

ACOUSTIC PERFORMANCE AND MODELING OF SUSTAINABLE SCB/PVA COMPOSITE MATERIALS

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ABSTRACT

The rising need to use sustainable and environmentally friendly materials in place of synthetic acoustic materials has resulted in the rising popularity of natural fiber composites. Sugarcane bagasse (SCB), an agricultural by-product that contains a high level of fibrous material, is also a potential solution in the sound absorption applications because of its porous structure and biodegradability. The purpose of the research is to compare the acoustic behavior of SCB-based composite panels bonded with polyvinyl acetate (PVA), and to compare experimentally obtained sound absorption coefficients (SAC) and those obtained using mathematical models. Three levels of SCB content (40%, 50% and 60%) and three thicknesses (10 mm, 20 mm and 30 mm) were used to make composite panels. The panels were described in terms of airflow resistivity, porosity, and tortuosity and the SAC values were determined using an impedance tube in accordance with ASTM E1050 and ISO 10534-2. The Miki, Delany-Bazley (DB) and Johnson-Champoux-Allard (JCA) models were also used to predict the SAC. Findings have shown that adding more SCB content and panel thickness has a significant effect on SAC especially at the low and mid frequency bands. Panels with 60% SCB and 30 mm thickness recorded the highest SAC values of more than 0.9, which validated their outstanding sound-absorbing performance. The JCA model was the closest to the experimental data among the models analyzed with the Miki and DB models under-predicted. This paper confirms SCB/PVA composites as a potential solution to sustainable acoustic panels usage.



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I. INTRODUCTION

The issue of environmental noise control has become a burning problem because of its prevalence among the population, mental health, and industrial performance. The long-term effects of noise pollution are negative health outcomes, such as hearing loss, stress, and cardiovascular issues, which necessitate the development of effective sound mitigation measures [1–4]. Sound-absorbing concrete and fiber-based panels have become vital in the construction sector to improve the acoustic comfort of high-density urban housing and commercial buildings, where the building code tends to insist on the use of noise control measures on walls, floors, and facades [4], [5]. Likewise, in the automotive sector, where the comfort and sustainability of consumers intersect, natural fiber-based and composite acoustic materials are actively studied to minimize cabin noise and vehicle weight, which can help to comply with the regulations and compete in the market [6–8]. The development of acoustic materials has also influenced the design of the public space, studios, and transport systems, where porous absorbers, micro-perforated panels, and bio-based composites are used to improve the quality of sound and environmental sustainability [9–11]. All of these developments highlight the growing need in the contemporary engineering and urban development sector to have efficient, cheap, and environmental-friendly noise control materials.

The use of porous materials and natural fiber composites has become an attractive sustainable substitute to the traditional synthetic sound absorbers because of their low environmental impact, biodegradability, and good acoustic performance. In comparison with synthetic fibers, including fiberglass or mineral wool, which are energy-intensive to produce and potentially dangerous to health, natural fibers like coconut coir, banana, kenaf, or sugarcane bagasse are similar in terms of sound absorption properties and reduce the environmental impact [12–16]. These natural materials are commonly made out of agricultural by-products and have high porosity and tortuosity which is important in dissipating energy and absorbing sound. Natural fiber boards have proven to be as effective in reducing noise coefficients as synthetic ones in building acoustics and contribute to the sustainability agenda [17–19]. The materials are not only concerned with waste valorization but also provide economic benefits due to low-cost production and renewability, which increases their applicability in automotive, aerospace, and architectural projects where high lightweight and effective acoustic insulation is needed [20–23]. All these results support the sustainability of natural porous composites as eco-friendly high-performance sound absorbers that will substitute synthetic counterparts in the next-generation acoustic solutions. The agro-industrial byproduct of sugarcane bagasse (SCB) has received growing interest as a sustainable raw material in the production of acoustic insulation because of the combination of physical and morphological properties. It is very absorbent in the range of low to mid-frequency because of its naturally porous and fibrous microstructure that allows effective dissipation of sound energy through friction, reflection, and resistance to air flow [10], [24–26]. SCB also has a low bulk density, which makes it lightweight and easy to handle, and it has low structural load in building and automotive designs [27–30]. Biodegradability is one of its most significant characteristics, which means that it can be used as a fully environmentally friendly alternative to synthetic acoustic panels that can be a safety concern to dispose of and be dangerous to human health. The capacity of SCB composites to achieve or surpass the acoustic performance of synthetic foams and be completely compostable at the end of the lifecycle has been confirmed in several studies [14], [31–34]. Porosity, light weight, and biodegradability are the key characteristics that make sugarcane bagasse a highly promising, green material that can be used in future acoustic applications in construction, transportation, and environmental engineering.

The mathematical modeling has now been a vital tool in the precise prediction of the sound absorption coefficient (SAC) of porous materials, which allows efficient designing of materials, saves of costs, and decreases the need to use time-consuming experimental testing. Conventional models like Delany Bazley, Johnson Champoux Allard (JCA), and Miki have been extensively applied to correlate physical and non-acoustic parameters of porous media with their frequency-dependent absorption behavior, and more recent models combine transfer matrix methods (TMM), finite element modeling (FEM), and inverse characterization methods [35–39]. Artificial intelligence methods like neural networks and deep learning have also been adopted in recent research to enhance the accuracy of prediction in complex geometries and real-world scenarios [40], [41]. Such modeling methods allow better insight into the acoustic behavior and optimize bio-based and composite materials to be used in architectural, automotive, and industrial noise control. The scientific literature has shown that natural fiber-based composites have a promising future in terms of acoustic performance and sustainability, which can be used as an alternative to synthetic materials in sound insulation. According to [17], low-density banana fiber boards were found to have the highest noise reduction coefficient of five types of natural fibers, whereas [42] determined kenaf fiber to be the most efficient in reducing noise in a variety of real-world sources, with up to 7.82 dB of sound reduction. In support of this, [43] showed that kenaf and *Calotropis gigantea* fibers in polypropylene composites offered high-mid frequency sound absorption and structural performance in the automotive applications. Likewise, [10] also produced sugarcane bagasse and bamboo charcoal composites that recorded more than 70 percent absorption in a humid environment, which has a potential in vehicle cabin applications. In other research with high-level modeling, [44] reported high SAC values of over 0.95 with close agreement to JCA predictions of CS-CSS composites, whereas [45] validated *Typha Latifolia* panels with JCAL and Attenborough models with a high degree of accuracy of about 95. Material innovation research is ongoing with [20] reporting SACs up to 0.604 with banana fiber-reinforced epoxy composites and [46] reporting SACs > 0.5 with date palm and pineapple fiber-based composites, which also exhibited good thermal and mechanical performance. Other eco-friendly materials like *Grewia Optiva* [47] and jutealoe vera laminates [48] had high SACs with the latter having 0.47 at 3000 Hz based on stacking order. According to [49], the insulators made of hemp outperformed the traditional insulators such as mineral wool in SAC with a peak of 0.99 at 2000 Hz.

Also, [50] emphasized the multifunctional character of jute-cork panels, which has better strength, thermal resistance, and 35% higher SAC than gypsum boards. Hybrid compositions like sisal-palm fiber with epoxy resin were also found to work, [51] found a 76.61% increase in SAC at 4000 Hz with this type of composition compared to others. Finally, [52] proved that natural fiber-glass wool-polyfiber sandwich composites are appropriate to use on walls and ceilings because of the increased absorption in the mid-to-high frequency range. The overall implications of these findings are that bio-based composites have a potential to develop high-performance sustainable acoustic solutions in the construction, automotive, and architectural industry. New developments in acoustic modelling have investigated numerous computational and experimental methods to forecast the sound absorption characteristics of natural fibre composites and designed porous structures. To model sound absorption of grid network structures, [53] proposed a one-dimensional transfer matrix method, which compares well with simulation and experimental outcomes and thus validates its practical use. The JCA model was used to predict the sound absorption properties of kenaf fiber-based porous absorbers and was experimentally validated by [31] and demonstrated high sound absorption properties depending on the thickness of the material, bulk density, and surface treatments, including spacer fabrics. In the data-driven modeling field, [54] used an artificial neural network (ANN) with airflow resistivity as the only input and was able to predict the sound absorption coefficient of multilayer fibrous materials more accurately than the conventional TMM methods based on Delany-Bazley and JCA models, especially in the high-frequency range of 3000-6000 Hz. Likewise, [55] showed that ANN was effective in predicting the acoustic behavior of broom fibers, and their model had a high correlation with the experimental values and was more predictive than linear regression. A detailed study of *Yucca Gloriosa* fibers by [56] through the integration of morphological characterization and 3D structural simulations revealed that the JCA model was better predictive over a wide frequency range (63-6300 Hz) than the Delany-Bazley and Garai-Pompoli models.

In line with these works, [57] optimized kenaf-reinforced polyurethane composites with response surface methodology and discovered that JCA model better predicted frequency-dependent acoustic behavior when compared to Delany-Bazley model, and also obtained a significant 35.4% increase in sound absorption compared with neat PU foam. Taken together, these works indicate the changing paradigm of mathematical and artificial intelligence-based modeling methods that contribute to the predictive quality and realistic design of bio-based acoustic materials. Although many studies have been done on natural fiber composites to apply in acoustic applications, there is a significant gap in the overall comparison of the experimentally determined SAC with the predictions of various established mathematical models, especially the composites that are made of SCB, which is a widely available but poorly utilized agro-waste. The originality of the work is that SCB/PVA composite panels are developed and the acoustic behavior of these panels is modeled in detail by Delany-Bazley, Miki and JCA models at different thicknesses and compositions. In contrast to the previous research which only examines experimental or single model analysis, this study gives a systematic analysis and verification of the various predictive models with regard to experimental data. The relevance of the study is based on the fact that it contributes to sustainable material development through encouraging the utilization of SCB waste in functional acoustic products and developing model-based design of sound-absorbing materials with a sustainable environment.

II. METHODOLOGY

In order to examine the acoustic behavior of sugarcane bagasse based composites, panels were made under controlled conditions and tested in a standardized impedance tube set up. This method was used to assure uniformity in material preparation and accuracy in measuring frequency dependent sound absorption properties.

II.1 COMPOSITE FABRICATION

The composite fabrication process entailed the fabrication of sugarcane bagasse (SCB)-based panels with the help of polyvinyl acetate (PVA) as a binding agent. The first step involved the collection of raw bagasse in the local sugar mills, sun-drying, and grinding to get fine and uniformly distributed fibers. These fibers were filtered using standard mesh in order to eliminate large particles and to achieve uniformity in the composite matrix. The bagasse was combined with the PVA binder in a weight ratio of 1:1 to provide enough bonding and structural strength. The fiber-binder mixture was stirred by a mechanical mixer to attain homogeneity and then cast into rectangular moulds of size 110 mm x 120 mm. In order to investigate the influence of thickness on acoustic properties, three panel thicknesses were made: 10 mm, 20 mm, and 30 mm. The samples were pressed at a constant load of 90 kgf and allowed to dry under pressure in 48 hours. The panels were dried under natural sunlight conditions (72 hours) after the molding process to finish the curing process and eliminate moisture. This was done to provide dimensional stability and sufficient bonding of the composite. Nine samples were made in three levels of composition SCB40, SCB50, and SCB60, which represents 40, 50, and 60 percent of bagasse content by weight respectively as presented in Table 1.

Table 1: Composition and Thickness Variants of Fabricated SCB/PVA Composite Panels.

Sample Code	SCB Content (%)	PVA Content (%)	Thickness (mm)
SCB40-10	40	60	10
SCB40-20	40	60	20
SCB40-30	40	60	30
SCB50-10	50	50	10
SCB50-20	50	50	20
SCB50-30	50	50	30
SCB60-10	60	40	10
SCB60-20	60	40	20
SCB60-30	60	40	30

Source: Authors, (2026).

For illustration, three composite panels (SCB60) with 10mm, 20mm and 30mm thickness are depicted in the Figure 1.

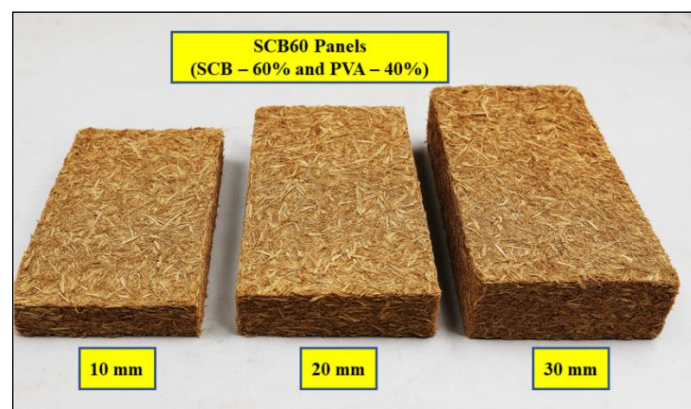


Figure 1: SCB60 Composite Panels with 10 mm, 20 mm and 30 mm thickness.

Source: Authors, (2026).

II.2 EXPERIMENTAL ACOUSTIC TESTING

Experimental assessment of the acoustic performance of the SCB/PVA composite panels was done using an impedance tube system as per ISO 10534-2 and ASTM E1050 standards. This system consists of a loudspeaker at one end of a cylindrical tube and two fine microphones at the opposite end of the tube at a specified distance to measure the incident and reflected sound pressure levels. The composite sample is put at the other end of the tube supported by a rigid termination to approximate the conditions of installation in the real world. A random noise signal was produced by a broadband and was introduced into the loudspeaker using a power amplifier and the microphones measured the sound field produced. The complex reflection coefficient was calculated using the transfer function method and the normal incidence SAC was determined using the formula $\alpha = 1 - |R|^2$. The measurements were conducted in the frequency range of 125 Hz to 4000 Hz to comprehensively evaluate the acoustic absorption behavior of the composite in the low, mid and high frequency ranges. Figure 2 demonstrates schematic layout and photograph of the impedance tube experimental set-up.

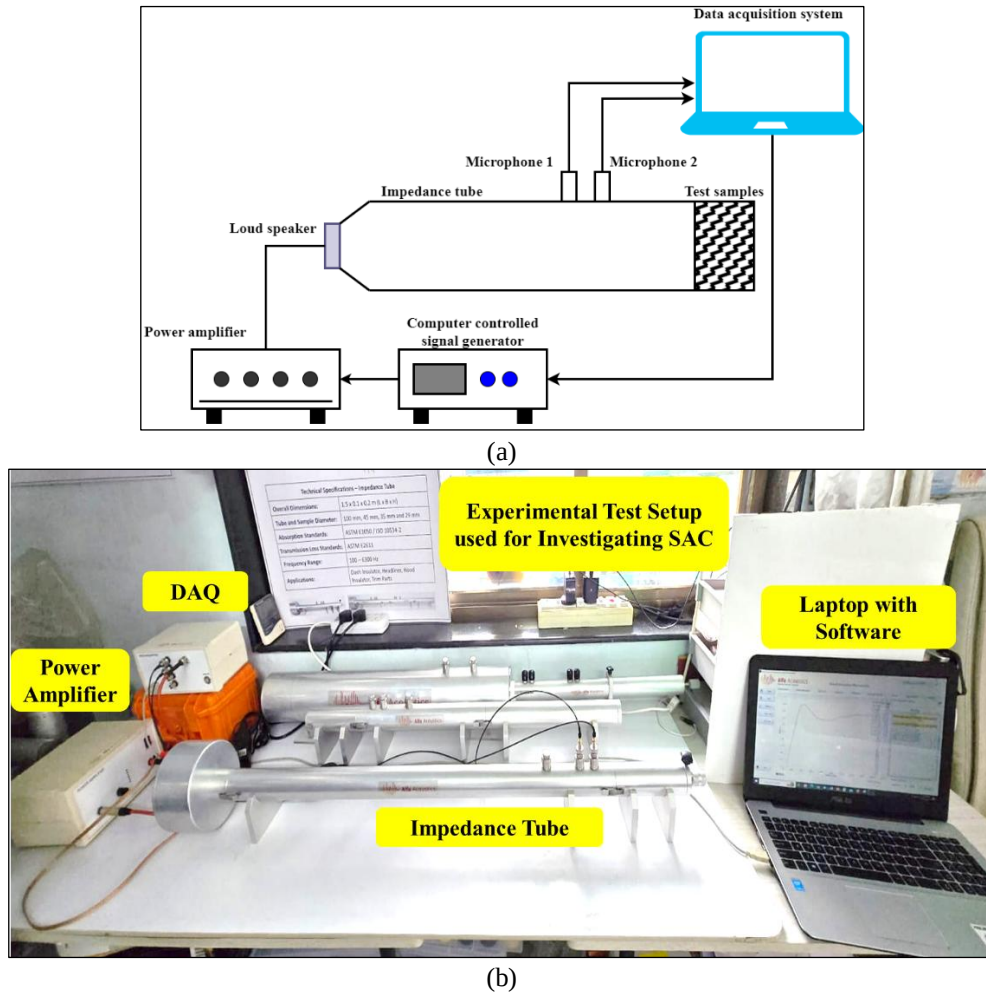


Figure 2: Impedance Tube Setup for SAC Measurement Based on ISO 10534-2 (a) schematic layout and (b) photograph. Source: Authors, (2026).

III. MATHEMATICAL MODELS FOR PREDICTION OF SOUND ABSORPTION COEFFICIENT

In order to examine the acoustic behavior of sugarcane bagasse based composites, panels were made under controlled conditions and experimented by a standardized impedance tube configuration. This method guaranteed the stability of material preparation and the accuracy of measuring the frequency-dependent sound absorption properties.

III.1 MIKI MODEL

Miki model is a semi-empirical acoustic model that is employed to model the sound absorption behavior of porous materials especially fibrous composites like natural fiber-based panels. It provides a simplified version of more complicated theoretical models such as the JCA model because it uses fewer material parameters but still can make fairly accurate predictions, particularly in materials where airflow resistivity is the most important controlling factor. The Miki model is based on the Delany-Bazley empirical model but with altered expressions of power-law characteristic impedance and complex wave number to make it applicable to a wider frequency range. The Miki model assumes that the material is a rigid-frame, isotropic, macroscopically homogeneous porous material, and its acoustic behavior can be well modeled using only flow resistivity and frequency, without necessarily modeling microstructural properties such as porosity, tortuosity, or characteristic lengths. This assumption simplifies the model computationally and simple to use, particularly in the preliminary material design phase or the rapid prototyping phase.

The dimensionless frequency parameter X , defined as $X = \frac{f}{\sigma/\rho_0}$, where f is the frequency in Hz, σ is the airflow resistivity (in Pa·s/m²), and ρ_0 is the density of air (typically 1.21 kg/m³), is central to the model. The normalized characteristic impedance: $\frac{Z_c}{\rho_0 c_0}$ and normalized complex wave number $\frac{k}{\omega/c_0}$ are given by the empirical relations:

$$\frac{Z_c}{(\rho_0 c_0)} = 1 + 0.070 X^{-0.632} - i \cdot 0.107 X^{-0.632} \quad (1)$$

$$\frac{k}{\omega/c_0} = 1 + 0.109 X^{-0.618} - i \cdot 0.160 X^{-0.618} \quad (2)$$

Where c_0 is the speed of sound in air and $\omega = 2\pi f$ is the angular frequency. Once the characteristic impedance Z_c and wave number k are calculated using these equations, the input impedance Z of the porous layer of thickness d can be determined as $Z = -iZ_c \cot(kd)$, assuming the material is backed by a rigid surface. The normal-incidence sound absorption coefficient $\alpha(f)$ is then calculated using the impedance mismatch equation:

$$\alpha(f) = 1 - \left| \frac{Z - Z_0}{Z + Z_0} \right|^2 \quad (3)$$

Where $Z_0 = \rho_0 c_0$ is the characteristic impedance of air. The importance of the Miki model is that it is easy to use and gives realistic acoustic forecasts with minimum input criteria, thus it is particularly appropriate in the initial acoustic description of natural fiber composites, including sugarcane bagasse-polymer mixtures. Although it is not as sensitive to the microstructure as more sophisticated models, its simplicity and empirical accuracy make it a useful instrument in the study of acoustic materials and in the engineering domain.

III.2 DELANY-BAZLEY MODEL

The Delany-Bazley model is a traditional empirical model that has been employed to model the acoustic behavior of fibrous and porous sound-absorbing materials, especially at mid-to-high frequencies. The model was developed in the 1970s after much experimental effort on fibrous glass materials had been done, and simple mathematical expressions were developed to represent the complex characteristic impedance and wave number of a porous medium in terms of the airflow resistivity of the material and the frequency of the incident sound wave. This model assumes that the porous material is a rigid-frame structure, in which the frame is not moved by sound waves, the material is homogeneous and isotropic and is thick enough that structural resonance effects and backing effect do not dominate the response. The most important simplification of the Delany-Bazley model is that it fails to consider microstructural parameters of porosity, tortuosity, or characteristic lengths, which reduces its accuracy but increases its utility in the practical engineering context. The model introduces a dimensionless frequency parameter $X = \frac{f}{\sigma}$, where f is the frequency in hertz and σ is the airflow resistivity in . Based on this parameter, the normalized characteristic impedance and normalized wave number $\frac{k_0}{k}$ are given by the following empirical formulas:

$$\frac{Z_0}{Z_c} = 1 + 0.0571 X^{-0.754} - i \cdot 0.087 X^{-0.732} \quad (4)$$

$$\frac{k_0}{k} = 1 + 0.0978 X^{-0.7} - i \cdot 0.189 X^{-0.595} \quad (5)$$

Where $Z_0 = \rho_0 c_0$ is the characteristic impedance of air, and $k_0 = \frac{\omega}{c_0}$ is the wave number in free air. Once the characteristic impedance and wave number are computed, the sound absorption coefficient at normal incidence can be derived using the same impedance-based relation used in other models:

$$\alpha(f) = 1 - \left| \frac{Z - Z_0}{Z + Z_0} \right|^2 \quad (6)$$

Where $Z = -iZ_c \cot(kd)$, and d is the thickness of the absorbing layer. The Delany-Bazley model is notable because it is simple and only one measurable property, airflow resistivity, is needed to give reasonably accurate predictions of many industrial fibrous materials. It is however most accurate in high porosity, high resistivity materials at frequencies above 500 Hz and less accurate at low frequencies or non-fibrous structures. In spite of these shortcomings, it is an empirically-based and easy to use tool that is popular in preliminary acoustic design, benchmarking, and education in the material acoustics field.

III.3 JOHNSON-CHAMPOUX-ALLARD (JCA) MODEL

The Johnson-Champoux-Allard (JCA) model is a well-known theoretical model that is applied to predict the acoustic behavior of porous materials, especially in estimating the sound absorption coefficient of porous materials at normal and oblique incidences.

The JCA model was developed as an extension of the simpler empirical models, and includes physical effects like viscous and thermal dissipation in the pores of a rigid-frame porous medium, and is particularly applicable to fibrous and granular composites, such as sugarcane bagasse-based materials. This model is based on the fact that the material is an equivalent fluid, i.e. the solid matrix does not contribute to the wave propagation, and is at rest. The JCA model treats the propagation of sound in porous media as a problem of two important frequency-dependent quantities, the complex effective density of the material $\rho(\omega)$, and the complex effective bulk modulus of the material $K(\omega)$. The equation of the effective density is:

$$\rho(\omega) = \rho_0 \cdot \alpha_\infty \left(1 + \frac{\sigma \phi}{i\omega \rho_0 \alpha_\infty} \sqrt{1 + \frac{4i\alpha_\infty^2 \eta \rho_0 \omega}{\sigma^2 \Lambda^2 \phi^2}} \right) \quad (7)$$

Where ρ_0 is the air density, α_∞ is the tortuosity, ϕ is the porosity, σ is the airflow resistivity, η is the dynamic viscosity of air, ω is the angular frequency, and Λ is the viscous characteristic length. Similarly, the complex bulk modulus is expressed as:

$$K(\omega) = \frac{\gamma P_0}{\gamma - (\gamma - 1) \left(1 + \frac{8\eta}{i\omega \rho_0 Pr \Lambda'^2} \right)^{-1/2}} \quad (8)$$

where P_0 is atmospheric pressure, γ is the specific heat ratio of air, Pr is the Prandtl number, and Λ' is the thermal characteristic length. These parameters are the energy losses of the acoustic wave to the porous structure through viscous and thermal interaction. Once $\rho(\omega)$ and $K(\omega)$ are determined, the characteristic impedance Z_c and complex wave number k are calculated as $Z_c = \rho(\omega) \cdot K(\omega)$ and $k = \omega \rho(\omega) / K(\omega)$, respectively. The input impedance Z of the material layer of thickness d is then computed using the relation $Z = -iZ_c \cot(kd)$. Lastly, the normal-incidence SAC, $\alpha(f)$ is obtained with the help of the formula of impedance mismatch:

$$\alpha(f) = 1 - \left| \frac{Z - Z_0}{Z + Z_0} \right|^2 \quad (9)$$

Where $Z_0 = \rho_0 c_0$ is the characteristic impedance of air. The JCA model is especially important as it is capable of capturing the complete frequency-dependent behavior of porous materials with reasonable precision, assuming that its input parameters, including porosity, tortuosity, flow resistivity and characteristic lengths, are well-characterized. Although it presupposes a solid frame that is rigid and may not apply to flexible or viscoelastic materials, its capability to include realistic microstructural effects in predictive acoustics makes it a foundation of the modeling of sound-absorbing composite materials.

IV. RESULTS AND DISCUSSION

IV.1 SCB40 COMPOSITE PANEL

Figure 3(a), 1(b) and 1(c) show the comparison of SAC values of experimental measurements and three popular theoretical models - Miki, DB and JCA of SCB40 composite panels with thickness of 10 mm, 20 mm and 30 mm respectively. The results show that the SAC increases significantly as the panel thickness increases, especially in the low-frequency range. In the case of the 10 mm panel in Figure 3(a) the experimental findings suggest that the highest SAC is about 0.88 around 3000 Hz and there is not much absorption in the low-frequency band. DB and Miki models are the ones that moderately reflect the rising trend but always underestimate the value, whereas the JCA model is a bit closer to predictions, particularly after 2000 Hz. In Figure 3(b), the 20 mm panel is shown to have better low-frequency absorption, and experimental SAC is more than 0.9 in the mid-frequency range. In this case, the JCA model provides a much more accurate fit to experimental data, especially at frequencies between 1500 and 4000 Hz, as DB and Miki are still under-predicting performance. This enhancement in the predictive accuracy of JCA can be explained by the fact that its predictive model incorporates poroelastic parameters such as tortuosity, flow resistivity, and characteristic lengths that are important in the description of the intricate internal structure of natural fiber composites. This tendency is also supported by figure 3(c), where the 30 mm panel has a high SAC in a broad frequency range, and the experimental values are always above 0.7 since 800 Hz. The JCA model is close to the experimental data throughout the range, and it is more predictive than both DB and Miki models. These observations confirm the usefulness of the JCA model in the modeling of thick, fibrous composites such as SCB/PVA panels, where airflow resistivity, porosity, and viscous-thermal interactions are the most important factors in governing acoustic behavior. On the whole, the discussion shows that simpler empirical models can give approximate predictions, the JCA model can make a more robust and physically based predictions of SAC in natural fiber-based acoustic materials, especially when the panel thickness is large.

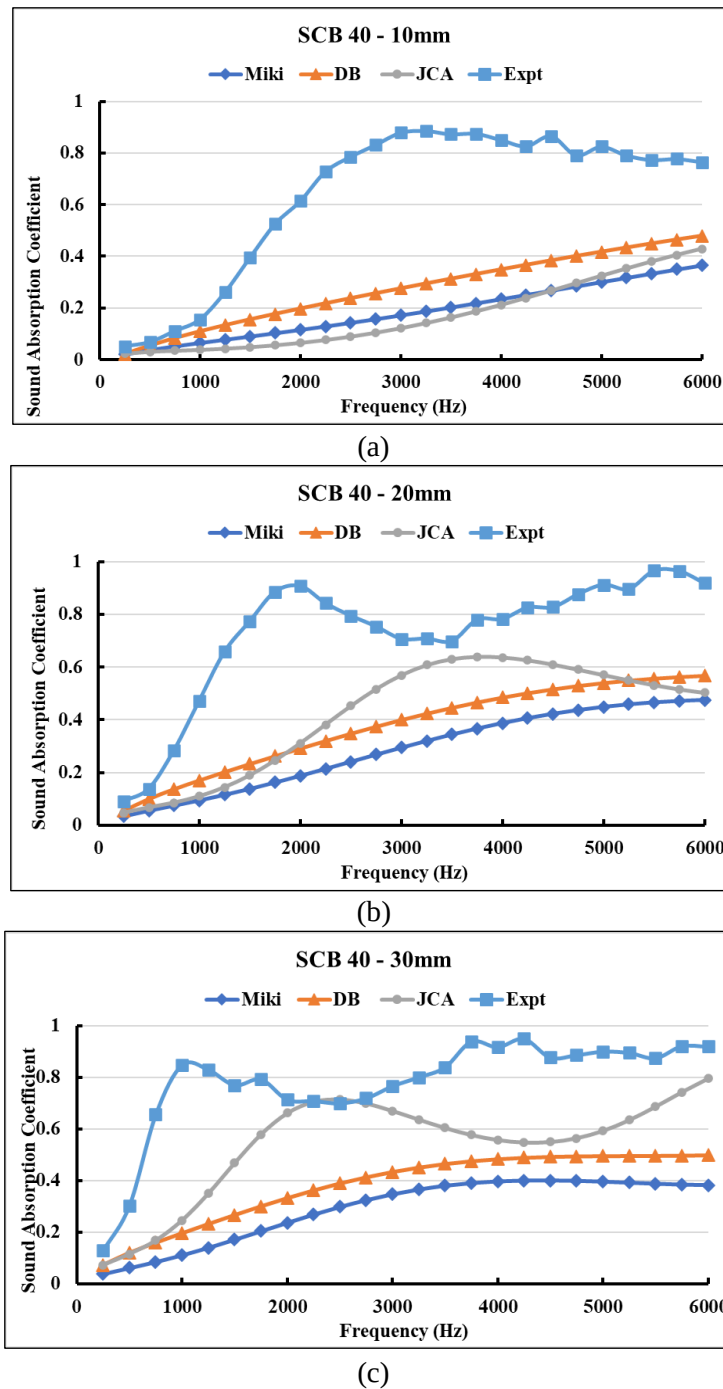


Figure 3: Comparison of SAC estimation with various mathematical models with experimental data for SCB40 composite. Source: Authors, (2026).

IV.2 SCB50 COMPOSITE PANEL

Figures 4(a), 4(b), and 4(c) show the comparison of experimental and model-predicted values of SAC of SCB50 composite panels of thicknesses 10 mm, 20 mm, and 30 mm, respectively. In Figure 4(a), the sharp increase in SAC with frequency is observed in the 10 mm thick panel, and it reaches its maximum value of about 0.92 at about 3000 Hz in the experimental results. Nevertheless, none of the three mathematical models, Miki, DB and JCA predict the SAC significantly underestimating the SAC at the frequency spectrum, especially at mid and high frequencies. The DB model demonstrates the nearest approximation yet it is far below experimental values. Figure 4(b) shows that the 20 mm thick panel has a better low-frequency absorption with the experimental SAC values being higher than 0.95 in the 1500-2500 Hz range and steadily high after that. In this case, the JCA model starts to agree with the experimental trend much better, particularly between 1500 and 4000 Hz, as DB and Miki models are still under-predicting. The better predictive capability of the JCA model can be attributed to the fact that the model incorporates the essential parameters of tortuosity, airflow resistivity and characteristic lengths, which enable the model to better depict the complicated porous structure and energy dissipation behavior of the SCB/PVA composite. Figure 4(c) is the experimentally determined SAC of the 30 mm thick panel, where the broad peak of the SAC is again observed to be near unity in the frequency range of 1000 to 3000 Hz, and the SAC is found to have values above 0.8 in most of the frequency range. The JCA model is no exception and shows the closest correspondence to experimental evidence and proves the soundness of its applicability to the modeling of thicker natural fiber composites.

Although the DB and Miki models are marginally better than the case of thinner samples, they still do not represent the higher absorption levels well. These findings support the finding that the JCA model offers the most credible prediction of SAC of all the models tested especially in mid-thickness and thick panels. The growing correspondence of the experimental results to the increasing panel thickness also confirms the idea that the proper modeling of acoustic performance in natural fiber composites should take into consideration the advanced material-specific parameters, which are well-considered in the JCA framework.

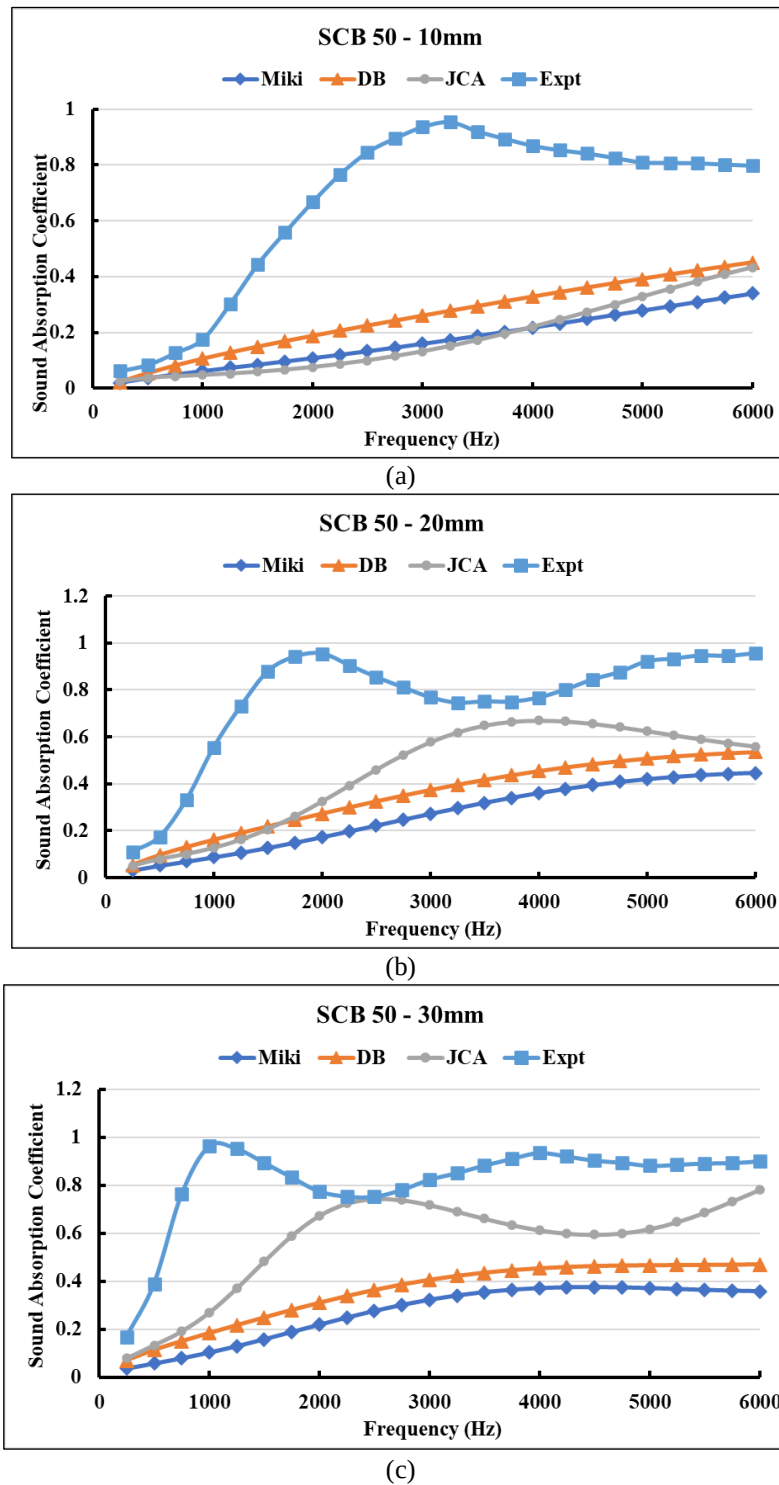
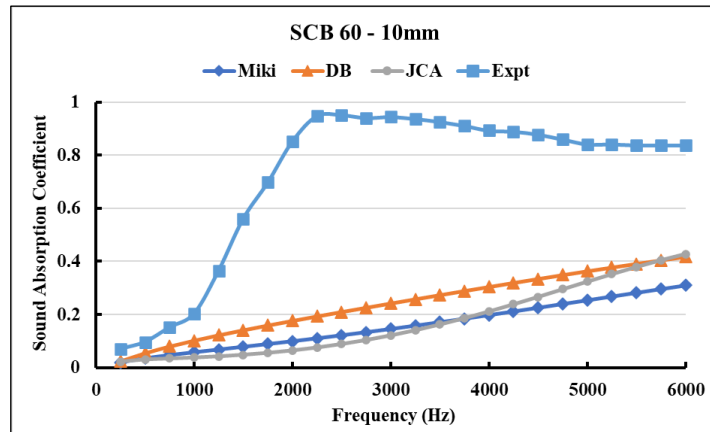


Figure 4: Comparison of SAC estimation with various mathematical models with experimental data for SCB50 composite.
Source: Authors, (2026).

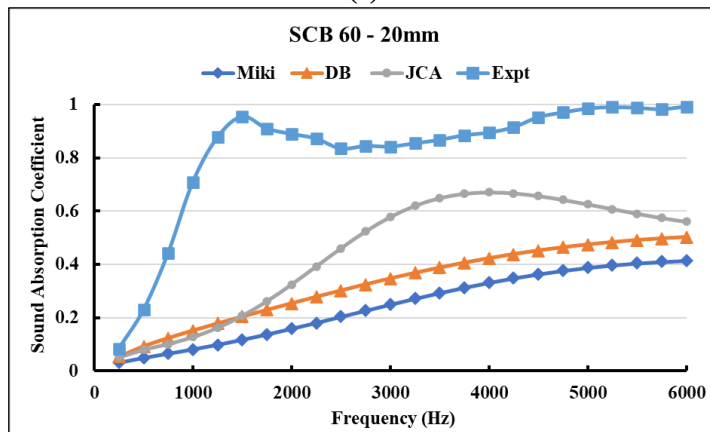
IV.3 SCB60 COMPOSITE PANEL

Figures 5(a), 5(b), and 5(c) show the comparison of SAC of SCB60 composite panels with the thicknesses of 10 mm, 20 mm, and 30 mm, respectively, by using experimental measurements and three predictive models, namely, Miki, DB, and JCA models. Figure 5(a) shows that the SCB60 panel of 10 mm thickness has good SAC performance, with experimental values reaching a peak of about 0.93 at about 2500 Hz and a value of 0.8 throughout much of the mid-frequency range. The JCA model gives the nearest approximation of the models especially above 2000 Hz, and both the DB and Miki models are always underestimating the SAC.

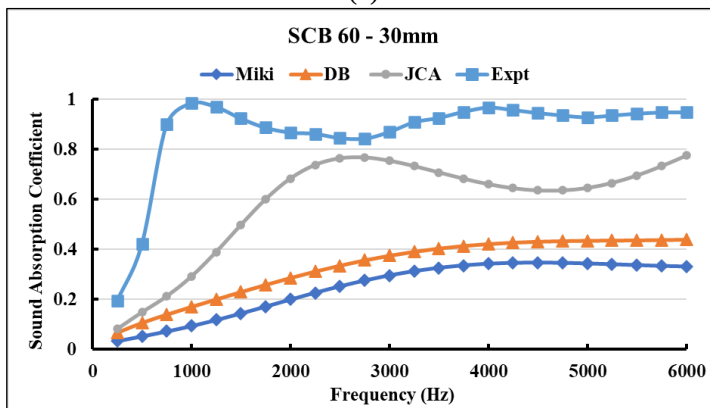
The experimental SAC is not only better at lower frequencies as the panel thickness is increased to 20 mm in Figure 5(b), but also has values above 0.85 over a wider range of frequencies, with values approaching unity above 4000 Hz. The JCA model is in line with the trend of the experiment, particularly between 1500 and 4000 Hz, and the peak and the wider absorption bandwidth is captured. In the meantime, DB and Miki models perform better as compared to the 10 mm case but still are far below the magnitude of the SAC. The experimental SAC of the 30 mm thick panel in Figure 5(c) is high throughout the entire frequency spectrum with a maximum of approximately 0.96 and sustained absorption of approximately 0.9 within a wide band. The JCA model shows an amazing capacity to reproduce this trend especially at 1500 Hz and above, both in shape and the level of the experimental curve. This high correlation points to the strength of the JCA model of predicting the acoustic behavior of thick, porous composite with large SCB content. The enhancement in the accuracy of the model as the panel thickness and the proportion of SCB increase can be explained by the increased porosity and internal structure that the JCA model can capture well due to the incorporation of parameters like the tortuosity, the viscous and thermal characteristic length, and the flow resistivity. On the contrary, the DB and Miki models, which are more empirical and designed to work with traditional fibrous absorbers, do not capture the intricate interactions that occur in bio-based composites and thus do not predict much. These observations confirm the applicability of the JCA model in the correct modeling of SAC in sustainable composites, particularly at higher fiber content and panel thickness, where the coupling between acoustic waves and the internal porous structure becomes more and more prevalent.



(a)



(b)



(c)

Figure 5: Comparison of SAC estimation with various mathematical models with experimental data for SCB60 composite.
Source: Authors, (2026).

V. CONCLUSION

The study examined the acoustic performance of sustainable composite panels constructed of SCB and PVA through experimental and theoretical methods. Composite samples of different SCB content (40%, 50%, and 60%) and thicknesses (10 mm, 20 mm and 30 mm) were made. They were experimentally measured in terms of their sound absorption coefficients (SAC) using an impedance tube according to ASTM E1050/ISO 10534-2. Moreover, SAC was modeled by three known mathematical models Miki, D) and JCA and model predictions were compared with experimental results.

- Adding SCB content and panel thickness increased SAC, particularly at low-to-mid frequencies because of increased porosity and internal damping.
- Thicker high-SCB panels had greater values of experimental SAC, which showed excellent sound absorption.
- JCA model gave more close correspondence with experiment results, particularly with thicker samples.
- DB and Miki models under-predicted SAC in all the samples, which validated the constraints of modeling complex natural fiber composites.

Future research can focus on hybrid binders or multilayer to maximize broadband absorption. Also, machine learning models can be combined with numerical simulations to enhance predictive performance and inform the design of bio-based acoustic materials to meet a variety of applications.

VI. AUTHOR'S CONTRIBUTION

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