Increased strength of laminated bamboo beams using a shear connector adhesive method

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Abstract. At this time the timber with good quality has been difficult to obtain, so the wood is increasingly rare for building construction. To reduce deforestation due to logging for construction materials, it is time to replace wood with bamboo. Laminated bamboo is an engineering building material that has a character like wood. Laminated bamboo structures can encourage the replacement of wood, steel and concrete materials so that the development of laminated bamboo technology can revolutionize the use of bamboo in construction. One of the weaknesses of the laminated bamboo beam structure is the adhesive line between the bamboo lamina. Mechanical lamination using a shear connector prevents horizontal slip between the bamboo lamina. Incising method is a method that makes the adhesive as well as the adhesive as well as the shear connector. *Dendrocalamus asper* research material with an average age of 4 years. The testing shear strength and tensile strength of bamboo block lamination was carried out based on ASTM D143 (2002). Experimental testing of flexural strength of laminated bamboo beams is carried out using a tool with a Multi Purpose Testing System and data logger. Changes in the structure of bamboo that are applied to lateral pressure are observed using SEM (Scaning Electron Microscopy). The use of Incising method in making laminated bamboo beams can significantly increase the strength of mechanical properties laminated beam structures.

1. Background

Global warming causes an increase in average temperatures on Earth. An increase in the average temperature of the earth's surface is less than 1 degree Celsius or 1.3 degrees Fahrenheit in the last 100 years [1]. In the last five decades, 1.2 billion hm^2 of land (11% of the total vegetation of the earth) has been degraded and damaged its original biotic function [2]. A quarter of land degradation is caused by humans (agricultural practices, excessive livestock grazing, deforestation, etc.) [3]. The need for wood for construction materials cannot be fulfilled at this time and moreover in the future.

To restore forest preservation, it is necessary to grow plants that are fast and able to absorb more carbon than hard plants. Bamboo is known as one of the fastest growing plants in the world, with growth rates ranging from 30 to 100 mm per day during growth. Bamboo plants can grow quickly which only takes about four years to reach adulthood, compared to woody plants and fruits that require a long time to reach adulthood. In addition, in terms of carbon dioxide absorption, bamboo absorbs more carbon dioxide than woody plants or fruits [1].

At this time the timber with good quality has been difficult to obtain, so the wood is increasingly rare for building construction. To reduce deforestation due to logging for construction materials, it is time to replace wood with bamboo. Bamboo has a good strength when used properly for construction [4]. The use of bamboo as an environmentally friendly construction material is very important to do. Bamboo plants at the age of 5-6 years can be harvested continuously and the growth of bamboo shoots grows fast. The rapid growth of bamboo is able to reduce the problems caused by global warming on earth. Bamboo is the fastest growing and renewable natural resource that absorbs carbon in the air [5]. With dense leaf clumps, the amount of biomass accumulation and the abundance of literfall makes bamboo play a major role in the rehabilitation of degraded land. In China, India and Thailand, bamboo agro-forestry models for degraded land have been developed [6].

Bamboo geometry which is round and hollow becomes an obstacle to be used as a structural construction material beam. So that lamination technology is needed to make bamboo into solid beam structures without cavities with various geometric shapes as desired. Lamination is the process of combining one part of material with another material, both similar and different materials into a single entity that cannot be separated. Laminated bamboo is an engineering building material that has a character like wood. One of the weaknesses of the laminated bamboo beam structure is the adhesive line between the bamboo lamina. Weak adhesive lines cause laminated bamboo blocks to fail to slide. The laminate beam is damaged before reaching maximum flexural strength. The lines of adhesive lines of laminated bamboo beams as shown in figure 1.

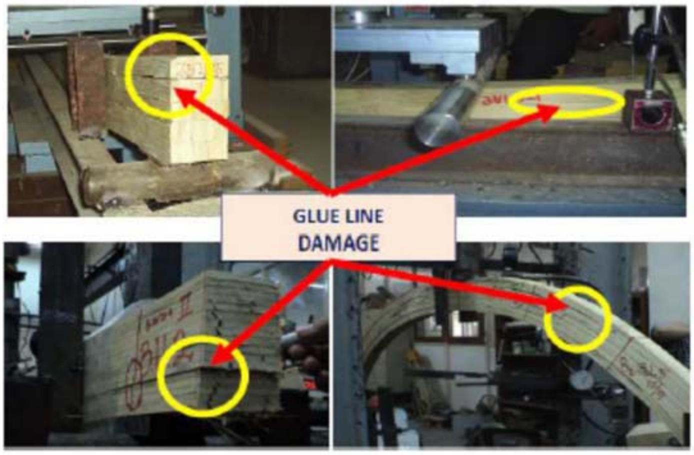

Figure 1. Bamboo Beam Shear Failure Caused By Damaging Adhesive Lines [7].

Mechanical laminated wood elements are structural components arranged by lamina (or called layers) horizontally or vertically, which are mechanically joined using nails, dowels, or bolts [8]. Mechanical lamination using a shear connector prevents horizontal slip between the bamboo lamina. Incising method is a method that makes the adhesive as well as the adhesive as well as the shear connector. So that the increase in the strength performance of laminated bamboo beams whose construction uses an incising system is very important will be research.

2. Literatur Review

Bamboo's own weight is light compared to steel, concrete and wood so that it can withstand more loads. Bamboo is one of the strongest construction materials. The tensile strength of bamboo (28,000 ponds per square inch), much higher than the tensile strength of steel (23,000 ponds per square inch).

The energy needed to produce a voltage of 1 m^3 per unit of structural material, it turns out that bamboo requires 50 times lower than steel or concrete [9]. The physical and mechanical properties of bamboo species and materials from engineered bamboo have shown that engineered bamboo has properties that are comparable to or superior to wood [10], [11]. Composite bamboo such as laminated bamboo eliminates the size limit of bamboo material and is able to provide the same dimensions, together with increased strength and uniformity [12]. Laminated bamboo structures can encourage the replacement of wood, steel and concrete materials so that the development of laminated bamboo technology can revolutionize the use of bamboo in construction. The advantages of laminated bamboo, among others, can be formed in a variety of sizes, better mechanical properties than the base material type of bamboo used [13].

3. Problem Identification

Damage to the laminated bamboo adhesive line results in the laminated bamboo blocks being damaged before its strength reaches a maximum value. In the structure of laminated bamboo blocks, the bamboo lamina layer that experiences compression is estimated to suffer damage to the fibers so that it affects the strength of the adhesive lines and the strength of the laminated bamboo beams [13].

Laminated bamboo beams that experience sliding failure are caused by damage to the adhesive line before the maximum load that is withheld is reached. This causes the strength of laminated bamboo beams not yet optimally utilized to withstand the load. So we need a method to strengthen the adhesive line so that the laminated bamboo blocks hold the load optimally.

4. Objectives

This study aims to analyze the mechanical properties of laminated bamboo blocks that are manufactured using the incising method. So that it can be seen the strength and stiffness of laminated bamboo beams as a wood substitute construction material.

5. Methodology

Dendrocalamus asper research material with an average age of 4 years. The bamboo part is chosen to get bamboo slats with an average thickness of 10 mm s. 15 mm and an average blade width of 35 mm.

Figure 2. Dendrocalamus asper as Materials Research.

Incising board is a board that has a steel needle with a diameter of 1 mm with a length of 1.5 mm that functions to make holes in the bamboo slats. The distance between steel needles is varied 4 mm x

4 mm, 6 mm x 6 mm and 8 mm x 8 mm. The position pattern of the steel needle on the incising board is diagonal.

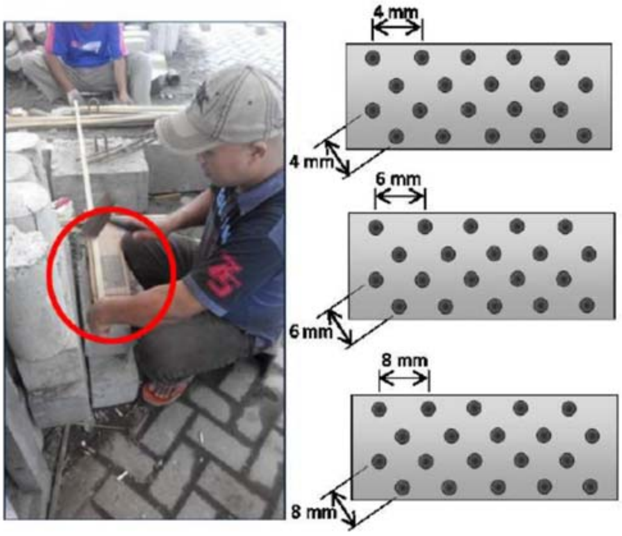

Figure 3. Incising Board to Make Bamboo Lamination Beam.

There are two groups of laminated bamboo shear blocks namely laminated blocks without incising and laminated blocks with incising. Laminated bamboo block groups with incising, varying the diagonal incising distance of 4 x 4 mm, 6 x 6 mm and 8 x 8 mm. In this study the testing shear strength was carried out based on ASTM D143, 2002 guidelines, crosshead speeds of 0.6 mm per minute, the size of the test object 50 × 50 × 63mm, with a shear plane of 50 × 50mm. The size of the laminated bamboo shear specimen is in accordance with ASTM D143 (2002). There are two groups of laminated bamboo tensile blocks, namely non-incising laminated blocks and incising laminated blocks. Laminated bamboo block groups with incising, varying the diagonal incising distance of 4 x 4 mm, 6 x 6 mm and 8 x 8 mm. The cross section planned for failure was made smaller with a size of 25 mm × 50 mm. Crosshead speeds are 2.5 mm per minute. Testing until the ultimate load and test pieces break (split or break), the strain that occurs is quite small and short should be observed from the beginning of loading until the test is complete. If the water content of the test object has reached the range of 12-13% then the test object is prepared for testing. Testing of flexural strength and shear strength of laminated bamboo beams is carried out using a tool with a Multi Purpose Testing System and data logger.

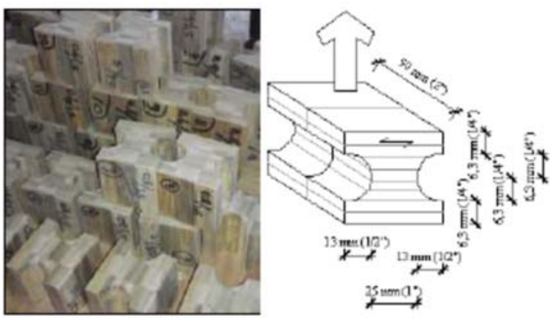

Figure 4. Tensile Strength Bamboo Block Laminations Specimens (ASTM D143, 2002).

6. Result And Discussion

From the results of experimental tests, laminated bamboo shear blocks that are made without using the incising method have an average shear strength of 4.972 MPa where the highest value is 5.735 MPa and the lowest value is 4.178 MPa. While the laminated bamboo shear block that is made using the incising method the average shear strength is 7.207 MPa where the highest value is 7.948 MPa and the lowest value is 6.274 MPa. The average shear strength of the laminated bamboo sliding block with the incising method increased by 44.95% compared to the laminated bamboo sliding block without using the incising method. The average tensile strength of the tensile block of the laminate without incising method is 1,119 MPa where the highest value is 1.236 MPa and the lowest value is 1.001 MPa. While the average tensile strength of tensile blocks of laminated bamboo which is made using the incising method is 1.591 MPa where the highest value is 1.935 MPa and the lowest value is 1.044 MPa. The average tensile strength of the laminated bamboo pull block with the incising method increased by 42.15% compared to the laminated bamboo pull block without using the incising method. Diagram of shear strength and tensile strength can be seen in figure 5 as follows.

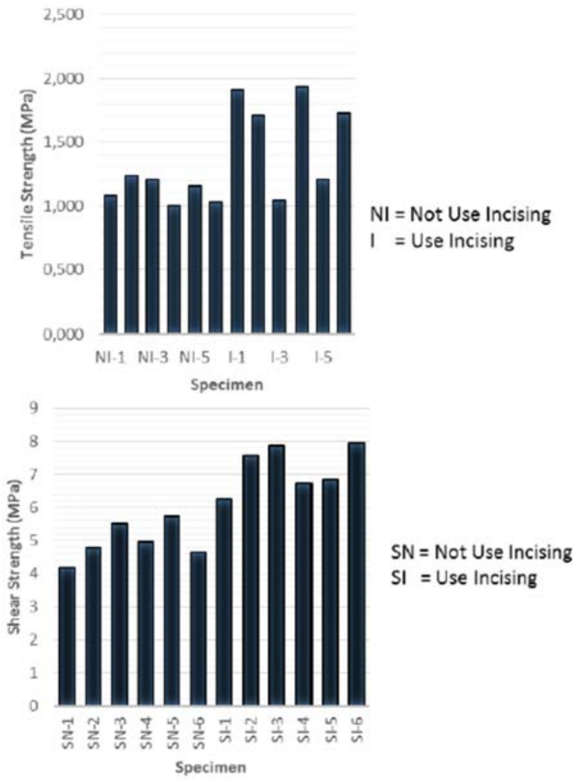

Figure 5. Diagram of Shear Strength and Tensile Strength Bamboo Block Lamination**.**

The flexural strength testing of the reference laminated bamboo beam (without using the incising method) shows that the RF-1 beam is able to withstand a maximum load of 18.32 kN. RF-2 laminated bamboo beams can withstand a maximum load of 17.85 kN. RF-3 laminated bamboo beams can withstand a maximum load of 16.29 kN. Reference laminated bamboo beams are able to withstand an average maximum load of 17.49 kN. Graph of load deflection of reference laminated bamboo beams as shown in figure 6.

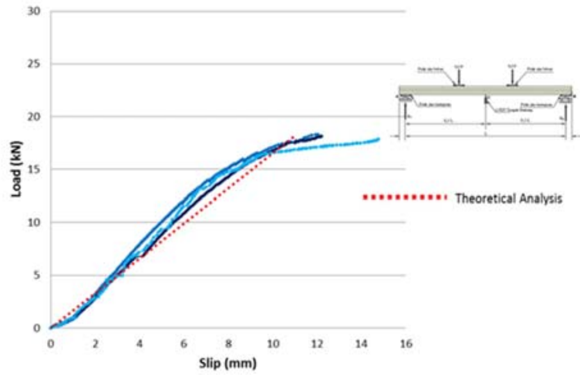

Fig. 6. Reference (non-Incising Method) Laminated Bamboo Beam with 1,5 MPa Lateral Stress.

The flexural strength testing of laminated bamboo blocks whose construction uses incising method with a distance of 4 x 4 mm shows that the IC44-1 beam is able to withstand a maximum load of 26.94 kN. IC44-2 laminated bamboo beams can withstand a maximum load of 26.48 kN. IC44-3 laminated bamboo beams can withstand a maximum load of 24.91 kN. Laminated bamboo beams with incising method distance of 4 x 4 mm can withstand an average maximum load of 26.11 kN. Graph of load deflection of reference laminated bamboo blocks as shown in figure 7.

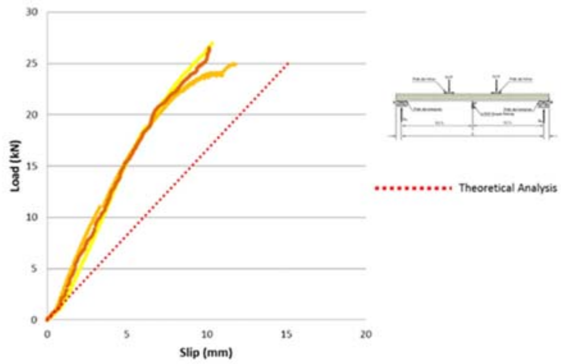

Fig. 7. Laminated Bamboo Beam Using Incising Method 4x4 with 1,5 MPa Lateral Stress.

Testing the flexural strength of laminated bamboo beams whose construction uses an incising method with a distance of 6 x 6 mm shows that the IC66-1 beam is able to withstand a maximum load of 24.16 kN. IC66-2 laminated bamboo beams can withstand a maximum load of 24.69 kN. IC66-3 laminated bamboo beams can withstand a maximum load of 24.77 kN. Laminated bamboo beams with an incising method distance of 6 x 6 mm can withstand an average maximum load of 24.54 kN. Graph of load deflection of reference laminated bamboo blocks as shown in figure 8.

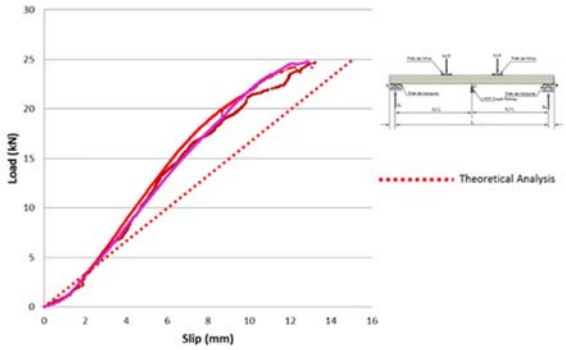

Figure 8. Laminated Bamboo Beam Using Incising Method 6x6 with 1,5 MPa Lateral Stress.

The flexural strength testing of laminated bamboo beams whose construction uses an incising method with a distance of 8 x 8 mm shows that the IC88-1 beam is able to withstand a maximum load of 22.35 kN. IC88-2 laminated bamboo beams can withstand a maximum load of 21.54 kN. IC88-3 laminated bamboo beams can withstand a maximum load of 18.12 kN. Laminated bamboo beams with an incising method distance of 8 x 8 mm can withstand an average maximum load of 20.67 kN. Graph of load deflection of reference laminated bamboo blocks as shown in figure 9.

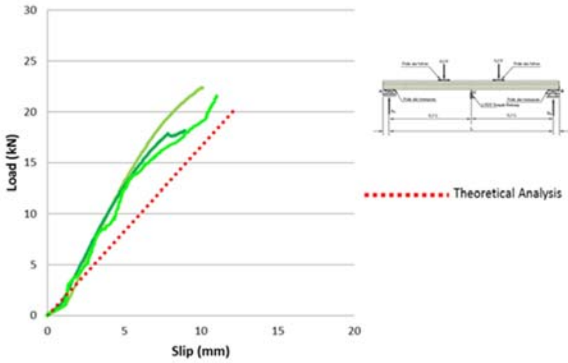

Figure 9. Laminated Bamboo Beam Using Incising Method 8x8 with 1,5 MPa Lateral Stress.

Laminated bamboo beams with a lateral stress of 1.5 MPa without using the incising method (reference laminated bamboo beams) are able to withstand an average maximum load of 17.49 kN. Laminated bamboo beams with incising method distance of 4 x 4 mm can withstand an average maximum load of 26.11 kN. Laminated bamboo beams with an incising method distance of 6 x 6 mm can withstand an average maximum load of 24.54 kN. Laminated bamboo beams with an incising method distance of 8 x 8 mm can withstand an average maximum load of 20.67 kN. Laminated bamboo beams with an incising method distance of 4 x 4 mm have increased load bearing by 49.31% compared to bamboo laminated bamboo blocks (without incising method). Laminated bamboo beams with an incising method spacing of 6 x 6 mm have increased load-bearing by 40.34% compared to the laminated bamboo beams of reference lamination (without the incising method). Laminated bamboo beams with an incising method distance of 8 x 8 mm have increased withstand a load of 18.20% compared to the laminated bamboo beams of laminated references (without incising method). The maximum load of each laminated beam with a lateral stress of 1.5 MPa can be seen in figure 10.

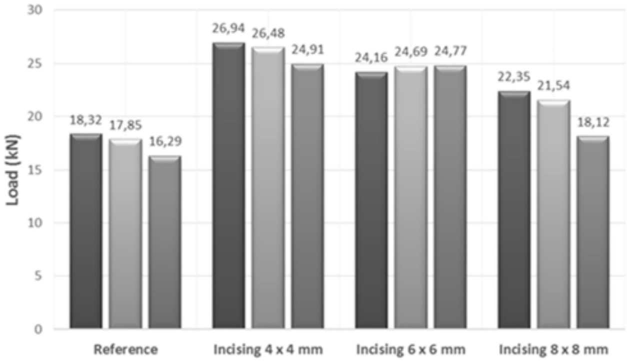

Figure 10. Barchart Load Maksimum Laminated Bamboo Beam With Lateral Stress 1,5 MPa.

The strength to withstand the burden of laminated bamboo beams by incising method has increased. The higher strength compared to laminated bamboo blocks without using the incising method is caused by the function of the adhesive as a mechanical laminate. So that the strength of laminated bamboo beams is more optimal. The elongated and transverse surface texture of the laminated bamboo beams as shown in figure 11.

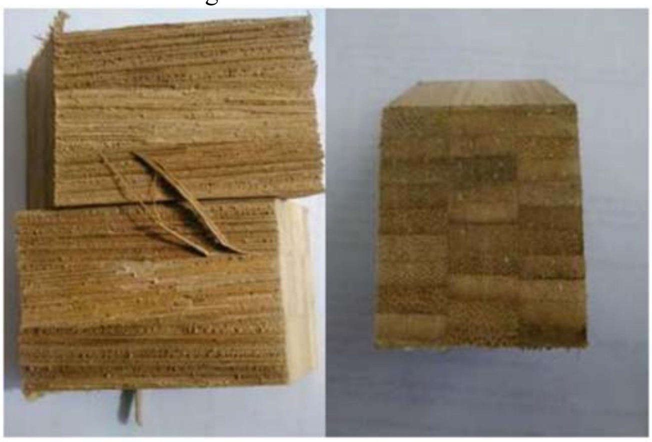

Figure 11. Texture Condition Elongated and Transverse Cross-Section Bamboo Laminated Beams Using Incising Method.

Changes in the structure of bamboo that are applied to lateral pressure are observed using SEM (Scaning Electron Microscopy). From the comparison of the Petung bamboo fiber cell dimensions in figure 12 (a) and figure 12 (b), it can be seen that there is a change in the shape of the Petung bamboo fiber cell when 1.5 MPa is compressed. From the comparison of microscopic images in figure 12 (c) and figure 12 (d), it can be seen that for the pressure of 2 MPa and bamboo presses have begun to experience cracking. At a pressure of 2.5 MPa, the fiber strands are limited by cracked parenchyma cells that cause the strands to split into an average of 15 irregular planes. Of the 6 pieces of fiber strands, only an average of almost all cracks in the fiber strand are limited by parenchyma cells. Microscopic image as shown in figure 12.

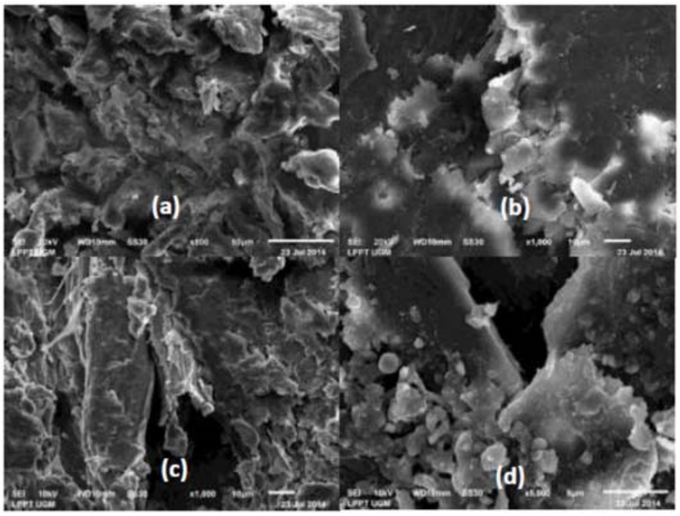

Figure 12. Result of SEM Observation : (a). Without Lateral Stress (b). 1.5 MPa Lateral Stress (c). 2 MPa Lateral Stress (d). 2.5 MPa Lateral Stess.

7. Conclusion

The average shear strength of the laminated bamboo sliding block with the incising method increased by 44.95% compared to the laminated bamboo sliding block without using the incising method. The average tensile strength of the laminated bamboo drag block with the incising method increased by 42.15%.

Reference laminated bamboo beams (without using the incising method) are able to withstand an average maximum load of 17.49 kN. Laminated bamboo beams with incising method distance of 4 x 4 mm can withstand an average maximum load of 26.11 kN. Laminated bamboo beams with an incising method distance of 6 x 6 mm can withstand an average maximum load of 24.54 kN. Laminated bamboo beams with an incising method distance of 8 x 8 mm can withstand an average maximum load of 20.67 kN. So that the use of Incising method in making laminated bamboo beams can significantly increase the strength of the laminated beam structures.

8. References

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