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Experimental Study on the Structural Performance of Laminated Beams Made from Sago Palm Stem Waste (Metroxylon sp) Based on Compressive Strength

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Abstract

Sago is potential food resources in Indonesia, with an estimated area of 6.5 million hectares. The sago bark is a by-product waste generated from processing the sago trunk. After further study and analysis, it was found that sago bark waste has potential to be utilized as a construction material. One method is to laminate the sago bark.

The method in this study processing the sago bark waste into thin wood sheets, which are then laminated using polyvinyl acetate (PVAc) adhesive as the bonding agent. The laminated sheets were then pressed with varying pressures of 0.4 MPa, 0.6 MPa, and 0.8 MPa.For test the flexural strength of the laminated beams was tested using single load method.

The results show the laminated sago bark sheets have the potential to be used for construction material. The modulus of elasticity (MoE) obtained from the flexural test was 4701.88 MPa for 0.4 MPa compressive, 5571.79 MPa for 0.6 MPa compressive, and 2765.07 MPa for 0.8 MPa compressive. The optimal compressive strength was found to be 0.6 MPa. In the classification, the laminated sago bark is categorized as Class V material.

Keywords : Timber, Lamination timber, Metroxylon sp, polyvinyl acetate (PVAc).

1. INTRODUCTION

According to the Minister of Industry, *"Indonesia possesses the largest sago plantation area in the world. Of the 6.5 million hectares (ha) of sago land globally, approximately 5.5 million ha, or about 85%, are located in Indonesia"* (Portal Informasi Indonesia, September 27, 2024). The vast extent of sago land indicates high production potential and significant economic value. However, it also gives rise to a new issue—the increasing amount of waste generated from sago processing. One notable type of waste is the sago bark, which has not yet been optimally utilized. In fact, sago bark contains a high fiber content, making it potentially useful in various industrial applications, such as construction materials, paper manufacturing, and handicraft products.

Sago bark contains up to 56.86% cellulose and 37.70% lignin (Kiat, 2006), making it a promising alternative raw material for wood-based products. One potential approach to utilizing sago bark is through lamination techniques to produce laminated beams. The performance of laminated beams is strongly influenced by bonding process parameters, particularly the pressing strength applied during lamination. The appropriate pressing strength determines the quality of interlayer bonding, density, stiffness, and overall mechanical strength of the resulting beam. If the pressure is too low, the adhesion between laminae becomes suboptimal, reducing both bending and shear strength. Conversely, excessive pressure can damage fiber structures and cause material deformation. Therefore, it is essential to conduct an experimental study to investigate the effect of pressing strength on the structural performance of laminated beams made from sago bark waste.

This research is expected to provide scientific contributions to the development of alternative construction materials derived from local biomass waste, while also supporting sustainable development efforts in the civil engineering and forestry sectors. Furthermore, the outcomes of this study may serve as a preliminary reference for engineering processes and the standardization of laminated materials made from sago waste in the future.

2. REVIEW OF LITERATURE

The quality of laminated beams is essentially influenced by several factors, including the raw materials used and the requirements for those materials, such as fiber density and specific gravity uniformity. The type of adhesive applied must correspond to the intended use of the laminated beam. The form of joints, the bonding process between laminated layers, and the pressing process must also be carefully considered. Therefore, testing that meets established standards is necessary before using laminated beams, especially when they are intended for structural functions (Tjokrowijanto, 2015).

An increase in bonding strength and flexural strength in laminated Keruing and Meranti wood does not always correlate directly with increased pressing pressure. The maximum strength values (both bonding and flexural) are achieved at a moderate pressing pressure of 0.6 MPa when using Melamine Formaldehyde (MF) adhesive. The most effective combination for flexural strength is Keruing–Meranti–Keruing (KMK) (Anshari, 2006).

Laminated boards made from a combination of Sengon wood and Petung bamboo, processed under pressing variations of 20 Nm and 30 Nm, exhibit good physical properties and meet certain national and international quality standards. Classified as Strength Class III, this product is suitable for protected heavy construction applications (Wulandari et al., 2023).

The Modulus of Rupture (MoR) is a mechanical property of wood that reflects its strength, representing the wood's ability to resist external loads or forces before failure occurs. MoR is commonly used as a reference for wood strength in the plywood industry, furniture manufacturing, and building construction (Khalifah, 2019). The formula used to determine the Modulus of Rupture (MoR) according to ASTM D198-2015 is as follows:

$$MoR = \frac{3.P_{maks}.L}{2.b.h^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The Modulus of Elasticity (MoE) is an indicator value that represents the ability of a material (wood) to resist deformation under load, often referred to as stiffness. Its value is obtained through a flexural test conducted in the laboratory by measuring the amount of deflection resulting from loading (Cahyono et al., 2014). The formula used to determine the Modulus of Elasticity (MoE) according to ASTM D1037-06 is as follows:

$$MoE = \frac{\Delta P.L^3}{48.I.\Delta Y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

SNI 7973:2013 stipulates that the Modulus of Elasticity (MoE), or Flexural Modulus of Elasticity, serves as the primary basis for classifying the quality of timber that is graded either mechanically (Machine Stress-Rated Timber) or visually (Visually Graded Timber) for structural design purposes, as shown in Table 1.

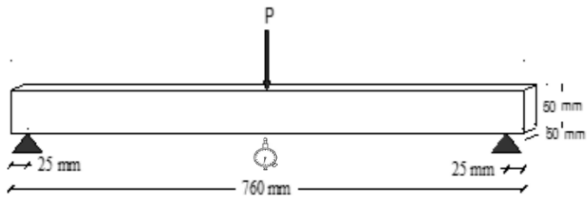
Table 1. Classification of strength class on MoE value (SNI 7973:2013)

Strength Class	Modulus of Elasticity (MoE)	Description
Class I	≥ 20.000 Mpa	Very stiff, suitable for major structural applications
Class II	15.000 – < 20.000 Mpa	Stiff, suitable for medium structural applications
Class III	10.000 – < 15.000 Mpa	Moderate, suitable for light structural applications
Class IV	5.000 – < 10.000 Mpa	Fairly flexible, suitable for light non-structural applications
Class V	< 5.000 Mpa	Highly flexible, not suitable for structural applications

3. METHOD

In this study, sago bark waste with an approximate length of ±1 m and a width of ±6.5 cm was used as the main material. The preparation of test specimens began by processing the waste into thin wood sheets through cutting and surface scraping. Subsequently, tests were conducted to determine moisture content, density, and tensile strength. The next step was the lamination process, in which ten sheets of wood were arranged and bonded using polyvinyl acetate (PVAc) adhesive. The laminated sheets were then pressed under three different pressures: 0.4 MPa, 0.6 MPa, and 0.8 MPa. From this process, laminated wood beam specimens were produced with dimensions of 760 mm × 50 mm × 50 mm, in accordance with SNI 03-3959:1995 and each variation was made 3 samples.

To obtain the flexural strength values, a bending test was performed by setting the span length to 760 mm with a single-point loading applied at the mid-span. A dial gauge was placed at the center of the span to measure the deflection that occurred, as shown in the following figure. The loading process was initially carried out under load control, followed by deflection control.



4. RESULT & DISCUSSION

Moisture Content

The moisture content test of the sago bark yielded a value of 13.69%. According to SNI 03-3527-1994 regarding timber for building construction, the maximum allowable moisture content for dry wood used in structural applications is approximately 15%. Therefore, the moisture content of the tested sago bark is still below the maximum limit specified by the SNI standard.

Density

The density test of the sago bark produced a value of 2.27 g/cm³. This indicates that the wood has a very compact structure, with low pore volume and tightly packed fibers. Such characteristics suggest that the wood possesses high mechanical strength, good dimensional stability, and is suitable for heavy construction applications such as structural frames, bridges, and high quality furniture. When compared to the strength classification standard based on density, the average density value of 2.27 g/cm³ is significantly higher than the minimum threshold for Strength Class I (≥ 0.90 g/cm³). Hence, the tested wood is classified as Strength Class I, the highest category in wood strength classification. This demonstrates that the wood has excellent potential for structural applications requiring high strength and long-term durability.

Tensile Strength

The tensile strength test of the sago bark resulted in a value of 113.47 MPa. Based on SNI 7973:2013 and general reference data, the tensile strength parallel to the grain for Sengon and Meranti wood ranges between ±40–100 MPa, while Teak and Mahogany range between ±90–130 MPa. This shows that the average tensile strength of the sago bark exceeds that of softwoods such as Sengon and Meranti, and is comparable to or slightly lower than Teak or Mahogany. This indicates that the tested wood possesses good structural quality and is suitable for use in structural frameworks, wooden bridges, and other building components.

Flexural Strength

The flexural strength test was conducted to determine the ability of the wood to resist bending forces before failure or fracture occurs. This test is essential for determining the mechanical performance of wood, assessing its capacity to withstand bending loads without cracking or breaking. In addition, two key mechanical properties were derived: the Modulus of Elasticity (MoE), which indicates the stiffness of the wood under bending, and the Modulus of Rupture (MoR), which represents the maximum bending stress the wood can withstand before failure.

Table 2. Results of Laminated Beam Tests with Different Pressing Variations

Benda Uji	L (mm)	b (mm)	h (mm)	I (m^4)	ΔP (N)	ΔY (mm)	Pmak (N)	MoR (*MPa*)	MoE (*MPa*)
0,4 A	710	56,1	57,9	907438,7	4200	7,16	4790	27,12	4820,06
0,4 B	710	58,9	56,9	904213,2	4200	9,11	4200	23,46	3801,84
0,4 C	710	57,8	63,9	1256750,8	3610	5,96	4200	18,95	3593,73
						Rata-rata		**23,18**	**4071,88**
0,6 A	710	64,4	63,7	1387148,4	2420	19,18	3010	12,27	1277,85
0,6 B	710	49,7	49,8	511520,65	2420	8,13	3010	26,01	4339,06
0,6 C	710	49,8	48,5	473449,12	4200	5,96	4790	43,55	11098,48
						Rata-rata		**27,27**	**5571,79**
0,8 A	710	55,9	61,3	1073030,3	3010	8,77	4200	21,29	2385,00
0,8 B	710	51,6	61,0	976018,3	3010	7,54	3610	20,02	3049,80
0,8 C	710	52,1	66,2	1259593,6	3020	6,25	3620	16,89	2860,42
						Rata-rata		**19,40**	**2765,07**

From Table 2, it can be seen that the optimal pressing pressure was 0.6 MPa, which produced the best results in terms of both the Modulus of Elasticity (MoE) and Modulus of Rupture (MoR), achieving a balance between bonding strength, stiffness, and overall strength. The 0.4 MPa pressure yielded acceptable but suboptimal results, while 0.8 MPa is not recommended as it was excessively high and led to a decrease in strength.

The laminated samples with varying pressing pressures showed a maximum MoE value of 5,571.79 MPa. According to the SNI 7973:2013 classification, this value is still below Class E7 (7,000 MPa). This discrepancy may be attributed to weaknesses in the adhesive used, as observed in Figure 2, since the tensile strength and density test results of the sago bark indicated that it belongs to the strong wood category.

Fig. 2. Gambar keruntuhan balok

5. CONCLUSION

The conclusions from the experimental study on the Compressive Strength and Structural Performance of Laminated Beams Made from Sago Bark Waste (Metroxylon sp) are as follows:

1. Based on the physical and mechanical property tests, sago bark waste can be utilized as a construction material.

2. From the flexural tests with varying pressing strengths, the highest Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) values were obtained at a pressing strength of 0.6 MPa.
3. The relatively low MoE and MoR values were caused by failure in the adhesive bonding of the laminated wood.

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