8.4 mm, respectively. The KN-L pressure-deformation graph can be seen in Figure 6. The maximum stress on KN-L 1, KN-L 2 and KN-L 3 test pieces is 28,582 MPa, 28,491 MPa and 27,059 MPa, respectively, with an average KN-L stress of 28,044 MPa. The KN-L Tension-Tension graph can be seen in Figure 7. (Li et al., 2013).

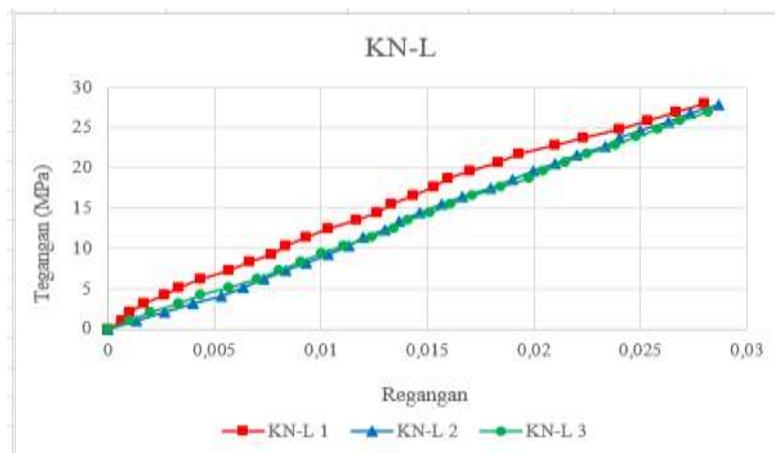


Figure 7. KN-L Stress-Strain Friction Chart.

Laminated Bamboo Short Column Coated with Epoxy Resin (KE-L)

The results of the compressive strength of KE-L can be seen in **Table 3** where the compressive strength values of the test pieces KE-L 1, KE-L 2 and KE-L 3 are 279.2 kN, 282 kN and 288.4 kN respectively, so that the average value of the compressive strength of KN-L is 283.2 kN. The pattern of damage that occurs in KE-L 1 is a compression failure that results in cracks at the top of the column. The pattern of damage that occurs in KE-L 2 is a material failure that results in cracks at the bottom of the column. The pattern of damage that occurs in KE-L 3 is a material failure resulting in cracks at the bottom of the column The KE-L damage pattern can be seen in **Error! Reference source not found.** (Morisco, 2017).



Figure 8. KE-L Damage Pattern.

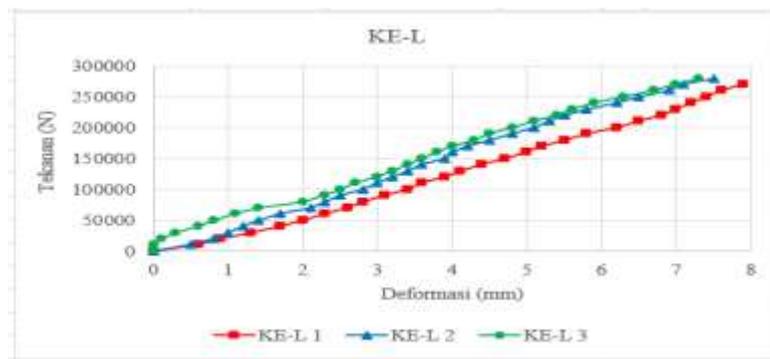


Figure 8. KE-L Pressure-Deformation Relationship Graph.

The deformation that occurred in the test pieces KE-L 1, KE-L 2 and KE-L 3 was 7.9 mm, 7.5 mm and 7.3 mm, respectively. The KE-L pressure-deformation graph can be seen in Figure 8. The maximum stresses on KE-L 1, KE-L 2 and KE-L 3 test pieces are 28,751 MPa, 28,593 MPa and 28,979 MPa, respectively, with an average KE-L stress of 28,774 MPa. The KE-L Tension-Strain graph can be seen in Figure 9. (Zhou et al., 2022).

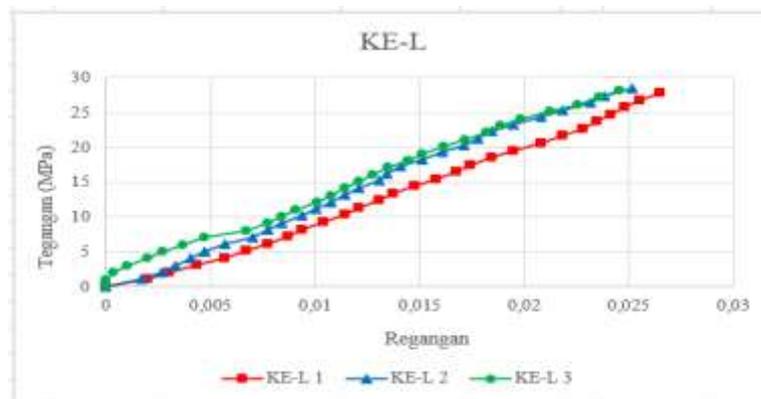


Figure 9. KE-L Stress-Strain Relationship Graph.

Laminated Bamboo Short Column Reinforced Steel Plate (KP-L)

The results of the compressive strength of KP-L can be seen in Table 3 where the compressive strength values of the test pieces KP-L 1, KP-L 2 and KP-L 3 are 290.3 kN, 301.9 kN and 312.6 kN, respectively, so that the average value of the compressive strength of KP-L is 301.6 kN. The pattern of damage that occurred in KP-L 1 was the failure of bamboo material which resulted in cracks in the top and bottom of the central steel plate. The pattern of damage

that occurred in KP-L 2 was the failure of the bamboo material which resulted in cracks at the bottom of the lower steel plate. The pattern of damage that occurred in KP-L 3 was the failure of the bamboo material which resulted in cracks at the bottom of the central steel plate. The KP-L damage pattern can be seen in **Error! Reference source not found.** (Wu et al., 2023).



Figure 11. KP-L Damage Pattern.

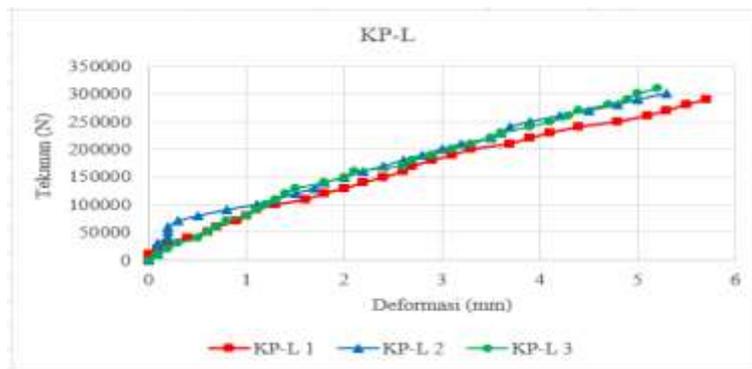


Figure 10. KP-L Pressure-Deformation Relationship Graph.

The deformation that occurred in the test pieces KP-L 1, KP-L 2 and KP-L 3 was 5.7 mm, 5.3 mm and 5.2 mm, respectively. The KP-L pressure-deformation graph can be seen in Figure 10. The maximum stress on the test pieces KP-L 1, KP-L 2 and KP-L 3 is 29,774 MPa, 31,151 MPa and 32,490 MPa, respectively, with an average KP-L stress of 31,138 MPa. The KP-L Stress-Strain graph can be seen in Figure 11. (PKKI, 1961).

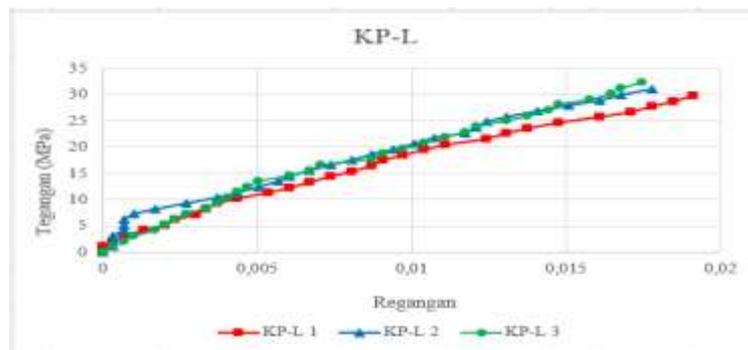


Figure 11. KP-L Stress-Strain Relationship Graph.

The recapitulation of the compressive strength value of laminated bamboo short column can be seen in Table 3.

Table 3. Compressive Strength Results of Laminated Bamboo Short Column Test Pieces.

Test Specimen Name	Compressive Strength Rating (MPa)	Average Compressive Strength (MPa)	Compressive Strength Increase Percentage (%)
KN-L 1	28,582	28,044	0
KN-L 2	28,491		
KN-L 3	27,059		
KE-L 1	28,751	28,774	2,54
KE-L 2	28,593		
KE-L 3	28,979		
KP-L 1	29,774	31,138	9,94
KP-L 2	31,151		
KP-L 3	32,490		

The results of the compressive strength test of laminated short column test pieces can be seen in Table 3. The average compressive strength values obtained were KN-L of 28.044 MPa, KE-L of 28.774 MPa and KP-L of 31.138 MPa. It can be concluded that the addition of an epoxy resin layer to KE-L increases the compressive strength value by 2.54% to KN-L. Meanwhile, the addition of steel plate reinforcement to KP-L can increase the compressive strength value by 9.94% against KN-L. A graph of the increase in compressive strength values can be seen in Figure 12. (SNI 7973, 2013)



Figure 12. Results of Laminated Bamboo Short Column Compressive Strength Test.

Variant Analysis

Analysis of Variance or ANOVA is one of the parametric tests that functions to distinguish the average values of more than two groups of data by comparing their variations. Variant analysis using the MiniTab 19 application. In the discussion based on the results of the research, *One-Way* Anova was used to analyze the average or influence between treatments on laminated bamboo short columns. *One-Way* Anova is called one-way because it is only interested in one factor. The results of the variant analysis can be seen in **Table 4**. (Darwis, Kuncoro, & Pratama, 2021).

Table 4. Variant Analysis Results.

Source	DF	Adj SS	ADJ MS	F-Value	P-Value
Test Specimen Name	2	15,697	7,8484	9,02	0,016
Error	6	5,223	0,8706		
Total	8	20,920			

Based on Table 4, the analysis results state that the P-Value value of 0.016 is smaller than the α value of 0.05, so H_0 (*Null hypothesis*) is rejected and H_1 (*Alternative Hypothesis*) is accepted. The results of the comparative analysis of each test piece using the Fisher method can be seen in Table 5. The comparison of KN-L with KE-L has a P-Value greater than the value of α so H_0 is accepted. The conclusion obtained was that the quality comparison of KN-L and KE-L was relatively the same. The comparison of KP-L with KE-L has a smaller P-Value than the α value, so H_0 is rejected. The conclusion obtained is that the comparison of the quality of KP-L and KE-L is not the same. To find out the quality of the treatment better based on the results of the compressive strength value, see

Table 6. Therefore, the quality of KP-L is better than KE-L. The comparison of KP-L with KN-L has a smaller P-Value than the α value, so H_0 is rejected. The conclusion obtained is that the quality comparison of KP-L and KN-L is not the same. To find out the quality of the treatment better based on the results of the compressive strength value, see

Table 6. Therefore, the quality of KP-L is better than KN-L. Based on

Table 6, KP-L has the best quality among KE-L and KN-L. (Zhou et al., 2022).

Table 5. Comparison Results Using Fisher Method.

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
KN-L – KE-L	-0,730	0,762	(-2,594 , 1,134)	-0,96	0,375
KP-L – KE-L	2,364	0,762	(0,500 , 4,228)	3,10	0,021
KP-L – KN-L	3,094	0,762	(1,230 , 4,958)	4,06	0,007

Table 6. Results of Treatment Comparison.

Test Specimen Name	N	Mean	Grouping
KP-L	3	31,138	A
KE-L	3	28,774	B
KN-L	3	28,044	B

3. CONCLUSION

The results of the compressive strength test of bamboo laminated short columns can be concluded that the role of laminated bamboo can be used as an alternative material to replace wood. Based on SNI 7379-2013. KN-L and KE-L are included in the E14 wood quality category, while KP-L is included in the E15 wood quality category. The addition of reinforcement to short column laminated bamboo can increase the compressive strength value. The addition of a layer of *epoxy resin* on the surface of the test specimen can increase the compressive strength value by 2.54%, while the addition of 2 mm thick steel plate

reinforcement on the top, middle and bottom of the test specimen can increase the compressive strength value by 9.94%. The results of the analysis using ANOVA prove that KP-L has the best compressive strength quality. (Bagus, 2017).

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