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ACOUSTIC AND MECHANICAL PERFORMANCE OF SUSTAINABLE PANELS MANUFACTURED FROM PLYWOOD SAWDUST WASTE

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ABSTRACT: The rapid expansion of the global interior design industry has intensified demand for plywood products, generating substantial processing waste that requires effective management strategies. This study investigates the development and performance evaluation of acoustic panels manufactured from plywood sawdust waste as a sustainable solution integrating circular economy principles with functional building materials. Three panels were fabricated using plywood sawdust combined with environmentally friendly binders, namely polyvinyl acetate (PVAc) and bio-resin. Comprehensive testing was conducted to assess acoustic performance through impedance tube measurements (ISO 10534-2, ASTM E1050-08), mechanical properties via compressive strength testing (ASTM D1037), and moisture resistance according to SNI 03-2105-2006 standards. Results demonstrated that all panel configurations exhibited strong sound absorption capabilities in the medium to high frequency range (400-6300 Hz), with Panel A achieving a peak sound absorption coefficient of 0.83 at 3150 Hz, qualifying as a Class B absorber per ISO 11654. Compressive strength values ranged from 0.21 to 0.35 MPa, adequate for non-load-bearing acoustic applications. Moisture content measurements confirmed dimensional stability, with all panels maintaining values well below the 14% maximum threshold specified by Indonesian standards. The findings validate the technical feasibility of converting plywood industrial waste into functional acoustic panels, offering the furniture and interior design sectors a practical waste valorization pathway while addressing acoustic comfort requirements in buildings. This research contributes to sustainable material innovation by demonstrating effective integration of waste management, environmental responsibility, and technical performance in acoustic panel development.

Keywords: Acoustic panels; Plywood sawdust; Sound absorption coefficient; Sustainable materials; Porous materials

1. INTRODUCTION

The global interior design industry has experienced remarkable growth, with market projections indicating an increase from US$ 138.63 billion in 2024 to US$ 208.16 billion by 2033, representing a compound annual growth rate (CAGR) of 4.62% [1]. This substantial expansion has significantly intensified demand for processed wood products, particularly plywood, across furniture manufacturing and interior construction sectors. However, this growth trajectory has simultaneously generated considerable production waste that necessitates proper management strategies to mitigate negative environmental impacts. Plywood waste, which is a byproduct of the cutting and sanding of plywood in the furniture and interior design industries, is often not utilized optimally and has the potential to pollute the environment if burned or disposed of carelessly [2, 3].

On the other hand, the circular economy approach offers sustainable solutions through the reuse of industrial waste as raw materials for value-added products. and the principle of zero waste [4, 5]. Previous studies have shown that the use of recycled aggregates in concrete is a cost-effective and environmentally friendly solution, contributing significantly to reducing production energy, waste, and pollution [6].

Sawdust waste processing has also been conducted in previous studies. The application of sustainable technology encourages the use of coconut powder and UPVC in the development of high-density composite board materials that have similar qualities to wood tiles, which are then evaluated through mechanical and physical property testing [7].

One potential application of sawdust plywood waste is as a base material for acoustic panels. Acoustic panels are an important solution for controlling noise and improving sound quality in rooms by absorbing incoming sound waves and reflecting them back [8]. In a study conducted by Bijan Samali, acoustic and thermal solutions in buildings were identified as important aspects, with foam-core composite sandwich panels considered an effective building material solution for structural applications [9].

The working principle focuses on sound wave absorption through porous structures or micro-holes in the panel, where air particles experience friction (viscous friction) with the pore walls, converting the kinetic energy of the sound waves into heat. Previous studies have shown that organic waste-based materials have potential as sound absorbers. Asdrubali reported that natural materials and agricultural waste can achieve sound absorption coefficients that are competitive with conventional synthetic materials [10]. Berardi and Iannace [11] found that natural fibers have good acoustic absorption capabilities in the mid to high frequency range (500-4000 Hz).

The sound absorption coefficient is used as a parameter to describe a material's ability to absorb incoming sound energy [12]. The ability of a panel to reduce sound is expressed through the sound absorption coefficient (α), which ranges from 0 to 1 [13]. Where α=0 describes a perfect reflector, while α→1 indicates a near-perfect absorber. In room acoustics, this parameter is the basis for assessing the ability of materials to control echoes, reverberation, and resonance within a room. Based on the international standard ISO 11654 Acoustics—Sound absorbers for use in buildings: Rating of sound absorption, a material is considered to have significant sound attenuation capabilities if its weighted sound absorption coefficient (αw) reaches a minimum of 0.15. This standard also classifies materials into sound absorption quality classes, namely Class A to Class E, as shown in Table 1.

Table 1. Absorption Class

Absorption Class	Absorption coefficient	Quality
A	0.90 − 1.00	Highly Absorbent (Best)
B	0.80 − 0.85	High Absorption
C	0.60 − 0.75	Absorbing Medium-High
D	0,30 − 0.55	Absorbing Enough
E	0.15 − 0.25	Low Absorption

Theoretically, α is greatly influenced by thickness, porosity, flow resistivity, and material density. Greater thickness increases absorption, especially at low frequencies, porosity. For normal incidence, the relationship between the sound absorption coefficient and the reflectance coefficient uses the formula :

$$\alpha = 1 - |R|^2 \quad (1)$$

so that an increase in α is always followed by a decrease |R|.

Compressive strength testing for wood-based and particleboard panels generally refers to ASTM D1037, using a Universal Testing Machine (UTM) with controlled axial loading until failure occurs. In interior acoustic panels, compressive strength is important for assessing local structural integrity (e.g., during handling, installation with screws/nails, or light mechanical contact), even though the panels typically serve as non-structural elements.

The moisture content (MC) of wood composite materials greatly affects their dimensions, mechanical strength, and acoustic performance. SNI 03-2105-2006 requires that the moisture content of particle boards in dry air conditions be in the range of 5-13% (maximum <14%) to ensure dimensional stability and prevent excessive deformation during use. Non-destructive MC measurements are commonly performed using resistive (pin-type) or dielectric (pinless) moisture meters, while reference MC determination can be performed using the oven-dry method.

Research into waste-based acoustic panels has been widely conducted and has demonstrated significant potential. Most of these studies still employ a single-stage mixing method using conventional binders. In this study, the researchers propose a different approach through the application of a two-stage mixing process using PVAc adhesive, which is then combined with a final coating of environmentally friendly resin spray. This approach is expected to optimise both the mechanical characteristics and the acoustic performance of the material.

Compared to previous studies on waste-based acoustic panels, which commonly utilize agricultural fibers such as rice husk, durian skin, and oil palm fibers with varying thicknesses and absorption performance, this study introduces a two-stage manufacturing process combined with PVAc and bio-resin binders to enhance both mechanical and acoustic properties. While many prior studies report high absorption at specific frequency ranges, the present study demonstrates competitive performance in the medium to high frequency range (400–6300 Hz), achieving a peak sound absorption coefficient of 0.83 (Class B) with a relatively thin panel thickness of 18 mm.

Therefore, the main contribution of this study lies in the development of a thin, waste-based acoustic panel using a two-stage binder system that achieves effective high-frequency sound absorption while maintaining structural and environmental performance.

This study aims to measure and analyze the sound absorption coefficient (SAC) value of acoustic panels made from multiplex (plywood) waste using an impedance tube (ISO 10534-2, ASTM E1050-08) and to evaluate mechanical properties such as compressive strength (ASTM D1037) and moisture content (SNI 03-2105-2006). Compressive strength testing on wood-based composite materials has been conducted by various researchers, with the ASTM D1037 standard as the main reference [14]. The moisture content of the material is also a critical factor that affects the dimensional stability and long-term strength of the panels, especially in environments with high relative humidity. Böhm et al. [15] reported that wood-based materials tend to expand and lose strength when exposed to high humidity. The urgency of this research lies in the urgent need for more effective industrial waste management strategies and the development of sustainable acoustic materials.

2. RESEARCH SIGNIFICANCE

This study contributes to the advancement of sustainable acoustic materials by utilizing plywood sawdust waste and environmentally friendly adhesives in acoustic panel production. The research addresses a gap in waste-based acoustic material studies, particularly the limited exploration of plywood sawdust compared to other biomass wastes. The findings provide practical and scientific contributions to building acoustics, interior material innovation, and circular economy implementation. In practice, the developed panels offer an alternative solution for medium- to high-frequency noise control while reducing industrial wood waste, supporting zero-waste principles and sustainable material development in the construction and interior industries.

3. MATERIALS AND METHOD

3.1 Materials

Research materials consisted of plywood sawdust obtained from plywood cutting waste in local furniture manufacturing facilities, as shown in Fig. 1.

Fig. 1 Plywood sawdust

The plywood sawdust used in this study was sourced from utility-grade (UTY) *semi-meranti* plywood, a composite wood panel widely used in the furniture manufacturing industry in Indonesia. This type of plywood consists of a softwood core made from *sengon* (Falcataria moluccana), a fast-growing plantation species, with outer and inner layers of *meranti* (Shorea sp.), a semi-hardwood. The sawdust exhibited heterogeneous particle size distribution typical of industrial wood processing operations.

The sawdust exhibited a heterogeneous particle size distribution typical of industrial wood processing operations. To provide a more quantitative description, a particle size distribution analysis was conducted based on sieving classification. The results indicate that the majority of particles fall within the fine to medium range, with approximately 40% in the range of 0.1–0.2 mm and 20% in the range of 0.2–0.5 mm. Additionally, 33% of the particles were distributed in the range of 0.5–5 mm, while smaller fractions included micro dust (<0.1 mm) at 2% and coarse particles (≥5 mm) at 5%.

This distribution suggests that the material consists predominantly of fine particles, which contribute to higher surface area and potentially enhance sound absorption performance. The detailed particle size distribution is presented in Table 2.

Table 2. Particle size distribution

Particle size range	Aprox. Weight grams (from 100gr sample)	Category
< 0.1 mm	2%	Micro dust
0.1 – 0.2 mm	40%	Very fine
0.2 – 0.5 mm	20%	Fine-medium
0.5 – 5 mm	33%	Medium-coarse
≥ 5 mm	5%	Coarse chips

A representative microscopic image of plywood sawdust illustrating particle size variation is shown in Fig. 2.

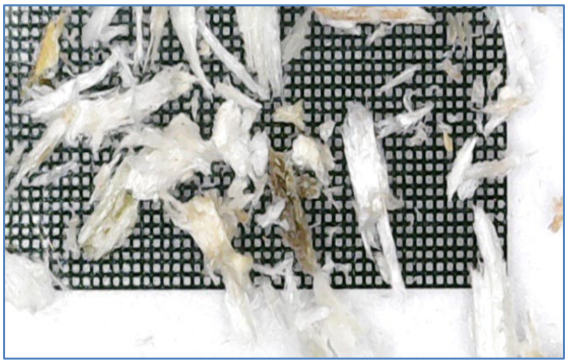

Fig. 2 Digital Microscope Image of Sawdust

Two types of environmentally friendly binders were systematically employed in this investigation. First type of binder is Polyvinyl Acetate (PVAc), a water-based white adhesive commonly utilized in wood industry applications, was selected for its non-toxic properties, excellent wood fiber adhesion characteristics, and low Volatile Organic Compound (VOC) emissions. PVAc demonstrates superior binding capability with cellulosic materials while maintaining environmental safety standards.

Other binder that being used in this study is Bio-resin. This material was specifically chosen for its environmental friendliness, characterized by minimal VOC content and biodegradability [16]. The application of bio-resin in this study was used for the final finishing through a spraying technique, providing additional structural reinforcement and moisture resistance.

The PVAc adhesive used in this study is a water-based polymer commonly applied in wood bonding, with a typical density in the range of 1.0–1.2 g/cm³ and moderate viscosity suitable for porous materials. The bio-resin (Cherfuly eco resin) is also a water-based material with low volatile organic compound (VOC) content. To prevent excessive pore blockage, the bio-resin was diluted with water at a ratio of 1:1 prior to application.

The binder composition in each panel was controlled based on weight proportion to ensure consistency across all samples. To prevent the pores from being completely covered by the resin, water was added to the resin mixture. The ratio of bio-resin to water used was 1:1 using a 100 ml spray bottle. This eco resin is water-based, so it is water-soluble and non-toxic.

The acoustic panels in this study were made from plywood sawdust with several variations in the mixture, the details of which are presented in Table 3. Each mixture variation was tested with three samples on each panel to obtain more accurate and representative measurement results. Finally, a resin spray mixed with water in a 1:1 ratio was applied as a finishing coat. Each panel tested has a thickness of 18 mm in a dry state.

Table 3. Panel composition and manufacturing process specifications

Panel	Sawdust (gram)	PVAc (gram)	Binder System	Mixing method
Panel A	100	100 (Stage 1) + 100 (Stage 2)	PVAc + bio-resin (1:1 dilution)	Two-stage mixing
Panel B	100	200 (Stage 1) + 100 (Stage 2)	PVAc + bio-resin (1:1 dilution)	Two-stage mixing
Panel C	100	250 (single stage)	PVAc + bio-resin (1:1 dilution)	Single-stage mixing

*) Manual pressing was performed using an approximately 400 g load applied uniformly across the surface. Drying was conducted at ambient temperature (27±2°C) for 3 days (Stage 1) and 5–7 days (Stage 2).

The panels were manufactured using either a two-stage or single-stage mixing and drying process, depending on the panel configuration. For Panels A and B, a two-stage process was applied. In the first stage, plywood sawdust was mixed with PVAc binder and allowed to dry at room temperature for three days to promote initial inter-particle bonding and structural stability. In the second stage, the dried material was remixed with additional PVAc binder, followed by manual compaction using a flat plate to ensure uniform pressure distribution. The compaction was maintained for approximately 3 hours.

For Panel C, a single-stage process was employed, in which plywood sawdust was directly mixed with PVAc binder and then compacted using the same manual method. Due to the higher binder content and single-stage process, the compaction time was extended to approximately 5 hours to achieve adequate bonding and structural integrity. This variation in compaction duration was intended to ensure consistent consolidation across different panel configurations.

All specimens were subsequently dried at room temperature for 5 to 7 days. The entire manufacturing process was conducted under controlled ambient conditions of 27±2°C to maintain consistency across samples.

3.2 Method

The research method used in this study was a quantitative method with a laboratory experimental approach

3.2.1 Acoustic Testing

Acoustic testing was conducted using an impedance tube system (BSWA SW477 and SW422) in accordance with ISO 10534-2 and ASTM E1050-08 standards, employing the transfer function method with a two-microphone configuration (Fig. 3). To cover a wide frequency range, a dual-tube setup was utilized. The SW477 tube, with an inner diameter of 30 mm, was used for high-frequency measurements (800–6300 Hz), while the SW422 tube, with an inner diameter of 100 mm, was used for low to medium frequencies (63–800 Hz). This configuration enabled comprehensive acoustic characterization across the frequency range of 63–6300 Hz.

Fig. 3 BSWA SW477 impedance tube

The measurement system utilized 1/4" MPA416 microphones connected to a data acquisition system, with calibration performed prior to testing using a CA115 acoustic calibrator (1000 Hz, 114 dB) to ensure measurement accuracy. The microphones were positioned according to the standard configuration of the impedance tube system. All measurements were conducted under controlled laboratory conditions at an ambient temperature of 27±2°C.

The acoustic test specimens were prepared from panels produced using a mould measuring 220 × 220 × 18 mm. The dried panels were then cut into circular specimens, with diameters adjusted to match the impedance tube dimensions (approximately 30 mm for the high-frequency tube and 100 mm for the low-frequency tube), while maintaining a constant thickness of 18 mm. The specimens were carefully fitted into the tube and sealed along the edges to prevent air leakage during testing. For each panel composition, three specimens were taken from different areas of the panel to represent material variability.

The test parameters included the sound absorption coefficient (SAC) and the reflectance coefficient over the frequency range of 63–6300 Hz. Three replicate specimens were tested for each panel composition to ensure measurement reliability and consistency.

3.2.2 Compressive Strength Testing of Panels

Compressive strength testing of panels was carried out using a Universal Testing Machine (UTM) in accordance with the general procedure of ASTM D1037 for wood-based panels and particleboard. In this test, plywood sawdust panels were cut into block-shaped specimens measuring 50 mm × 50 mm × 50 mm. Each specimen was weighed and measured using a vernier caliper to determine the cross-sectional area and material density.

The compressive load was applied perpendicular to the panel surface (through-thickness direction) to represent typical loading conditions for panel-type materials. The loading was applied gradually without a controlled loading rate.

Fig.4 Compressive Strength Testing of Panels

The compressive strength (σ_c) was calculated using the following equation:

$$\sigma_c = \frac{F}{A} \quad (2)$$

where F represents the peak load at failure (N) and A represents the compressed cross-sectional area (mm²).

During testing, the failure behavior of the specimens was observed and recorded. The panels generally exhibited progressive densification rather than sudden brittle failure, indicating gradual compaction of the porous internal structure (Fig.4).

3.3.3 Panel Moisture Testing

Water content testing was conducted using a dielectric (pinless) digital moisture meter.

Measurements were taken at several predetermined points on the surface of each specimen and averaged to obtain representative values. The measurement procedure generally followed the principles outlined in Indonesian National Standard (SNI) 03-2105-2006 for wood-based panels.

Moisture testing was carried out to evaluate the panel's response to short-term water exposure under humid interior conditions using a non-destructive approach. Each panel was cut into specimens measuring 100 × 100 × 18 mm. The initial moisture content was first measured at defined points on the specimen surface.

The panel surface was then exposed to controlled moisture using a cloth saturated with water and wrung to a saturated surface dry condition. The damp cloth was placed in contact with the panel surface for 2 hours. After exposure, the cloth was removed, and the surface was gently dried using tissue without applying pressure. The final moisture content was then measured at the same locations as the initial measurement. The change in moisture content was calculated as:

Water Content (%) = MC_end−MC_initial (3)

It is acknowledged that pinless moisture meters can be material-dependent and ideally require calibration against oven-dry reference values. However, the oven-dry method was not applied in this study, as preliminary attempts at elevated temperatures (approximately 100°C) resulted in partial thermal degradation and charring of the wood-based material. Therefore, the measured values are interpreted as indicative values for comparative purposes rather than absolute moisture content. Despite this limitation, the measurements provide a consistent basis for evaluating relative moisture behavior among the panel specimens.

4. RESULT AND DISCUSSION

The density of the acoustic panel is presented in Fig. 5. Acoustic panels with lower density generally exhibit higher porosity, enabling better sound absorption performance. Conversely, an increase in density results in a more compact material structure, which may enhance mechanical resistance but can potentially reduce sound absorption if the pores become closed or diminished.

The porosity of the panels was not directly measured in this study. However, it is qualitatively influenced by the particle size distribution and compaction method applied during fabrication. These factors are expected to affect the internal pore structure and flow resistivity, which in turn influence the sound absorption performance.

The density of the panels is also influenced by the composition of constituent materials, the type and proportion of binder used, as well as the pressing pressure and drying process during panel fabrication. Therefore, density control is a critical factor in achieving a balance between mechanical strength and optimal acoustic performance. Density can be calculated using the following equation:

$$\rho = \frac{m}{V} \quad (4)$$

where m is the mass of the specimen and V is the volume of the specimen

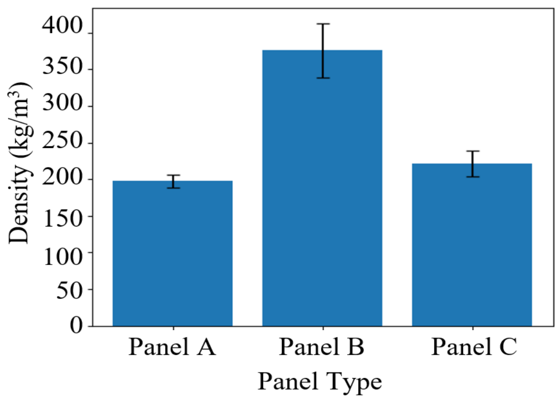

Fig. 5. Density of Panels A (197.44 kg/m³), B (375.79 kg/m³), and C (221.03 kg/m³)

From Fig. 5 it can be observed that Panel B exhibits the highest density along with the largest variation, indicating less uniform compaction compared to the other panels. In contrast, Panel A shows lower density with relatively small deviation, suggesting a more homogeneous internal structure. Panel C demonstrates intermediate behavior in both density and variability.

Higher density panels generally provide greater resistance to sound wave penetration, enhancing absorption at mid to high frequencies, while lower density panels tend to exhibit better performance at lower frequencies due to increased porosity.

4.1 Acoustic Testing Data

Table 4 shows the comprehensive average sound absorption coefficient values for each panel variation across the frequency spectrum. For clarity and readability, only representative frequency bands are presented in the tables, while the complete frequency data are shown in the corresponding figures. At low frequencies (63-315 Hz), all three panel configurations show relatively moderate absorption coefficients, ranging from 0.01 to 0.33, indicating limitations in absorbing low-frequency sound waves.

Table 4. Sound absorption coefficient (α) of panels (mean ± SD, n = 3)

Frequency (Hz)	Panel A	Panel B	Panel C
63	0.33 ± 0.27	0.16 ± 0.05	0.00 ± 0.07
125	0.07 ± 0.04	0.05 ± 0.02	0.06 ± 0.02
250	0.07 ± 0.01	0.05 ± 0.02	0.07 ± 0.00
500	0.10 ± 0.04	0.05 ± 0.00	0.06 ± 0.04
1000	0.29 ± 0.17	0.15 ± 0.09	0.19 ± 0.10
2000	0.48 ± 0.07	0.36 ± 0.02	0.28 ± 0.08
4000	0.80 ± 0.04	0.39 ± 0.08	0.81 ± 0.01
6300	0.57 ± 0.04	0.53 ± 0.02	0.56 ± 0.05

As shown in Fig. 6, all three panels exhibit strong sound absorption performance at higher frequencies. This suggests that the acoustic efficiency of each panel increases significantly with frequency, which is typical for porous or fibrous materials. At higher frequencies, sound waves have shorter wavelengths, allowing them to be more easily attenuated within the internal structure of the panels.

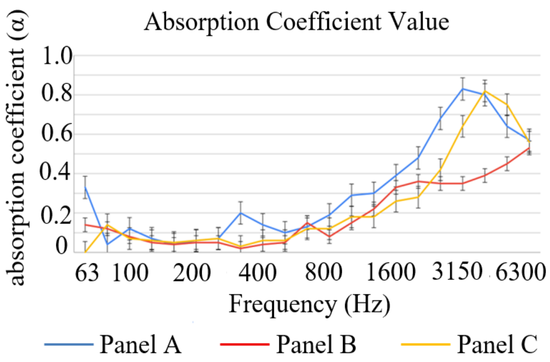

Fig. 6. Sound absorption coefficient (α) of Panels A, B, and C

However, this also highlights the limitation of porous materials in absorbing low-frequency sound, where the pore size is insufficient for effective energy capture. This limitation is associated with the relationship between wavelength and pore dimensions, as longer wavelengths at lower frequencies require larger cavities or deeper structures for optimal dissipation.

At mid-range frequencies (400-1600 Hz), there is a systematic and progressive increase in the absorption coefficient across all three types of panels. Panel A shows a consistent increase, with the absorption coefficient rising from 0.14 at 400 Hz to 0.39 at 1600 Hz. This increase indicates that the porous microstructure of the material begins to effectively capture and convert sound wave energy into thermal energy through the mechanism of air friction within the material's pore network. The gradual transition reflects the optimal match between the acoustic wavelength and the pore dimensions in this frequency range.

At high frequencies (2000-6300 Hz), all three panels achieve maximum absorption performance. Panel A achieves peak absorption of 0.83 at 3150 Hz, then decreases to 0.57 at 6300 Hz. Panel B shows a similar spectral pattern with a maximum value of 0.53 at 6300 Hz, while Panel C achieves peak absorption of 0.82 at 4000 Hz. This optimal high-frequency performance is due to the beneficial interaction between shorter acoustic wavelengths and pore dimensions, which facilitates effective energy dissipation through viscous losses at the pore boundaries. The peak value of 0.83 on Panel A meets the criteria for Class B absorbers (0.80-0.85) according to ISO 11654 classification, indicating high absorption capabilities suitable for professional acoustic applications.

The sound absorption coefficient values obtained were then compared with the reflectance coefficient values of each panel to validate the results from the impedance tube, yielding the results shown in Table 5. The reflectance coefficient and sound absorption coefficient were obtained using Eq.1 mentioned earlier.

Table 5. Sound reflection coefficient (|R|) of panels (mean ± SD, n = 3)

Frequency (Hz)	Panel A	Panel B	Panel C
63	0.80 ± 0.18	0.96 ± 0.53	1.00 ± 0.01
125	0.97 ± 0.02	0.97 ± 0.01	0.97 ± 0.01
250	0.97 ± 0.01	0.98 ± 0.01	0.96 ± 0.00
500	0.95 ± 0.03	0.97 ± 0.00	0.97 ± 0.01
1000	0.83 ± 0.11	0.92 ± 0.05	0.91 ± 0.06
2000	0.72 ± 0.03	0.80 ± 0.01	0.85 ± 0.02
4000	0.45 ± 0.04	0.78 ± 0.05	0.43 ± 0.02
6300	0.65 ± 0.03	0.69 ± 0.01	0.66 ± 0.05

At 63 Hz, the reflectance coefficient values obtained for Panel C exceeded the physically valid range ($|R| > 1$), indicating measurement uncertainty. This condition is commonly associated with limitations in low-frequency impedance tube testing, such as air leakage within the tube system or imperfect sealing between the specimen and tube

wall. This adjustment does not affect the overall interpretation of the results, as low-frequency absorption remains limited across all panel configurations.

To maintain physical consistency, the reflectance coefficient for Panel C at this frequency was limited to a maximum value of |R| = 1.00. Therefore, the reported value should be interpreted with caution and considered indicative rather than absolute.

Fig. 7 indicates that all three panels exhibit relatively high reflectance values at low frequencies, meaning that a significant portion of the incident sound energy is reflected rather than absorbed. This behavior is consistent with the general acoustic characteristic of many porous materials, which tend to be less effective in absorbing sound in the low-frequency range due to the longer wavelengths involved.

Furthermore, as illustrated in Fig. 7, the reflectance coefficient values are inversely proportional to the sound absorption coefficient values obtained from the measurements. In other words, when the absorption coefficient of a panel is low, its reflectance value becomes high, and vice versa. This inverse relationship confirms the validity of the experimental results, as it aligns with fundamental acoustic principles stating that the total incident sound energy is distributed among absorption, reflection, and transmission. Therefore, the high reflectance observed at low frequencies directly corresponds to the lower sound absorption performance of the panels within that frequency range.

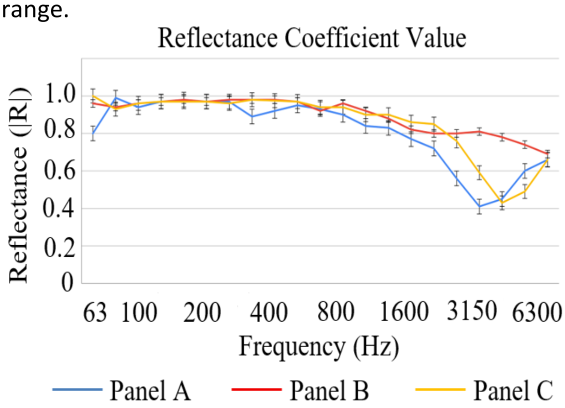

Fig. 7. Reflectance Coefficient Values (|R|) of Panels A, B, and C

The acoustic behavior observed in this study is strongly influenced by the internal pore structure and airflow resistivity of the material. However, flow resistivity and open porosity were not directly measured in this study.

The differences in acoustic performance among the panels can be qualitatively associated with variations in density and particle distribution, which are known to affect airflow resistivity and pore connectivity. Panels with higher density are expected to exhibit higher airflow resistivity, while lower density panels tend to have more open pore structures, facilitating sound energy dissipation at higher frequencies. The observed frequency-dependent behavior is consistent with classical porous absorber theory.

Although direct measurement of flow resistivity and porosity was not conducted, the observed trends can be further supported through comparison with similar waste-based composite panels reported in previous studies, as presented in Table 6 and Fig. 8.

Table 6. Comparison table of waste-based acoustic panels

Waste Material	Sound absorption coefficient (α)	Optimal Frequency (Hz)	class ISO	References
Plywood sawdust (panel A)	0.83	3150	B	This study
Plywood sawdust (panel B)	0.45	6300	D	This study
Plywood sawdust (panel C)	0.82	4000	B	This study
Oil Palm Fruit Bunch Fiber	0.99	500	A	[17]
Durian Skin	0.96	2000	A	[18]
Pineapples leaves	0.87	8000	B	[19]
Tea-Leaf Fiber 30 mm	0.65	5600	C	[20]
Rice husks	0.86	2000	B	[21]
Cassava Skin 35 mm	0.45	500	D	[22]
Rice straw	0.59	1000	C	[23]
Composite panel: Plywood-fiber carbon	0.7	6300	C	[24]

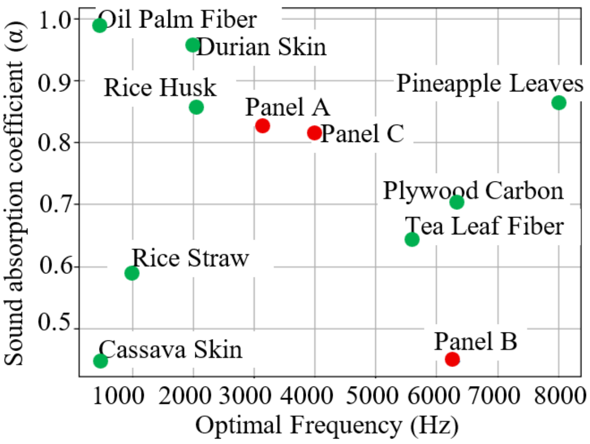

Fig. 8 Comparison of sound absorption performance with other waste-based composite panels

Most acoustic panels developed from waste materials show more effective sound absorption performance in the high-frequency range, as illustrated in Fig. 9 The graphical comparison provides a clearer overview of the relative performance of sawdust-based panels and conventional acoustic materials across different frequency bands.

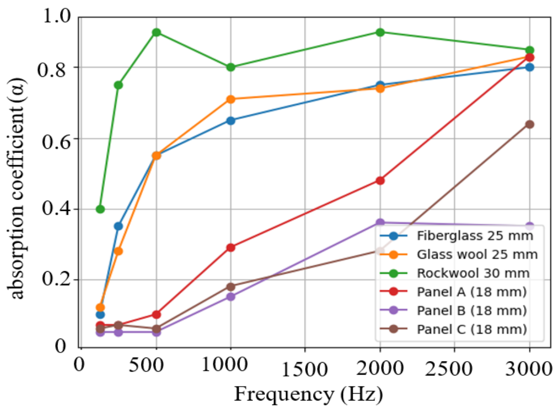

Fig. 9 Comparison of sound absorption performance between sawdust-based panels and conventional acoustic materials

The sound absorption coefficient (α) of each material is strongly influenced by its physical characteristics, including thickness, density, and porosity. To ensure a fair comparison, only materials with comparable thickness (18–30 mm) are considered in Fig. 12.

As shown in the figure, conventional materials such as fiberglass, glass wool, and rockwool exhibit relatively higher sound absorption at mid frequencies (500–2000 Hz), reflecting their well-established porous structures and optimized material properties. Among them, rockwool demonstrates consistently high performance across a wider frequency range.

In contrast, the developed sawdust-based panels (18 mm thickness) exhibit lower absorption at low to mid frequencies (125–500 Hz), where the sound absorption coefficient remains relatively small (<0.20). However, their performance increases significantly at higher frequencies, with Panel A reaching α = 0.83 at 3000 Hz and Panel C showing comparable improvement.

These results indicate that although thinner waste-based panels are less effective for low-frequency sound absorption, they are capable of achieving competitive performance at high frequencies. This behavior is consistent with the characteristics of porous materials, where absorption efficiency depends on the interaction between sound wavelength and internal pore structure.

Overall, the findings highlight the potential of plywood sawdust-based panels as efficient and sustainable acoustic materials, particularly for applications requiring high-frequency sound control with reduced material thickness.

4.2 Compressive Strength

The compressive strength results for the three panels after testing using a universal testing machine showed that Panel B had the highest compressive strength compared to the other two panels, with an average value of 0.35 MPa, followed by Panel C (0.27 MPa) and Panel A (0.21 MPa). Although these values are relatively low compared to structural materials, they are sufficient for acoustic panel applications that do not bear loads, as shown in Table 8.

Table 8. Compressive Strength of panels

Panel	Mean (MPa)	SD	Min	Max
Panel A	0.209	0.100	0.100	0.298
Panel B	0.353	0.020	0.330	0.368
Panel C	0.231	0.159	0.129	0.413

The data shows that there is variation in compressive strength between samples, with the highest value being 0.35 and the lowest being 0.21. This variation indicates that there are differences in material homogeneity or composite composition quality between samples, but they are still within a relatively close range.

4.3 Moisture Test Results Data

Table 9 presents the results of the water content testing, which was conducted to evaluate the dimensional stability of the acoustic panels. Water content is an important parameter because it influences the panel's resistance to moisture-related deformation, such as swelling, shrinkage, and warping, which may affect both structural integrity and acoustic performance during long-term use. Lower water content generally indicates better dimensional stability and greater resistance to environmental humidity variations.

Among the tested specimens, Panel C demonstrated the best performance, recording the lowest water content value of 2.4%. This result indicates that Panel C possessed the highest dimensional stability and the lowest tendency to absorb moisture. The superior performance of Panel C may be associated with its denser internal structure and stronger particle bonding, which reduced the availability of voids that allow water penetration. In contrast, Panel A exhibited a water content value of 3.3%, while Panel B showed the highest value at 4.8%. Although Panel B absorbed relatively more moisture compared to the other configurations, the value remained relatively low and still reflected acceptable stability characteristics for practical applications.

The differences in water content among the panels indicate that variations in material composition, particle arrangement, and binder interaction influenced the moisture absorption behavior of each panel configuration. Panels with more compact structures and improved inter-particle adhesion generally exhibited lower moisture uptake due to reduced capillary spaces within the material matrix.

Table 9. Moisture Content of Panels

Panel	Mean (%)	SD	Min	Max	n
Panel A	3.30	0.26	3.10	3.60	3
Panel B	4.80	0.36	4.40	5.10	3
Panel C	2.40	0.20	2.20	2.60	3

Despite these variations, all panel configurations satisfied the requirements specified in SNI 03-2105-2006 for wood-based panels, which establishes a maximum allowable water content of 14%. Therefore, all tested panels can be considered compliant with the applicable national standard. The relatively low water content values obtained in this study suggest that the developed acoustic panels possess good dimensional stability and are suitable for indoor building applications where moderate environmental humidity conditions are expected.

5. CONCLUSION

This study addresses the growing need for sustainable building materials by exploring the use of plywood sawdust waste as an alternative acoustic panel material. The research demonstrates the feasibility of converting industrial wood waste into functional panels through the integration of circular economy principles and environmentally friendly binders.

The experimental results show that all panels exhibit strong sound absorption performance in the medium to high frequency range (400–6300 Hz), which is characteristic of porous materials. Panel A achieved the highest sound absorption coefficient (SAC) of 0.83 at 3150 Hz, meeting the criteria for Class B absorbers according to ISO 11654. Panel C demonstrated comparable performance with a peak value of 0.82 at 4000 Hz, while Panel B reached 0.53 at 6300 Hz. These findings indicate that plywood sawdust-based panels are particularly suitable for high-frequency noise control in interior applications.

Mechanical testing revealed that Panel B exhibited the highest compressive strength (0.35 MPa), followed by Panel C (0.27 MPa) and Panel A (0.21 MPa). Although these values are relatively low compared to structural materials, they are adequate for non-load-bearing acoustic applications. Moisture content evaluation further confirmed that all panels satisfy the requirements of SNI 03-2105-2006, with values well below the 14% threshold, indicating good dimensional stability.

Despite these promising results, several limitations should be noted. Flow resistivity and porosity were not directly measured, and the manual fabrication process may introduce variability in material properties. These factors may influence the acoustic behavior and should be addressed in future investigations.

Future research is recommended to include quantitative measurement of flow resistivity and porosity, optimization of panel thickness for improved low-frequency absorption, and the application of predictive acoustic models such as Delany–Bazley or Johnson–Champoux. Further development may also explore the integration of these panels into composite systems with enhanced structural performance.

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