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BOLTED CONNECTIONS: A STUDY OF EXPERIMENTAL STRENGTH IN LAMINATED BAMBOO PEDESTALS

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Abstract
Laminated bamboo technology has emerged as a promising alternative to traditional wood-based materials for various construction applications. Inspired by the concept of laminated wood blocks, glued bamboo blocks consist of thin layers of bamboo that are assembled and bonded together to form strong and versatile building elements. One of the key advantages of this technology is its ability to mitigate issues related to cracks, breaks, and defects caused by drying, owing to the rapid and efficient drying process of the thin bamboo sheets. Additionally, the mechanical strength of laminated bamboo, particularly its bolt resistance, has been investigated through various tests to assess its ultimate strength under compressive loading. However, despite its potential, the mechanical properties of laminated peton bamboo, including the Poisson's ratio, remain unexplored in previous studies. Bamboo, as a construction material, offers numerous economic and ecological benefits. Its widespread availability, cost-effectiveness, and structural strength make it an attractive option for sustainable building practices, potentially curbing deforestation caused by excessive wood consumption. Furthermore, bamboo's unique properties, such as its lightweight and tall stature, make it an ideal choice for various structural applications. The study covers all aspects of bamboo structures throughout their life cycle, encompassing design, manufacturing, transportation, construction, operation, maintenance, and future reuse planning.

Research has demonstrated the superior mechanical properties of laminated bamboo when engineered with multiple layers and a substantial resin matrix. Furthermore, investigations into the variability of laminated bamboo strength have been influenced by factors such as bamboo type, strip density, thickness, growth stage, treatment methods, adhesive type, and application areas in construction.

In recent years, laminated bamboo construction has gained significant attention, especially for applications in civil engineering. However, the absence of standardized building codes for bamboo structures necessitates the use of wooden structure codes by engineers. Thus, there is a growing need to establish a comprehensive standard system to facilitate the widespread adoption of bamboo structures.

This paper also explores engineered wood and bamboo composites that aim to reduce the natural material's variability while providing superior material properties and structural performance compared to raw bamboo. Types of engineered wood composites, including Fiber Reinforced Polymer (FRP), Reinforced Bonded Laminated Timber, Cloth Laminated Timber (CLT), and Wood Scorer, have been investigated, alongside newly developed bamboo composites like Laminated Bamboo

(LBL), Glued Laminated Bamboo (Glubam), and bamboo scribes, along with their fabrication techniques, modeling approaches, and mechanical characteristics.

Keywords: Laminated bamboo, mechanical properties, bolt resistance, Poisson's ratio, sustainable construction, engineered wood composites

1. Introduction

Laminated bamboo technology was originally based on the concept of laminated wood blocks. Glued wood blocks consist of relatively thin layers of wood that can be assembled and glued together into blocks of various sizes and lengths, [2]. One of the advantages of lamination technology means that it can indirectly solve the problem of cracks, breaks and defects caused by drying due to the presence of laminate. Thin sheet for faster and easier drying. The strength of screws is mechanical. Determination and description of material properties based on test results Ultimate strength of wood around compressed holes or bolts [3], [4], [5].

One of the advantages of lamination technology is that it can indirectly solve the problem of cracks, breaks or defects due to drying. Because laminate consists of thin sheets, it dries quickly and easily. Bolt resistance is a mechanical property of a material, determined based on test results, that describes the ultimate strength of wood around a hole or bolt under compressive loading. The P5% value is the intersection of the test result graph and the 5% offset line for the measured bolt diameter. A 5% diameter offset method was used to determine the 5% offset value for each test. Object. This value was obtained from the intersection of a plot of torsional strength test results for laminated bamboo and the 5% diameter bolt offset line.

Research to know the mechanical properties of peton bamboo. Mechanical properties of bamboo materials are essential for further analysis of bamboo structure. Further research is needed to obtain the Poisson's ratio of the laminated peton bamboo, as the mechanical properties, especially the Poisson's ratio, of the laminated peton bamboo were not discovered in previous studies. Because the structure of laminated bamboo is generally geometrically similar to wood, the timber calculation criteria for laminated bamboo can be used.

Bamboo is a building material that has the potential to be developed for construction. From an economic point of view, bamboo is very beneficial because it is cheap and readily available, but from a structural point of view, bamboo is quite strong, Bamboo production as a substitute for wood can prevent excessive deforestation and keep forests sustainable. The advantages of using bamboo as a building material are that it is an upgradable building, very long construction time, low construction cost, and no need for advanced equipment. Another advantage of this bamboo is that it is light and tall.

The research provides a description of bamboo structures that can be used for projects and covers all stages of the building life cycle. A cycle contains a design. Manufacturing; transportation; buildings; operation and maintenance; as well as planning for future reuse. The building consists of a structural modular configuration. Number of laminated bamboo layers (3-7 layers) for several mechanical tests, including impact test, bending test, lap shear test impact of differences.

Several mechanical tests examining the material behavior under various layers of Apus bamboo laminates were validated and the following conclusions were drawn. In multiple mechanical tests, including tensile, flexural, impact and shear tests in laps, the 7-layer laminated bamboo showed superior mechanical properties, followed by the 5- and 3-layer laminated bamboos. The use of bamboo composites with thin bamboo lamella thickness, many bamboo layers and a large resin matrix can improve the mechanical properties, [15], [16], [17]. A study on the feasibility of laminated bamboo sheets of the Oritake sp. (Bambusa Arundinacea) as an alternative to fishing boat construction. Bamboo laminates have excellent mechanical properties, making them ideal for boat construction and other structures [18]. The variability of LBL strength values is influenced by bamboo type, strip density and thickness, growth stage, treatment type, regulation and adhesive type, classifying LBLs based on strength level, hardness level and impregnation need to do it and by permeability, as well as areas of application in construction. The studies shared and discussed conclude observations, gaps in current research, and directions for future research on the mechanical properties of LBL [19].

This case is an excellent example of application of laminated bamboo construction, and has attracted the attention of many engineers in the industrial world. The laminated bamboo wood structure should have a bright future. It is one of the main forms of construction in civil engineering. However, there are currently no building codes for bamboo structures, so engineers should refer to those for wooden structures. Establishing a standard system is essential for applications involving artificial bamboo structures. With the efforts of more and more scientists, building a code system may not be a long road [20].

Engineered wood or bamboo intended to reduce the variability of natural materials can provide superior material properties and structural performance compared to genuine sawn or raw bamboo. Three new types of engineered wood composites namely Fiber Reinforced Polymer (FRP), Reinforced Bonded Laminated Timber, Cloth Laminated Timber (CLT), Wood Scorer and three newly developed types of bamboo composites namely Laminated Bamboo (LBL)), paid special attention to glued laminated bamboo (Glubam) and bamboo scribes, their fabrication techniques, modeling techniques, and mechanical properties [21].

2. Methods

This study was conducted to determine the characteristics of the static loads that can be endured and the deformation of laminated bamboo that occurs under the loads. To get the data, we need to do laboratory tests, i.e. bamboo pivot strength tests to find Fe max and Fe 5%. The tools used in the bamboo assembly process are kitchen knives, which are also used to clean the outer shell of the bamboo, peel the bamboo, and split the bamboo into bamboo slats. A handsaw is used to cut the bamboo to a specified size by hand by placing a saw blade on the laminated bamboo. A long tub with a width of 39.5 cm, a height of 45 cm, and a length of 450 cm. The bamboo board is flattened using a kitchen knife or sharpener, then shaped and made into an exact size. Another tool to prepare is a digital scale used to weigh the amount of preservatives used in the bamboo canning process. A whetstone cutting machine is used for cutting laminated bamboo and leveling laminated bamboo blocks. In addition, the drill has the function of making holes in the laminated bamboo for bolts to pass through, and uses drill bits with a diameter of 8mm and 10mm.

The equipment used to test the strength of laminated bamboo pivots are UTM (universal testing machine), monitor and caliper. A UTM is a machine that can be used for many different types of tests, and the load factor of the UTM machine can be adjusted as needed. The load rate specified in this study was 1.50mm/min and the results obtained from the tests are in shape. of load curves and deformation. A patch meter is used to read a scale that determines the amount of deformation that

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occurs in the test object. The patch meter used has an accuracy of up to 0.01 mm. The drilling machine has the function of drilling bolt holes in laminated bamboo, and uses drill bits with a diameter of 8mm and 10mm. Vernier calipers are used to measure the dimensions of laminated bamboo and the diameter of studs. Mon-itors, on the other hand, are used to read load and decline. In this study, a 10 cm x 10 cm x 4 cm measurement object is used to test the strength of laminated bamboo pivots on bolts (see Figure 1).

Fig 1. Strength Testing of Bamboo Buds Laminated

The number of test objects used in this study was 12. The variations of the laminated bamboo specimens used in this study were the parallel variation and the zigzag variation. A variety of test objects are useful for determining differences in strength and deflection. Figures 2a and 2b show sequential images of the zigzag and parallel test objects.

Fig 2. Model (a) zig zag , (b) parallel Laminated

The diameters used are aligned and zigzag shapes of 8mm and 6mm respectively. The first step of testing the strength of the laminated bamboo pivots performed in this study started by cutting the laminated bamboo block according to the standard [13], then coded the test object based on the variation in screw diameter used. The specimen is then semi-circular in size depending on the screw used. Then bolts are attached to the specimen and the specimen is placed in his UTM machine and loaded until the specimen is pushed to its limits. Based on the strength test results of laminated bamboo shafts, we made a graph of the relationship between load (N) and deformation (mm). Fig. 3 shows the configuration of the laminated bamboo fulcrum strength test by the half-hole method using a UTM (universal testing machine). It can be seen from the figure that the method used was the half-hole method or the half-hole test tested by [22].

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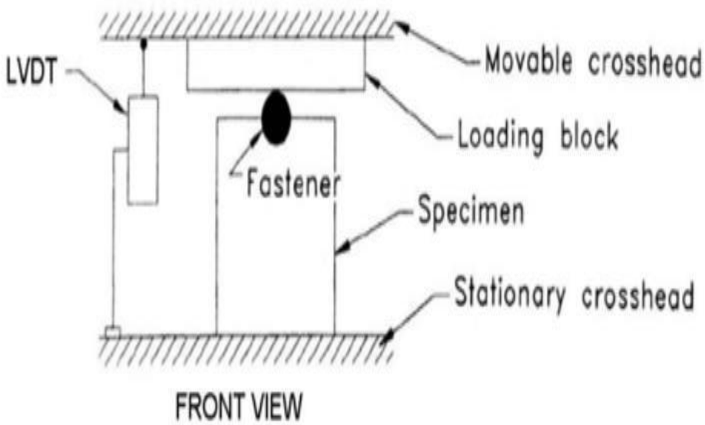

Fig 3. Setting up a half-hole test fulcrum strength test [22].

3. Results and Discussion

This study used two hump size variations, 8 mm and 10 mm in size, and 12 samples of laminated bamboo specimens measuring 10 cm x 10 cm x 4 cm. When testing the strength of a pivot, data are generated in the form of load (N) and reduction (mm). Shrinkage and misalignment that occur in laminated bamboo are caused by the tension applied to the crimping pins. Using two types of specimens, a parallel fluctuation specimen and a zigzag fluctuation specimen, a strong axis pivot test is performed on laminated bamboo. Two variations of the diameter of the screws used were used when conducting the tests 8mm and 10mm diameter screws. An image of the test results is shown in Figure 4, and an image of the test object is shown in Figure 5.

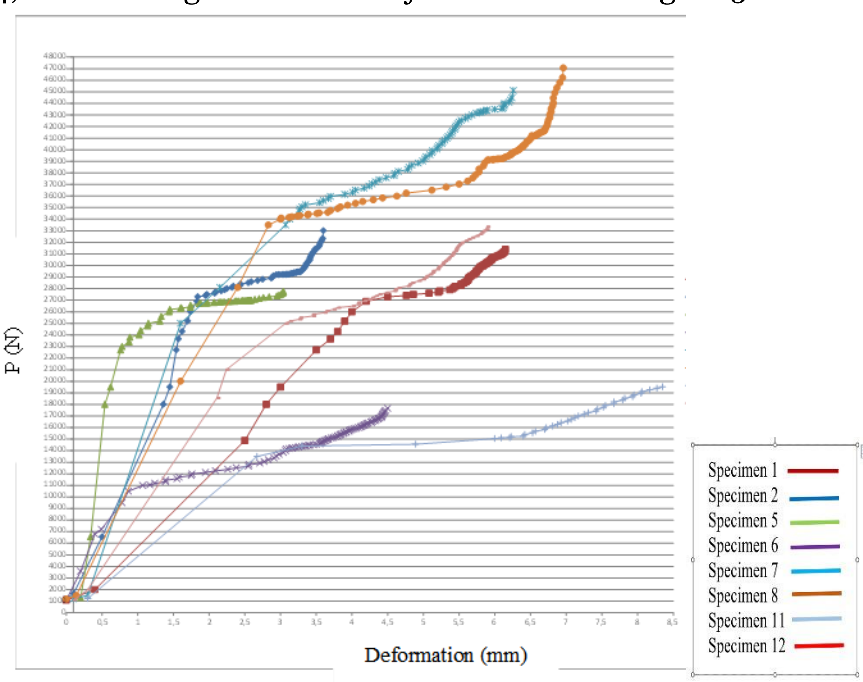

Fig 4. Strength Test Chart of Laminated Bamboo.

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Fig 5. Specimens.

Calculation of the strength value of laminated bamboo fulcrum (Fe) with bolt stacker using the maximum load method (Pmax). The Pmax value is obtained from the maximum load that the test piece can withstand at the time of testing. The following Figure 6 shows a graph of the results of the fulcrum strength test on a test object 6, 8 mm in diameter.

The following is a calculation of the strength value of the laminated bamboo fulcrum (Fe) on the test object sample 6 diameter 8 mm, with the P maximum load method using Equation (1).

Measured Diameter (D) = 7.56 mm
Bamboo Sample Thickness (t) = 40 mm
Maximum load (Pmax) = 17651.97 N
Strong Sample Holders KT-8 mm-3 Zigzag

$$Fe = \frac{P\ max}{D \times t} \quad (1)$$

= 58.373 MPa.

Using the same equation, the results of the calculation of the strength of the laminated bamboo fulcrum with the P max = load method can be seen in Table 1.

Table 1. Results of Strength with Maximum Load

	D Bolt (mm)	**D Measurable (mm)**	**T (mm)**	**P max (N)**	**Fe max (Mpa)**
BU 1 - D8 mm– Zigzag	8	7.56	40	31,381.28	103.774
BU 2 - D8 mm– Zigzag	8	7.57	40	32,999.38	108.981
BU 3 - D8 mm– Zigzag	8	7.57	40	27,850.89	91.978
BU 4 - D8 mm- Paralel	8	7.58	40	17,848.10	58.886
BU 5 - D8 mm– Paralel	8	7.58	40	27,752.82	91.533
BU 6 - D8 mm– Paralel	8	7.56	40	17,651.97	58.373

BU 7 - D10 m – Zigzag	10	9.06	40	45,110.59	124.447
BU 8 - D10 mm–Zigzag	10	9.06	40	47,071.92	129.889
BU 9 - D10 mm – Zigzag	10	9.05	40	23,535.96	65.016
BU 10 - D10 mm – Paralel	10	9.08	40	31,381.28	86.402
BU 11 - D10 mm – Paralel	10	9.07	40	19,515.23	53.791
BU 12 - D10 mm – Paralel	10	9.06	40	33,342.61	92.005

Calculation of strength value of laminated bamboo pivot (Fe) with pin stacker by offset load 5% diameter (P5%) method. The 5% bolt diameter offset load value is obtained from the intersection of the pivot strength test results graph and the 5% smooth diameter offset line. Figure 7 shows how to determine P5% for a 6.8 mm diameter specimen. To determine the P5% offset line on the chart, we can use equation (2.1) to do the following calculation:
0.05 x Depth Six test object samples of the following diameters were used in this test:
d = 8 mm, offset 5% = 0.05 x 8 = 0.4.
The following is a calculation of the strength value of the laminated bamboo fulcrum (Fe) on the sample Test Object 6 8 mm diameter, with the offset load method of 5% diameter using equation (2).
Rated Diameter (D) = 7,56 mm
Bamboo Sample (t) = 40 mm
5% offset load (P5%) = 11.200 N
Strong fulcrum Sample KT-8 mm-3 Zigzag

$$Fe = \frac{P\,5\%}{D \times t} \qquad (2)$$

= 37.037 MPa
Using the same equation, the results of the calculation of the strength of the laminated bamboo fulcrum with the P5% load method can be seen in Table 2 below.
Table 2. The result of the calculation of the strength of the master with a load of P5%.

	D Bolt (mm)	**Measurable (mm)**	**T (mm)**	**P 5% (N)**	**Fe 5% (Mpa)**
BU 1 - D8 mm– Zigzag	8	7.56	40	27,500	90.939
BU 2 - D8 mm– Zigzag	8	7.57	40	28,500	94.122
BU 3 - D8 mm– Zigzag	8	7.57	40	-	-
BU 4 - D8 mm-Par-alel	8	7.58	40	-	-
BU 5 - D8 mm–par-	8	7.58	40	23,400	77.177

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alel					
BU 6 - D8 mm – Paralel	8	7.56	40	11,200	37.073
BU 7 - D10 mm – Zigzag	10	9.06	40	27,000	74.503
BU 8 - D10 mm – Zigzag	10	9.06	40	34,500	95.199
BU 9 - D10 mm – Zigzag	10	9.05	40	-	-
BU 10 - D10 mm – Paralel	10	9.08	40	-	-
BU 11 - D10 mm – Paralel	10	9.07	40	14,400	39.691
BU 12 - D10 mm – Paralel	10	9.06	40	25,000	68.985

Graphs of the maximum load strength (Fe max) values of 8 mm and 10 mm diameters can be seen in Figure 6 and Figure 7.

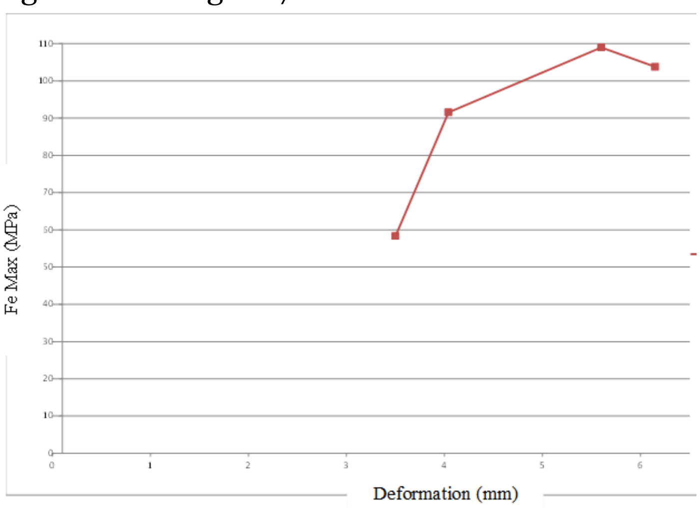

Fig 6. Fe Max Value Diameter 8 mm.

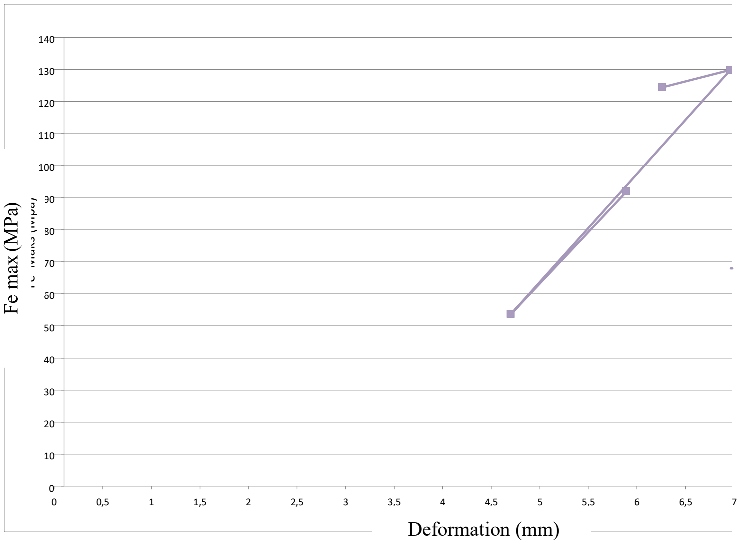

Fig 7. Fe Max Value Diameter 10 mm.

Graphs of the maximum load strength (Fe5%) values of 8 mm and 10 mm diameter can be seen in Figure 8 and Figure 9.

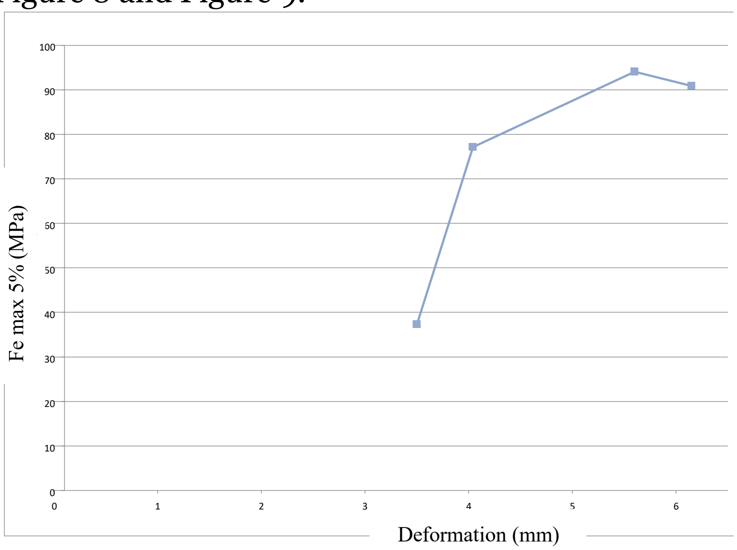

Fig 8. Fe Max 5% Value Diameter 8 mm.

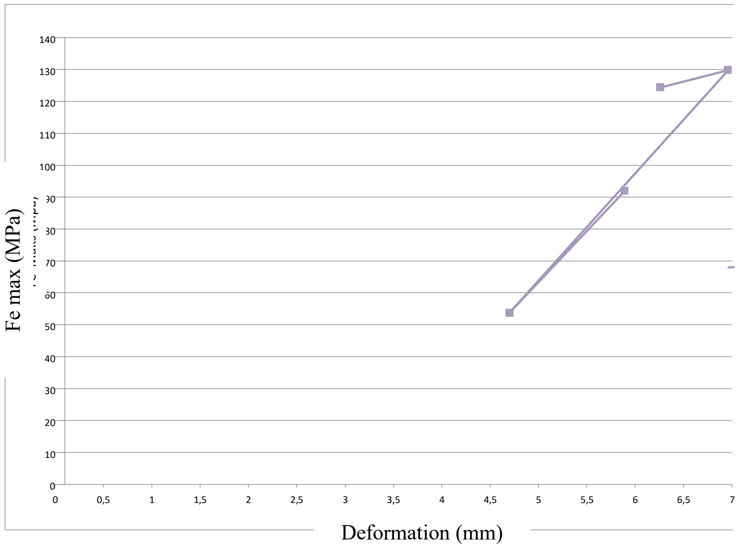

Fig 9. Fe Max 5% Value Diameter 10 mm.

4. Conclusion

The following results were obtained based on the analysis and consideration of the strength test of laminated bamboo joints. Variation in bolt diameter size affects the average pivot point strength (Fe), with larger diameter bolts increasing stress. Based on the results of testing the strength of laminated bamboo pivots, the average Fe max values for 8mm and 10mm diameter screws are 85,584 MPa and 91,930 MPa, respectively. The strength of laminated bamboo pivots with Fe5% value tested with 8 mm and 10 mm diameter screws was 74,819 MPa and 65,594 MPa. The maximum tested result for pivot strength (Fe Max) at maximum load is 108.981 MPa at 8 mm diameter and the minimum Fe Max at 8 mm pin diameter is 58.373 MPa. The 10mm maximum (Fe Max) diameter is 129.889MPa and the minimum Fe Max bolt diameter is 53.791MPa at 10mm. 5. The maximum value of the test results is 94.122 MPa at 5% (Fe max 5%) 8 mm diameter unbalanced load strength, and the minimum value is 37.037 MPa at Fe 5% bolt diameter 8 mm. The maximum value (Fe5%) for 10mm diameter is 95.199MPa, while the minimum value for Fe5% for 10mm pin diameter is 39.691MPa. In the test, two types of variation, a parallel variation test and a zigzag variation test, were used for the shape of the laminated bamboo test product. The specimen that broke during the test was a damage of the strength of the specimen that changed in a zigzag with a bolt diameter of 10 mm.

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