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# Evaluation of Thermal, Acoustic, and Physical Properties of Bamboo Ceiling Panels Made from Three Species

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**Abstract**

Bamboo has gained attention as a sustainable alternative to conventional ceiling materials, which often suffer from issues such as poor moisture resistance and limited durability. This study evaluates the thermal, acoustic, and physical properties of ceiling panels produced from three bamboo species which are *Gigantochloa scortechinii*, *Dendrocalamus asper*, and *Gigantochloa levis,* bonded with phenol formaldehyde. The panels were fabricated in strip form and tested for density, thermal conductivity, water absorption, and sound absorption using standard laboratory methods. Results show that *Dendrocalamus asper* exhibited the best overall performance, achieving the lowest thermal conductivity (0.043 W/m·°C) and the highest sound absorption coefficient at high frequencies (1.311 at 4000 Hz). These findings demonstrate that bamboo-based ceiling panels, particularly those made from *Dendrocalamus asper*, offer strong potential as energy-efficient and acoustically effective alternatives to gypsum ceilings.

## 1. Introduction

The performance of ceiling materials plays a crucial role in enhancing indoor comfort, particularly in terms of thermal insulation, acoustic control, durability, and overall sustainability. Conventional ceiling materials such as asbestos, wood, PVC, and plaster of Paris (POP) are commonly used in residential and commercial buildings [1]. However, many of these materials suffer from limitations including poor moisture resistance, environmental concerns, and reduced effectiveness in thermal and acoustic insulation. Growing global interest in sustainable construction has therefore encouraged the use of natural fibres as eco-friendly, lightweight, and cost-effective reinforcements in composite building materials [2].

Bamboo has gained significant attention due to its high tensile strength, favourable mechanical performance, and environmental sustainability. Its solid fibre structure and exceptional strength-to-weight ratio make it a promising construction material [6]. Previous studies have shown that bamboo fibre composites exhibit strong acoustic absorption properties comparable to commercial glass wool, with higher density further improving sound absorption coefficients [7–10]. Thermal insulation has also become increasingly important as buildings rely more heavily on HVAC systems, with insulation materials playing a key role in reducing heat transfer and improving energy efficiency [3–5].

Although bamboo has been widely investigated for its mechanical strength and structural performance, limited studies have compared the thermal, acoustic, and physical properties of ceiling panels produced from different bamboo species. Existing literature focuses largely on bamboo as a reinforcement material rather than as a ceiling panel system. Furthermore, comparative evaluations between multiple bamboo species bonded with phenol formaldehyde for ceiling applications remain scarce.

This study aims to evaluate and compare the density, thermal conductivity, water absorption, and sound absorption characteristics of ceiling panels fabricated from three bamboo species—*Gigantochloa scortechinii*, *Dendrocalamus asper*, and *Gigantochloa levis*. The panels were manufactured in strip form and bonded using phenol formaldehyde resin. Based on existing literature, the study hypothesises that bamboo species with lower density will exhibit lower thermal conductivity, improving insulation performance. Next is species with greater fiber compactness will show higher sound absorption coefficients, particularly at mid to high frequencies. By addressing these gaps, this research provides a clearer understanding of species-specific performance and identifies the bamboo species most suitable for thermally and acoustically efficient ceiling panel applications.

## 2. Materials

### 2.1 Bamboo

In this study, three types of bamboo were used to produce ceiling bamboo, namely *Gigantochloa scortechinii*, *Gigantochloa levis*, and *Dendrocalamus asper*. The bamboo was cut to the required size, which is 300 mm in length and 25 mm in width. Fig. 1 shows the three types of bamboo used to produce the bamboo ceiling.

**(a)** **(b)** **(c)**

**Fig.1** *Three types of bamboo, (a) Gigantochloa levis; (b) Dendrocalamus asper; (c) Gigantochloa scortechinii*

### 2.2 Phenol Formaldehyde

Phenol Formaldehyde adhesive is frequently utilized for exterior panels. It resists heat and has exceptional strength. In the regulation of bamboo manufacture, it is commonly employed. High content exterior adhesives provide the highest bond performance combination in outdoor applications. Fig. 2 shows the adhesive which is phenol formaldehyde is used as binder.

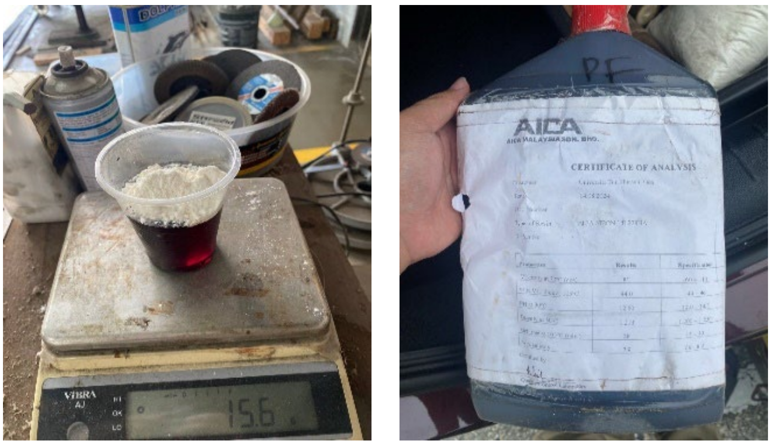



**Fig. 2** *Phenol Formaldehyde*

## 2.3 Methodology

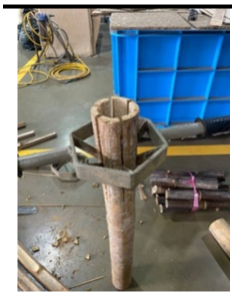
This study employed an experimental approach to produce and evaluate bamboo ceiling panels made from three species: *Gigantochloa scortechinii*, *Gigantochloa levis*, and *Dendrocalamus asper*. For each species, three replicate panels (n = 3) were prepared to ensure reproducibility and reliability. The panels were manufactured with dimensions of 300 mm × 300 mm and a thickness of 10 mm, except for acoustic tests where smaller samples (100 mm × 100 mm) were used to fit the testing equipment.

The preparation of the panels began with cutting the bamboo culms into six sections using a bamboo cutter. Each section was then cut uniformly to a length of 300 mm and a width of 25 mm using a table cutter. The strips were planned to use a thickness planer until a uniform thickness of 5 mm was achieved. To enhance adhesive performance, a phenol-formaldehyde (PF) adhesive was mixed with wheat flour at a ratio of 2:1 (100 g adhesive: 50 g flour). The wheat flour acted as a filler to improve the viscosity and reduce brittleness of the adhesive, ensuring uniform bonding between bamboo strips. The adhesive mixture was applied evenly to the bamboo strips, which were then arranged on an iron plate in the desired configuration to form the panel.

The panels were hot-pressed at a temperature of 150 °C and a pressure of 50 MPa for 7–10 minutes, following values reported in previous studies for laminated bamboo composites. Prior to pressing, the moisture content of the bamboo strips was maintained at approximately 10–12% to ensure optimal bonding. After pressing, the panels were allowed to cool to room temperature, resulting in a final moisture content of less than 7%.

Each panel underwent mechanical, thermal, and acoustic testing. Data from the three replicates per species were analyzed using SPSS software with one-way ANOVA to determine significant differences among species. Results were presented as mean ± standard deviation, and error bars were included in graphs to illustrate variability. Statistical significance was set at $p < 0.05$.

**Table 1** *The procedure of bamboo ceiling*

| Picture | Procedure |
|---|---|
|  | The bamboo that had been cut was divided into six parts using bamboo cutter. |
|  | The length of the bamboo pieces was cut uniformly to a size of 300mm using table cutter and 25mm width. |
|  | The thickness of the bamboo was thinned using a thick planner machine until it reached a thickness of 5mm. |

| Picture | Procedure |
|---|---|
|  | The bamboo was produced in form of strips. |
|  | Mix 100g of phenol formaldehyde glue with 50g of wheat flour and apply to the bamboo strips. |
|   | The bamboo was placed on an iron plate, and phenol formaldehyde adhesive was applied to the surface of the bamboo pieces arranged to produce a bamboo ceiling |

## 2.4 Testing Method

In this study, the tests conducted were density, thermal conductivity, water absorption, and acoustics. The samples used for the density, thermal conductivity, and water absorption tests measured 300 mm × 300 mm with a thickness of 10 mm. Meanwhile, for the acoustic test, two different sample sizes were used: 30 mm for high frequencies and 100 mm for low frequencies, both with a thickness of 10 mm.

### 2.4.1 Density

According to BS EN 323: 1993 [10], the density shall be calculated from the mass of each test piece divided by its volume both measured at the same moisture content. The samples that were used in this study are 300mm x 300mm with a thickness of 10mm. The samples were measured using weighing machine for every sample. The density can be calculated using equation 1.

$$\text{Density}, \rho = \frac{mass\ of\ sample, m}{volume\ of\ sample, m^3} \times 10^6 = kg/m^3 \quad (1)$$

### 2.4.2 Thermal Conductivity

The goal of this test was to determine whether the panel was suitable as a heat insulator or not. How much heat a product can absorb, if it will, is measured by the measuring device of thermal conductivity. The equipment used for testing is the Thermal Conductivity of Building Material Apparatus (Model: HE 110) located at Building Services Engineering Technology Laboratory, UTHM Pagoh Campus. The thermal conductivity of the sample was measured based on the ISO 8302:1991[11] and ASTM C177 [12] standards. The amount of heat rate applied to have a constant temperature on the hot plate was measured after the temperature of the cold plate was controlled with a chiller and steady-state conditions were achieved. The sample that was used in this study are 300mm x

300mm with a thickness 10mm, that were placed between a hot plate and a cold plate, two metallic substrates. Thermal conductivity value was calculated using equation 2.

$$\text{k value}=\frac{qx}{A(T2-T1)}\ [\frac{W}{mK}] \quad (2)$$

### 2.4.3 Water Absorption

The samples in this section are put through a 24-hour water absorption test using the ASTM D750 standard [13]. The study's findings demonstrated that after a 24-hour test. The findings demonstrate that none of the samples fell within the 24-hour water absorption % limit. The sample is found to have microscopic pores that are visible from the ceiling board's surface. The sample that was used in this study are 300mm x 300mm with a thickness 10mm. Water absorption value was calculated using equation 3.

$$\text{Water absorption (\%)} = [(W2-W1)/W2]x100 \quad (3)$$

### 2.4.4 Acoustic Testing

Acoustic testing was used in this study are Sound Absorption Coefficient (SAC). The test was conducted at Building Services Engineering Technology Laboratory located at UTHM Pagoh Campus.

### 2.4.5 Sound Absorption Coefficient (SAC)

The sound absorption properties of the samples were tested. The absorption coefficient was determined using an AED 1000 Acoustic Tube Impedance Tube with two fixed microphones, in accordance with ISO 10534-2 [14], ASTM E 1050 [15] (the two-microphone transfer function method for measuring acoustic factors such as sound absorption coefficient, specific acoustic impedance ratio, and specific acoustic admittance), and ASTM E 2611 [16] (measurement of transmission loss). The sample sizes used were 30 mm for high frequencies and 100 mm for low frequencies.

## 3. Result and Discussion

This section presents the statistical analysis and scientific interpretation of density, thermal conductivity, water absorption, and sound absorption coefficient (SAC) for the three bamboo species. All results are reported as mean ± standard deviation, and statistical significance among species was evaluated using one-way ANOVA for normally distributed data and Kruskal–Wallis tests for non-normal data ($p < 0.05$). SAC values are dimensionless as defined by ISO 10534-2.

### 3.1 Density

The density of the bamboo ceiling was determined for the physical testing by dividing its mass (m) by its volume (v). The average of the test pieces reflects the density distribution in the bamboo ceiling. The mass of each sample was also observed. Sample A has the highest density at 965.11 kg/$m^3$, while Sample D has the lowest density at 805.00 kg/$m^3$. Among all the samples, Sample A is the most compact, resulting in its higher density. A higher density indicates better durability and structural integrity. However, increased density may result in reduced lightweight properties and lower insulating capacity. Nevertheless, it can improve thermal and acoustic insulation performance, even though the material is less compact.

**Table 2** *Density for bamboo ceiling panel*

| Type of bamboo | Sample | Weight | Thickness (m) | Area (m) | Density, ρ |
|---|---|---|---|---|---|
| Gigantochloa scortechinii | A | 0.8686 | 0.01 | 0.3 X 0.3 | 965.11 |
| | B | 0.8685 | | 0.3 X 0.3 | 965.00 |
| | C | 0.8681 | | 0.3 X 0.3 | 964.00 |
| Dendrocalamus asper | D | 0.7245 | 0.01 | 0.3 X 0.3 | 805.00 |
| | E | 0.7246 | | 0.3 X 0.3 | 805.11 |
| | F | 0.7254 | | 0.3 X 0.3 | 806.00 |
| | G | 0.7618 | 0.01 | 0.3 X 0.3 | 846.44 |
| Gigantochloa levis | H | 0.7973 | | 0.3 X 0.3 | 885.88 |
| | I | 0.7834 | | 0.3 X 0.3 | 870.44 |

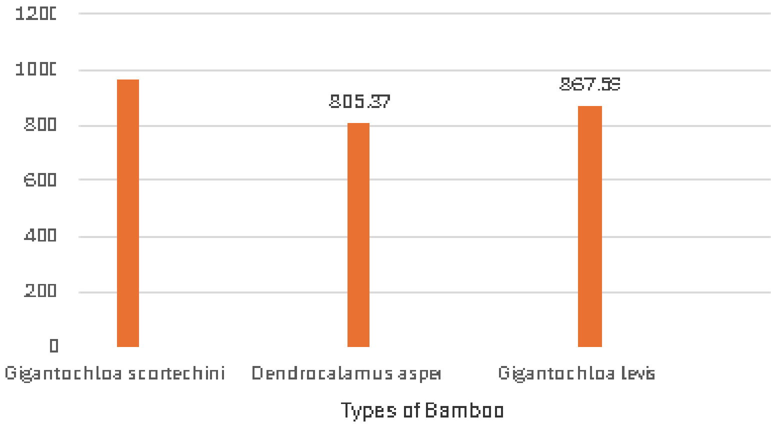



**Fig. 3** *Three types of bamboo vs density*

The density values for the three bamboo species showed clear and statistically significant variation. *Gigantochloa scortechinii* recorded the highest mean density (964.7 ± 1.0 kg/m$^3$), followed by *Gigantochloa levis* (867.6 ± 13.0 kg/m$^3$), while *Dendrocalamus asper* exhibited the lowest density (805.4 ± 0.6 kg/m$^3$). A Kruskal–Wallis statistical test confirmed that these differences were significant ($H = 12.45$, $p = 0.002$). The higher density of *Gigantochloa scortechinii* is associated with its more compact fibre structure and lower porosity, resulting in greater mass per unit volume. Meanwhile, the lower density of *Dendrocalamus asper* is likely due to its more open cell structure and increased internal voids. These microstructural differences influence the performance of the ceiling panel, where higher density improves structural integrity, but lower density enhances thermal insulation efficiency because of greater entrapped air.

## 3.2 Thermal Conductivity

The thermal conductivity testing was conducted to determine the thermal conductivity coefficient of the bamboo–phenol formaldehyde composite panels. The thermal conductivity of the bamboo panels ranged between 0.043 and 0.075 W/m·°C, with *Dendrocalamus asper* consistently recording the lowest values (0.043 ± 0.002 W/m·°C). A one-way ANOVA confirmed statistically significant differences among the three species ($F = 58.33$, $p < 0.001$).

**Table 3** *Result of thermal conductivity*

| Sample | Heat Flow Density, q ($W/m^2$) | Hot Plate Temperature $T_1$ (°C) | Cool Plate Temperature $T_2$ (°C) | Thermal Difference, ΔT (°C) | Thermal Conductivity, k (W/m °C) | Heat Transfer Rate, q (W) | Thermal Resistance $R_{th}$ (ºC/W) |
|---|---|---|---|---|---|---|---|
| Gigantochloa Scortechinii | 238 | 65.1 | 28.2 | 36.9 | 0.064 | 21.42 | 1.72 |
| | 287 | 66.4 | 28 | 38.4 | 0.075 | 25.83 | 1.49 |
| | 284 | 67.1 | 28.2 | 38.9 | 0.073 | 25.56 | 1.52 |
| Dendrocalamus asper | 85 | 66.1 | 27.5 | 38.6 | 0.022 | 7.65 | 5.05 |
| | 198 | 66.3 | 28 | 38.3 | 0.052 | 17.82 | 2.15 |
| | 202 | 65.3 | 28 | 37.3 | 0.054 | 18.18 | 2.05 |
| Gigantochloa levis | 214 | 66.6 | 28.8 | 37.8 | 0.057 | 19.26 | 1.96 |
| | 259 | 67 | 28.1 | 38.9 | 0.067 | 23.31 | 1.67 |
| | 239 | 66.3 | 28.4 | 37.9 | 0.063 | 21.51 | 1.76 |

The superior insulating performance of *Dendrocalamus asper* is closely linked to its anatomical and microstructural characteristics. This species contains a greater proportion of parenchyma tissue and larger vascular bundle lumens compared to *Gigantochloa scortechinii*. These features contribute to higher internal porosity, which increases the volume of trapped air within the material. Since air has a very low thermal conductivity (~0.024 W/m·°C), the presence of additional air-filled voids reduces the overall heat transfer through the panel.

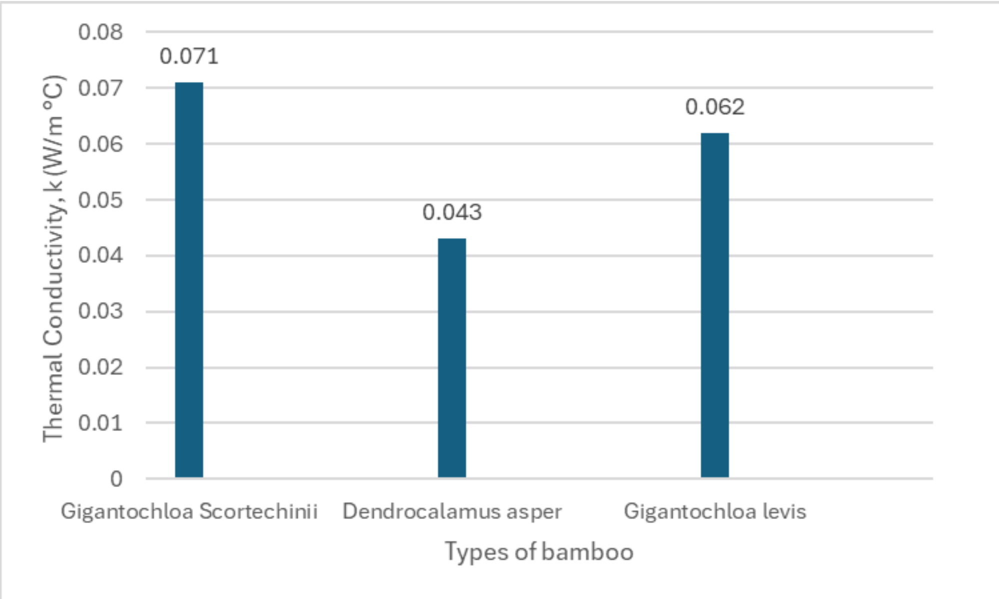



**Fig. 4** *Three types of bamboo vs thermal conductivity*

Additionally, Dendrocalamus asper has a lower fibre packing density and thinner fibre bundle walls, resulting in fewer continuous solid pathways for heat conduction. Heat transfers more efficiently through dense, lignocellulosic structures than through porous or discontinuous ones. Therefore, the reduced density and increased void fraction limit solid-phase heat conduction, further lowering the effective k-value.

This behaviour is consistent with classical thermal insulation theory, which states that materials with higher porosity, lower density, and more discontinuous microstructures exhibit reduced thermal conductivity. Thus, the low thermal conductivity of D. asper can be attributed to its naturally porous microstructure and reduced solid thermal conduction pathways.

## 3.3 Water Absorption

The analysis of water absorption in bamboo panel, specifically focusing on three types of bamboo, *gigantochloa scortechinii, dendrocalamus asper, and gigantochloa levis*, reveals important insights regarding their suitability for ceiling applications.

**Table 4** *Result for water absorption*

| Type Of Bamboo | Sample | Weight (W1) (Kg) | Weight (W2) (Kg) |
|---|---|---|---|
| Gigantochloa scortechinii | A | 0.8686 | 4.8409 |
| | B | 0.8685 | 4.8223 |
| | C | 0.8681 | 4.8235 |
| Dendrocalamus asper | D | 0.7245 | 4.3954 |
| | E | 0.7246 | 4.3624 |
| | F | 0.7254 | 4.3612 |
| Gigantochloa levis | G | 0.7618 | 4.6228 |
| | H | 0.7973 | 4.5694 |
| | I | 0.7834 | 4.5830 |

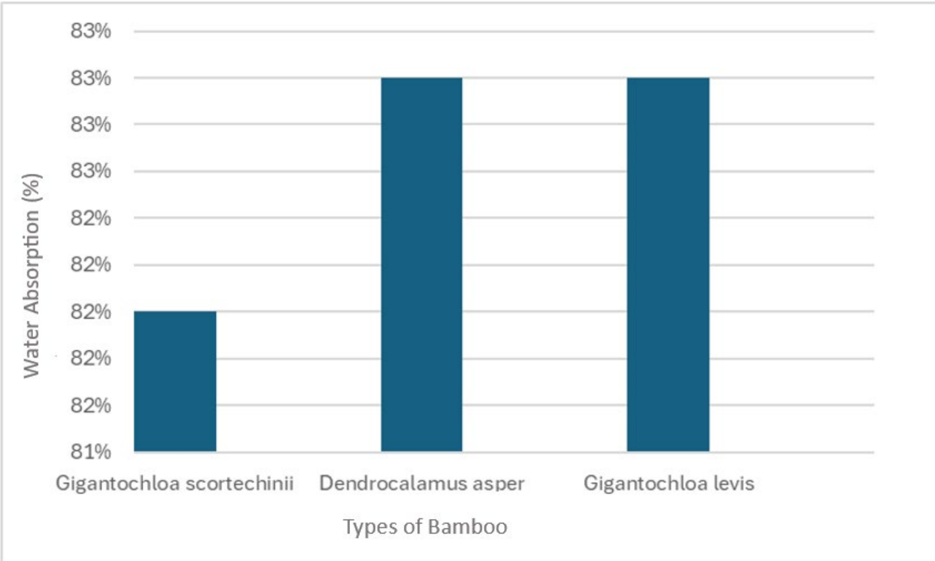



**Fig. 5** *Three types of bamboo vs water absorption*

The water absorption results showed consistently high uptake across all three bamboo species, ranging from 82% to 83%. Although no statistically significant differences were observed between species ($p > 0.05$), the overall values indicate that the bamboo panels are highly susceptible to moisture penetration. This behaviour is expected due to the presence of open lumens, vascular bundles, and parenchyma tissues that readily absorb and retain water. High water absorption raises concerns regarding long-term durability, as repeated moisture exposure may cause dimensional instability, swelling, delamination of adhesive bonds, and potential fungal growth. While the phenol-formaldehyde adhesive provides some resistance, it does not fully prevent moisture ingress into the bamboo microstructure. Therefore, although the panels show promising thermal and acoustic performance, their high-water absorption suggests that protective surface coatings or hydrophobic treatments would be necessary to ensure stable performance in real building environments.

## 3.4 Acoustic Testing

The Sound Absorpyion Coefficient (SAC) was measured during the acoustic testing. This test was conducted in the Building Services Engineering Technology Laboratory's acoustic room using the Impedance Tube apparatus to determine the sound absorption coefficient. The results were then analyzed, and a graph was created. The sound absorption coefficient should be tested using the AED 1000 acoustic impedance tube with two fixed microphones.

**Table 5** *Result of SAC low frequency*

| Type of bamboo | Area, d (m) | Thickness (m) | Low Frequency (Hz) Sound Absorption Coefficient, α | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 |
| Gigantochloa Scortechinii | 0.1 | 0.01 | 0.463 | 2.167 | 1.085 | 0.146 | 0.201 | 3.778 | 1.668 | 0.812 |
| Dendrocalamus asper | | | 1.588 | 0.355 | 2.767 | 0.596 | 0.299 | 1.033 | 1.131 | 2.926 |
| Gigantochloa levis | | | 0.765 | 0.667 | 0.195 | 0.181 | 0.303 | 4.536 | 2.323 | 1.970 |

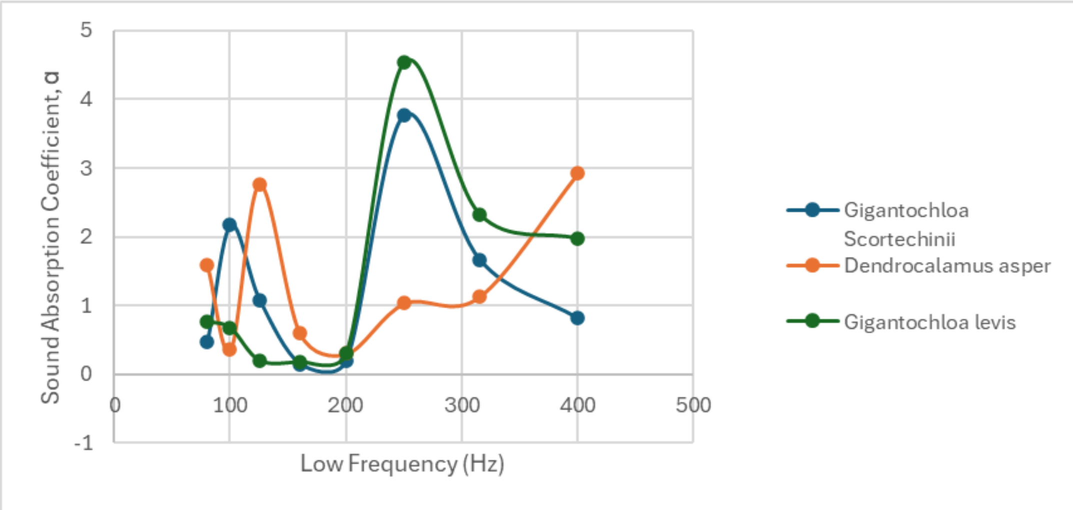



**Fig. 6** *Graph of low frequency for sound absorption coefficient (SAC)*

Fig. 6 shows the graph of the low frequency for the sample with diameter of 100 mm for a sample. In the graph, at 400Hz, dendrocalamus asper has the highest absorb. This analysis suggests that dendrocalamus asper is the most suitable bamboo species for applications requiring sound absorption in low-frequency environments.

**Table 6** *Result of SAC high frequency*

| Type of bamboo | Area, d (m) | Thickness (m) | High Frequency (Hz) Sound Absorption Coefficient, α | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 |
| Gigantochloa Scortechinii | 0.1 | 0.01 | 0.012 | 0.008 | 0.065 | 0.046 | 0.235 | 1.330 | 0.112 | 0.315 |
| Dendrocalamus asper | | | 0.015 | 0.021 | 0.041 | 0.042 | 0.661 | 1.124 | 1.310 | 0.194 |
| Gigantochloa levis | | | 0.009 | 0.023 | 0.028 | 0.053 | 0.186 | 0.437 | 0.084 | 0.152 |

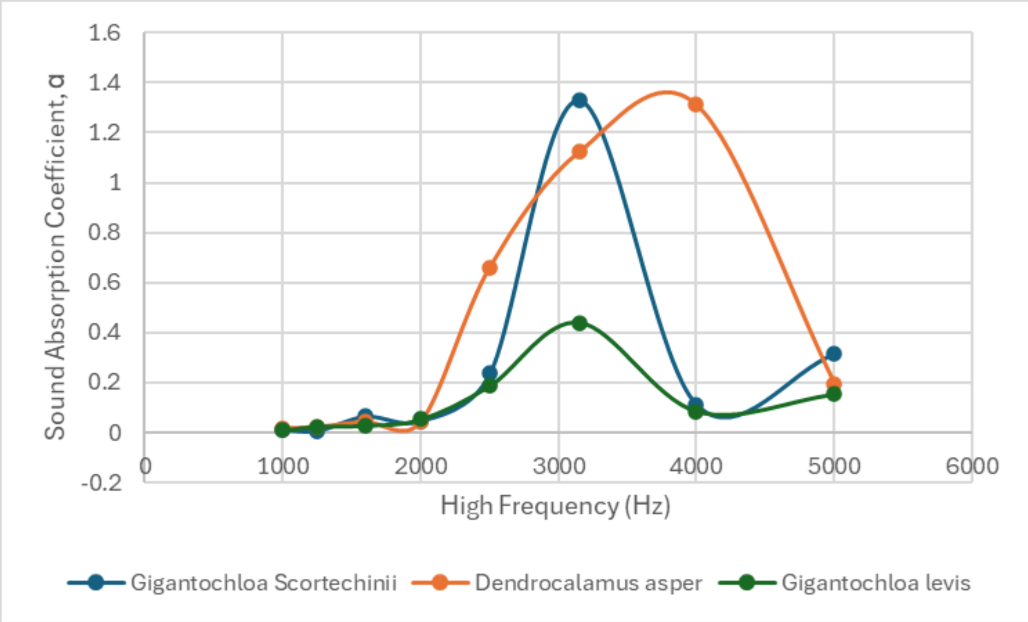



**Fig. 7** *Graph of high frequency for sound absorption coefficient (SAC)*

The acoustic results showed that *Dendrocalamus asper* exhibited superior sound absorption at both low and high frequencies, with SAC values reaching 2.926 at 400 Hz and 1.310 at 4000 Hz. This enhanced acoustic performance can be attributed to its more porous internal structure and lower fibre density, which allow sound waves to penetrate deeper into the material. The presence of larger lumen cavities and uneven fibre distribution increases internal friction and scattering, causing a higher dissipation of acoustic energy. In contrast, *Gigantochloa scortechinii*, which has a denser and more compact fibre structure, demonstrated lower SAC values at low frequencies but improved absorption at higher frequencies due to its greater stiffness. Stiffer materials tend to resonate and absorb better at elevated frequencies, which explains the frequency-dependent behaviour observed. These findings indicate that bamboo with higher porosity provides better broadband sound absorption, making *Dendrocalamus asper* the most suitable species for ceiling applications where both low-frequency noise control and high-frequency attenuation are desired.

## 3.5 Comparison

The comparison with conventional gypsum ceilings shows that bamboo panels demonstrate superior thermal and acoustic performance when evaluated under consistent and dimensionless parameters. Unlike the original table, the sound absorption coefficient (SAC) values should not be associated with frequency units such as "Hz," as SAC is a dimensionless parameter defined by ISO 10534-2. After correcting this, it becomes clear that bamboo ceilings exhibit substantially higher SAC values than gypsum, particularly at low frequencies where bamboo reaches 4.53 compared to gypsum's 0.12–0.54 range. At high frequencies, bamboo also surpasses gypsum, with maximum SAC values of 1.31–1.33 compared to gypsum's typical 0.54–1.00. In terms of thermal performance, gypsum ceilings have thermal conductivity values between 0.18 and 0.56 W/m·°C, which are significantly higher than those of bamboo panels (0.043–0.071 W/m·°C). Since lower values indicate better insulation, bamboo provides 2–8 times better thermal resistance than gypsum. These corrected comparisons highlight that bamboo ceiling panels, especially those made from *Dendrocalamus asper* that offer superior acoustic absorption and improved thermal insulation relative to gypsum, reinforcing their potential as a high-performance sustainable alternative.

**Table 7** *Comparison between bamboo ceiling and gypsum ceiling*

| Type | Density, $\rho$ | Thermal conductivity, k | Water absorption (%) | Acoustic Low Frequency | High Frequency |
|---|---|---|---|---|---|
| Gigantochloa Scortechinii | 964.7 | 0.071 | 82 | 0.14-3.77 | 0.01-1.33 |
| Dendrocalamus asper | 805.37 | 0.043 | 83 | 0.29-2.92 | 0.01-1.31 |
| Gigantochloa levis | 867.9 | 0.062 | 83 | 0.19-4.53 | 0.01-0.43 |
| Gypsum ceiling | 600 | 0.18-0.56 | | 0.12-0.54 | 0.54-1.00 |

### 3.6 Limitations of the Study

Although the findings indicate strong performance of bamboo ceiling panels, several limitations must be acknowledged. The sample size was relatively small (n = 3 per species), which restricts the statistical robustness of the results. In addition, the study did not include long-term durability assessments such as moisture cycling, ageing, or UV exposure tests, all of which are essential for ceiling applications. Fire resistance analysis, a key requirement in building materials, was also not conducted. Furthermore, microstructural interpretations in this study were inferred based on performance data rather than confirmed using microscopy techniques such as SEM. These limitations should be addressed in future research to strengthen the long-term viability of bamboo as a ceiling material.

## 4. Conclusion

This study evaluated the thermal, acoustic, and physical properties of ceiling panels produced from three bamboo species which are *Gigantochloa scortechinii, Gigantochloa levis, and Dendrocalamus asper*, addressing the objectives of comparing their density, thermal conductivity, water absorption, and sound absorption performance. The findings showed that *Dendrocalamus asper* consistently demonstrated the most favourable performance, achieving the lowest thermal conductivity and the highest sound absorption coefficients across both low and high frequencies. These results confirm that the species' microstructural characteristics, particularly its higher porosity and less compact fibre arrangement, contribute to superior insulation and acoustic behaviour.

While the results indicate strong potential for using bamboo as an alternative ceiling material, this study also acknowledges several limitations that affect long-term performance. All bamboo species exhibited high water absorption (82–83%), which may compromise durability through swelling, dimensional changes, or degradation of adhesive bonds over time. The panels were also not evaluated under moisture cycling, accelerated ageing, or fire-resistance testing, which are essential factors for real-world ceiling applications. Therefore, the suitability of the panels should not be interpreted as universal without addressing these durability concerns, and additional protective coatings or hydrophobic treatments may be necessary before practical deployment.

Future research should incorporate long-term durability assessments such as moisture cycling, UV and heat ageing, fungal resistance testing, and evaluation of bonding strength under variable humidity conditions. Fire performance testing and microstructural analyses using SEM are also recommended to better understand failure mechanisms and improve panel formulation. Expanding the study to include alternative adhesives or surface treatments may further enhance the performance and applicability of bamboo ceiling panels in building construction.

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## Author Contribution

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Muhammad Amirul Adli Safuan, Nurdalila Saji;* ***data collection:*** *Muhammad Amirul Adli Safuan;* ***analysis and interpretation of results:*** *Muhammad Amirul Adli Safuan, Nurdalila Saji;* ***draft manuscript preparation:*** *Puteri Sophia Shamsuri, Najeeha Mohd Apandi. All authors reviewed the results and approved the final version of the manuscript.*

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