MECHANICAL AND PHYSICAL ANALYSIS OF SENGON PARTICLEBOARDS BONDED WITH MODIFIED PVAC ADHESIVES

Ardintio Guswidanto, Danang Dwi Saputro, Widi Widayat, Rahmat Doni Widodo, Karnowo
Mechanical Engineering Study Program
Universitas Negeri Semarang
guswidanto29@students.unnes.ac.id
DOI: https://doi.org/10.15294/tm.v1i1.353
QRCBN 62-6861-4134-224

ABSTRACT
Wood processing waste especially sawdust is often underutilized. One effective way to optimize its use is by converting it into particleboards. This study explores the use of PVAc adhesive combined with citric acid and tapioca in producing particle boards from sengon wood particles. Three adhesive variations were tested: 40% PVAc, 20% PVAc + 20% citric acid, and 20% PVAc + 20% tapioca. Each composition used 40% adhesive and 60% air-dried wood particles by weight. The boards were hot-pressed at 160°C under a pressure of 30 kg/cm^2 for 10 minutes. The particleboards were evaluated based on the JIS A 5908-2003 standard for physical and mechanical properties. Physically, the boards met the standard. The highest density 0.525 g/cm^3 was observed in boards with 20% PVAc + 20% tapioca, while the lowest moisture content 5.125% was found in boards with 40% PVAc. However, the mechanical properties did not meet the standard requirements. The highest Modulus of Elasticity (MOE) was 4372.776 kg/cm^2 in the board with 20% PVAc + 20% citric acid, and the highest Modulus of Rupture (MOR) was 66.48 kg/cm^2 in the board with 20% PVAc + 20% tapioca. Overall, the study shows that sengon wood particles combined with PVAc based adhesives and natural additives like citric acid and tapioca have potential as raw materials for

particleboards, though improvements are needed in mechanical strength.

Keywords: *Citric Acid, Composite, Mechanical Properties, Particleboard, Sengon wood, Tapioca*

INTRODUCTION

Wood is a material that is often found because it is easy to find and can be used for various things. Along with the production that often uses wood materials as the material, the remains of powder caused by wood cutting are becoming more and more. This only makes it waste, therefore one of the solutions to overcome these shortcomings while optimizing the use of wood is to process wood waste such as sawdust into particleboards. Composites are a new breakthrough in materials as constructions other than metal. Composite is a material produced from the combination of two or more basic materials that are arranged to obtain new materials.

Particleboard is a type of composite product or wood panel made from wood particles or other lignocellulose materials, which are bonded with synthetic adhesive or other binding materials and hot-pressed. The advantages of particleboard include having good dimensional stability, can produce a wide field, the work is easy and fast and easy to finish and can be coated with decorative paper, so that it can indirectly provide positive value for saving the use of whole wood. One of the adhesives that is often used in the manufacture of particleboard is PVAc. The effect of adding 20% PVAc glue to the binder had a considerable influence on the biocomposite on the mechanical characteristics, where for the result of bending strength it was shown that in the ratio of volume fraction 30%:20%:50% had the highest bending strength.

One of the natural adhesives that can be used as an activator developed is citric acid (2-hydroxy-1,2,3-propanetricarboxylic acid). Citric acid is an organic carboxylic acid that has three carboxyl groups. Citric acid is contained in citrus fruits such as lemons. Citric acid is a material that has the potential to reduce the use of synthetic adhesives that can cause formaldehyde emissions. The amount of citric acid affects the physical and mechanical properties of using 0%, 15% and 30% of the dry weight of citric acid in the manufacture of composite boards from kenaf fibers, showing that a concentration of 30% results in optimal values.

Citric acid and sucrose have proven to be effective as natural adhesives in the manufacture of sengon particleboard. The combination of the two, in particular with a 50:50 ratio and 15% adhesive count, results in a quality board that meets the JIS A 5908 standard.

Another example that can be used as an adhesive in composites is tapioca flour. Tapioca flour comes from the tubers of cassava trees that are made into flour, which is often used as an ingredient for making cakes and various dishes. The use of tapioca flour as an adhesive material for starches found in the form of carbohydrates in cassava tubers which function as food reserves. Tapioca when made as an adhesive has high adhesion compared to other types of flours.

Sengon trees are trees that are tolerant of where they grow or their habitat. Sengon trees can also grow on very barren soils and sengon wood has advantages when used as an industrial raw material. Seeing the many industries in this wood processing industry, a very large amount of waste will be obtained. Thus, in order for the waste to provide added value, it needs to be processed into products such as particleboards.

This chapter aims to evaluate the effect of PVAc adhesive composition modified with citric acid and tapioca on the physical and mechanical properties of particleboard made from Sengon wood waste. Additionally, the study examines the potential of these bio-based adhesive formulations to meet JIS A 5908-2003 standards as part of sustainable material engineering efforts.

A. ADHESIVE FORMULATION AND BOARD MANUFACTURING

Sengon wood particles were selected as the primary raw material due to their widespread availability and low density, which makes them ideal for lightweight composite applications. The particles were pre-treated through sundrying and oven-drying to ensure minimal moisture interference during the adhesive blending process. To achieve a consistent size distribution, particles were sieved using a 10-mesh and held at 20-mesh, ensuring uniformity in bonding and board density.

The adhesive system was prepared using three distinct formulations to explore the bonding potential of synthetic and natural components. The first formulation consisted solely of polyvinyl acetate (PVAc), known for its strong adhesive characteristics and water resistance. The second blend combined PVAc with citric acid, an organic acid that enhances cross-linking through esterification when exposed to heat. In the third formulation, tapioca starch was introduced as a renewable biopolymer, replacing citric acid to assess its bonding behavior in combination with PVAc. All adhesive blends accounted for 40% of the total composite mass, with the remaining 60% comprised of sengon particles.

Each adhesive was prepared in advance. Citric acid was diluted with water at a 1:1 ratio to enhance its reactivity and dispersion throughout the wood particles. The blending process was carried out manually in a 30-liter mixing container to ensure thorough incorporation of the adhesive into the lignocellulosic matrix. The prepared mixture was then transferred into 27 × 27 cm molds, lined with aluminum plates to prevent sticking and ensure smooth board surfaces.

To maintain board thickness at exactly 1 cm, steel spacers were placed on either side of the mold. Compression was applied using a hydraulic hot press under a constant pressure of 30 kg/cm^2 at a temperature of 160 °C for 10 minutes. These conditions facilitated proper adhesive curing, especially for thermosetting interactions involving citric acid. Following hot pressing, boards were naturally cooled at ambient conditions before being stored for a 7-day conditioning period shown in Figure 1. This step ensured moisture equilibrium and allowed further stabilization of the internal bonding structures.

The resulting boards were then cut and prepared for quality assessment. Their performance was evaluated through both physical and mechanical perspectives based on Japanese Industrial Standards (JIS A 5908-2003), focusing on density, moisture content, modulus of elasticity (MOE), and modulus of rupture (MOR). Test samples were dimensioned accordingly, with physical tests conducted on 10 × 10 × 1 cm specimens and mechanical tests performed on 20 × 5 × 1 cm samples using a Universal Testing Machine (UTM).

Figure 1. Seven-Day Conditioned Particleboard Progress

1. **Particleboard Physical Properties Testing**

The physical properties testing of particleboard includes the evaluation of both density and moisture content, which are essential parameters to determine the board's overall quality and performance. These two tests provide insights into the material's structural integrity and water retention behavior. A detailed explanation of each test method, procedure, and its relevance to particleboard performance will be provided in the following sections.

In this test, the sample used was (10x10x1) cm^3 in an air-dried state. Particleboard density is calculated using Equation (1).

$$\rho = \frac{m}{V} \quad (1)$$

Where

ρ = density (g/cm^3)

m = weight (g)

V = volume (cm^3)

2. **Testing of the Mechanical Properties of Particleboard**

The mechanical properties testing of particleboard involves the assessment of MOE and MOR, which are critical indicators of the board's strength and flexibility under load. These tests help evaluate the particleboard's ability to withstand stress and deformation, which is essential for structural applications. The following sections will provide a detailed explanation of the testing methods, procedures, and the significance of MOE and MOR values in determining the mechanical performance of particleboard using UTM shown in Figure 2.

a. MOE

The test was carried out using a UTM machine with a test sample size (20x5x1) cm^3. For testing, the spacing distance used is 15 cm. The MOE and MOR tests were performed simultaneously, but what was recorded in this test was a change in deflection of any specific load change using the Equation (2).

$$\text{MOE} = \frac{\Delta p L^3}{4 \Delta y b h^3} \quad (2)$$

Where

MOE = modulus of elasticity (kg/cm^2)
L = spacing distance (cm)
b = test sample width (cm)
h = test sample thickness (cm)
Δp = load difference (kg)
Δy = deflection changes that occur in the load (cm)

b. MOR

The test was carried out using a UTM machine with a test sample size (20x5x1) cm^3. For testing, the spacing distance used is 15 cm. The value of the MOR is calculated by the Equation (3).

$$\text{MOR} = \frac{3pL}{2bh^3} \quad (3)$$

Where

MOR = modulus of rupture (kg/cm^2)
P = maximum load (kg)
L = spacing distance (cm)
b = test sample width (cm)
h = test sample thickness (cm)

Figure 2. Testing Specimens Using Universal Testing Machine

B. PHYSICAL PROPERTIES ANALYSIS OF SENGO PARTICLEBOARDS

The physical properties testing of particleboard includes the evaluation of both density and moisture content, which are essential parameters to determine the board's overall quality and performance. These two tests provide insights into the material's structural integrity and water retention behavior. A detailed explanation of each test method, procedure, and its relevance to particleboard performance will be provided in the following sections.

Based on the results of the tests carried out, it was obtained that the particleboard density value was between 0.503 g/cm^3 to 0.525 g/cm^3 shown on Table 1. Although the density figures of the three board variants do not have a great comparison, the highest density is obtained by boards with 20% PVAc + 20% Tapioca and the boards with the lowest density are found in boards with 40% PVAc. The JIS A 5908-2003 standard requires that a good particleboard density is 0.5-0.9 g/cm^3.

Table 1. Particleboard Density Test Results

No.	Type	Average Density (g/cm^3)
1	20% PVAc + 20% Citric acid	0.516
2	40% PVAc	0.503
3	20% PVAc + 20% Tapioca	0.525

The particleboards made in this study are in accordance with the targeted density standard, which is around 0.5 g/cm^3. The physical and mechanical properties of the board are greatly influenced by the degree of adhesive used. The higher the adhesive content, the better the particleboard properties. However, the results of the study show that the density value decreases because the thickness of the board is made differently from the edge and center side of the board. This causes the effect of the density that depends on the volume of the board.

The results of the tests conducted in this study showed that the moisture content value of the particleboard ranged from 5.125% to 6% shown on Table 2. The lowest moisture content is obtained by boards with 40% PVAc, while the highest moisture content value is found in 20% PVAc + 20% Tapioca boards. The JIS A 5908-2003 standard requires that the moisture content value of particleboard ranges from 5-13%. Thus, the moisture content of the particleboard in this study of all variations is in accordance with the JIS A 5908-2003 standard.

Table 2. Particleboard Moisture content test

No.	Type	Average MC (%)
1	20% PVAc + 20% Citric acid	5.75
2	40% PVAc	5.125
3	20% PVAc + 20% Tapioca	6

C. MECHANICAL PERFORMANCE AND CHALLENGES IN ADHESIVE EFFICIENCY

The mechanical properties testing of particleboard involves the assessment of MOE and MOR, which are critical indicators of the board's strength and flexibility under load. These tests help evaluate the particleboard's ability to withstand stress and deformation, which is essential for structural applications. The following sections will provide a detailed explanation of the testing methods, procedures, and the significance of MOE and MOR values in determining the mechanical performance of particleboard.

The JIS A 5908-2003 standard requires the MOE on particleboard to be 20,000kg/cm^2. MOE value obtained ranges from 3554,154 kg/cm^2 to 4372,776 kg/cm^2 shown on Table 3. The highest MOE value is found in particleboard with 20% PVAc + 20% citric acid and the lowest MOE value is obtained in board with a composition of 40% PVAc. In this study, the resulting particleboard has not met the JIS A 5908-2003 standard.

Table 3. MOE Particleboard Test Results

No.	Type	MOE (kg/cm2)
1	20% PVAc + 20% Citric acid	4372.776
2	40% PVAc	3554.154
3	20% PVAc + 20% Tapioca	4300.639

It is known that the factor of the number of sengon particle mixtures greatly affects the MOE of the resulting particleboard. This is due to the uneven mixing of adhesives and sengon particles, where the greater the percentage of adhesive weight, the less raw materials. The composition of sengon particles that reaches 60% causes the particle board to become stiffer and inelastic.

The results of the fracture modulus test can be seen in Table 4. The MOR value of the particleboard obtained ranges from 41.4kg/cm^2 to 66.48kg/cm^2. The highest MOR value was obtained by 20% PVAc + 20% Tapioca board, and the lowest MOR value was obtained by particleboard with a composition of 20% PVAc + 20% Citric acid. The JIS A 5908-2003 standard requires a good particleboard MOR value of 82 kg/cm^2 to 184 kg/cm^2. In this study, the MOR value of the particleboard has not met the JIS A 5908-2003 standard, it is estimated that because the particles do not fill each other and bind to each other between one particle and another, so the fracture strength of the particle board is very low.

Table 4. MOR Particleboard Test Results

No.	**Type**	**MOE (kg/cm2)**
1	20% PVAc + 20% Citric acid	41.4
2	40% PVAc	61.65
3	20% PVAc + 20% Tapioca	66.48

CONCLUSION

This study demonstrates that wood processing waste, particularly sengon wood sawdust, can be effectively utilized as a raw material for value-added particleboard production. The results indicate that PVAc adhesives modified with citric acid and tapioca can function as effective binders, either individually or in combination.

The physical properties of the resulting particleboards meet the requirements of the JIS A 5908-2003 standard, while the mechanical properties fall below the standard threshold. Adhesive content significantly influences density, moisture content, modulus of elasticity (MOE), and modulus of rupture (MOR). The highest density (0.525 g/cm^3) was achieved with a 20% PVAc + 20% tapioca composition, while the lowest moisture content (5.125%) was obtained using 40% PVAc.

Although the MOE and MOR values did not meet the standard, the highest MOE (4372.78 kg/cm^2) was recorded for boards with 20% PVAc + 20% citric acid, and the highest MOR (66.48 kg/cm^2) was achieved with 20% PVAc + 20% tapioca. Overall, this study confirms the potential of combining sengon wood particles with PVAc and natural additives like citric acid and tapioca to produce environmentally friendly particleboards, though further optimization is required to improve mechanical strength.

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