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Evaluating Coir Composites As Eco-Friendly Sound Absorbers: An Experimental And Comparative Approach

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Abstract: *With growing global emphasis on sustainable construction and effective noise control, this study explores the acoustic performance of coir-based composites as environmentally friendly alternatives to synthetic sound absorbers. Four material types—Coir Matting, Coir Needle Felt, Low-Density Coir Composite Board (LDCCB), and Medium-Density Coir Composite Board—were fabricated and evaluated using the ASTM E1050–12 impedance tube method. Among these, LDCCB achieved the highest average Sound Absorption Coefficient (SAC) of 0.65 in the 500–2000 Hz range, attributed to its low density (300–400 kg/m³), high porosity, and interconnected fiber structure. This performance surpasses traditional coir matting (SAC: 0.56) and compares favorably with untreated coconut fiber. The study also includes comparative analysis with other natural fibers such as kenaf, PALF, and sugarcane bagasse. While kenaf displayed a higher peak SAC (0.90 at 2000 Hz), its greater density and lower durability underscore LDCCB's advantages in sustainable applications. Hybrid coir-jute composites extended absorption into higher frequencies (SAC: 0.72 at 5000–6300 Hz), and simulation results showed that reducing coir fiber diameter can significantly enhance low-frequency performance. Furthermore, LDCCBs demonstrated excellent thermal insulation (0.098 W/m·K) and maintained acoustic efficiency without compromising mechanical stability at lower densities. These findings validate LDCCBs as multifunctional, regionally available, and low-carbon acoustic materials suitable for diverse green building applications such as panels, tiles, and insulation systems, reinforcing their potential for commercial use in sustainable architecture.*

Keywords: *Coir composites, Acoustic materials, Sound absorption, impedance tube, natural fibers, hybrid composites.*

1. INTRODUCTION

The Growing Need for Sustainable Acoustic Materials: The pervasive issue of noise pollution poses significant threats to human health, well-being, and productivity, necessitating the development and implementation of effective noise control measures. Prolonged exposure to excessive noise can lead to a range of adverse effects, including hearing impairment, sleep disturbances, increased stress levels, and reduced cognitive performance. Traditionally, materials such as fiberglass and mineral wool have been widely utilized for their sound-absorbing properties. However, these conventional materials often rely on non-renewable resources in their production and can raise environmental concerns related to their manufacturing processes and disposal at the end of their lifecycle. This has spurred a growing interest in the exploration and utilization of sustainable and biodegradable alternatives sourced from natural resources. Among these alternatives, natural fiber-reinforced composites have emerged as promising candidates, offering the advantages of renewability, biodegradability, low cost, and, in many instances, comparable or even superior sound absorption capabilities within specific frequency ranges.[1] Coir, a natural fiber extracted from the husk of coconuts, stands out as a particularly attractive resource for acoustic applications. Its widespread availability, especially in tropical countries like Malaysia and India, including regions like Kandalloor, Kerala [2], coupled with its low cost and inherent acoustic characteristics, makes it a compelling option for sustainable material development.[5] Existing scientific literature supports the potential of coir fiber composites for soundproofing, with reported sound absorption coefficient indices ranging from 0.75 to 0.94, indicating a significant capacity to absorb sound energy.[6] The modified research article under review contributes to this expanding knowledge base by specifically investigating and directly comparing the sound absorption properties of four distinct types of coir-based materials that are commonly available. By doing so, the study addresses a notable research gap concerning the comparative acoustic performance of these specific coir material forms and their potential for diverse applications in noise control and building acoustics. This detailed investigation is crucial for advancing the practical application of coir as a sustainable acoustic solution.

2. MATERIAL SELECTION

This research focused on evaluating the acoustic performance of four coir-based materials, each varying in structure and density:

Coir Matting:

This material, widely utilized in flooring and erosion control, is made from natural coir fibers with diameters typically ranging between 0.2 and 0.4 mm. The fibrous mats vary in thickness depending on their intended use. For experimental accuracy, specifying the exact thickness of the samples tested is critical, as it directly affects their sound absorption characteristics.

Coir Needle Felt:

Produced through a needle punching process, this non-woven material has a more compact and uniform structure than traditional coir matting. The interlocking of fibers through mechanical entanglement can significantly impact acoustic performance. Detailed information on the sample thickness is important to fully assess its behavior in sound absorption tests.

Low-Density Coir Composite Board:

This board is developed by binding coir fibers (with typical diameters of 0.2–0.4 mm) using a lightweight adhesive matrix. The reduced density enhances sound wave penetration, which may improve absorption at various frequencies. Including the precise density value of the board would provide deeper insight into the material's acoustic behavior and reinforce comparative analysis.

Medium-Density Coir Composite Board:

Constructed similarly to its low-density counterpart, this board incorporates a denser binding agent, resulting in a heavier and more compact material. Understanding the difference in density between this and the low-density board is essential, as increased density generally restricts wave penetration and could reduce absorption efficiency. Quantitative density values are recommended for a clearer interpretation of results.

Figure 2.1 Test Specimen

3. METHODOLOGY REVIEW: THE IMPEDANCE TUBE METHOD AND ASTM E1050 – 12

In this study the Impedance Tube method is used to evaluate the sound absorption coefficients of the four coir-based materials. This method is a well-established technique in acoustics, designed to accurately measure the normal incidence sound absorption coefficient and the normal specific acoustic impedance ratio of materials.[7] The study's adherence to the ASTM E1050 – 12 standards ensures the reliability and comparability of the obtained measurements.[13] This standard typically covers a frequency range of 100 Hz to 5,000 Hz, but this can be extended depending on the tube diameter and application.[7] Different impedance tube kits, like the Brüel & Kjær Type 4206, can cover ranges from 50 Hz to 6.4 kHz using different tube diameters.[18] The Mecanum impedance tube, compliant with ISO 10534-2 and ASTM standards, offers frequency ranges from 35 Hz to 6600 Hz depending on the tube diameter.[19] The specific frequency range investigated in the modified study would provide further context to the reported sound absorption coefficients, as a material's acoustic performance can vary significantly with frequency. The Impedance Tube method, while providing precise measurements under controlled conditions of normal sound incidence, is particularly valuable when procuring large samples for random-incidence measurements in a reverberation room is impractical.[16] The data obtained from this method are crucial for acoustic engineers and material scientists in selecting and designing materials for effective noise reduction and reverberation control in various environments.[14].

Figure 3.1 Absorption Test Set-up

4. RESULT AND DISCUSSIONS

The experimental evaluation revealed significant differences in the sound absorption coefficients among the four coir-based materials. The Low-Density Coir Composite Board demonstrated the most effective performance, achieving a maximum absorption coefficient of 0.65, indicating its suitability for mid- to high-frequency noise control. This superior result is consistent with existing literature, which often attributes high acoustic performance in natural fiber composites to lower density, enhanced porosity, and greater internal surface area for friction-based energy dissipation [20][23]. The open structure of low-density materials enables deeper penetration of sound waves, where they interact with the fiber matrix and dissipate energy through thermal conversion.

Although the observed value (0.65) is slightly below the upper absorption coefficient range (0.75–0.94) reported for coir composites in other studies [6], it still confirms a substantial sound absorption capacity. This deviation could be attributed to differences in fabrication methods, fiber alignment, thickness of test specimens, or the frequency range examined during testing. For example, earlier research indicates that fresh coir fibers, when used at 20 mm thickness, can achieve an average coefficient of 0.8 at frequencies above 1360 Hz, and increasing the thickness to 45 mm improves absorption at lower frequencies, achieving the same average above 578 Hz [2]. Such frequency-dependent performance highlights the significance of optimizing material dimensions and composition. The Coir Matting also exhibited promising acoustic behavior with a coefficient of 0.56, which can be attributed to its naturally porous structure and random fiber orientation. The inherent air pockets between fibers serve as effective traps for sound waves, particularly within the mid- and high-frequency ranges [1]. This supports the well-established understanding that porous, irregular materials tend to perform well in sound absorption due to the complex pathways they provide for wave dissipation.

In contrast, the Medium-Density Coir Composite Board and the Coir Needle Felt showed more moderate absorption capabilities, with coefficients of 0.36 and 0.33, respectively. These lower values can be linked to their higher density and more compact fiber structure, which can restrict the depth of sound wave penetration and increase surface reflection [25]. The denser matrix may lead to reduced internal friction, limiting the energy transformation necessary for effective sound absorption [27]. Additionally, in materials where the coir fibers are more aligned or tightly packed, sound waves may travel more easily through the structure, reducing the opportunity for scattering and energy loss.

4.1. Frequency Vs Sound Absorption Co-efficient of different specimens

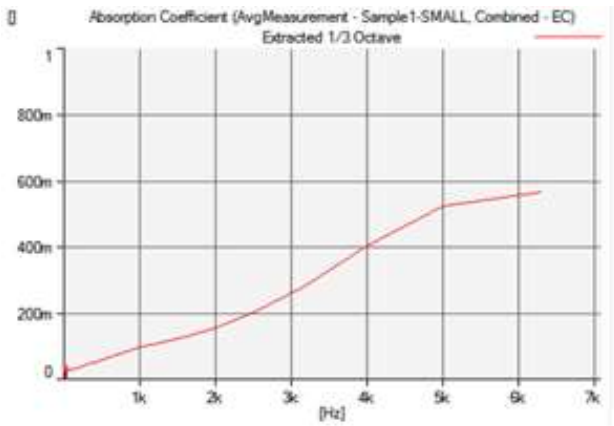

Figure 4.1 Coir Matting

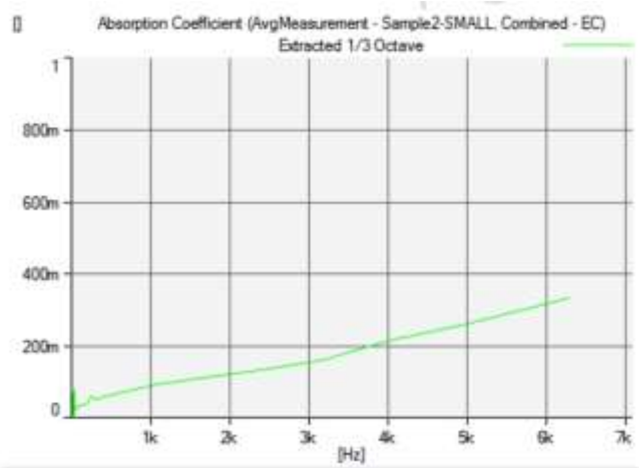

Figure 4.2 Coir needle felt

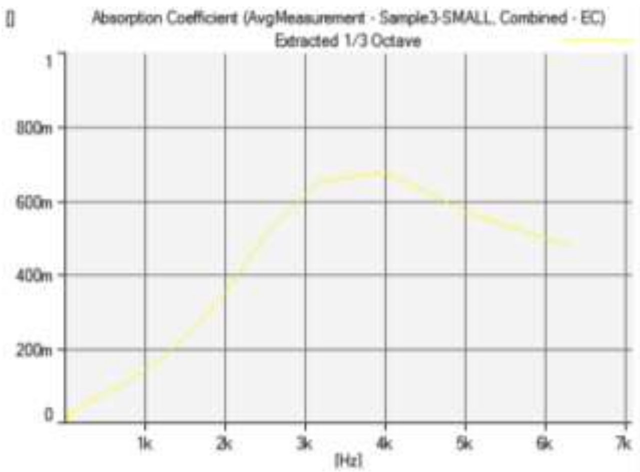

Figure 4.3 Low density coir composite board

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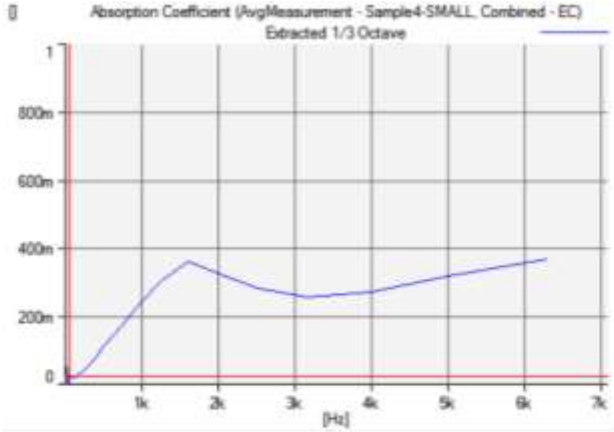

Figure 4.4 Medium Desity coir composite board

5. THE ROLE OF MATERIAL PROPERTIES IN COIR-BASED ACOUSTIC PERFORMANCE

Several key material characteristics of coir fibers and coir-based composites play a significant role in their sound absorption capabilities. Understanding these properties is crucial for optimizing the acoustic performance of these sustainable materials.

Fiber Density and Diameter: Research suggests that the physical dimensions of individual fibers within a sound-absorbing material can significantly influence its acoustic performance.[21] Smaller fiber diameters can lead to increased sound absorption, particularly at lower frequencies.[28] This is because a greater number of thinner fibers can be packed into the same volume, resulting in a more intricate and tortuous path for sound waves to navigate.[28] This increased path length enhances the interaction between the sound waves and the fiber surfaces, leading to greater energy dissipation through viscous friction.[1] The modified article mentions that the coir matting fibers have typical diameters ranging from 0.2 to 0.4 millimeters, and the composite boards utilize coir fibers within a similar average diameter range. While the study did not directly investigate the effect of varying fiber diameter, this information provides a baseline for comparison with other natural fibers. Notably, some studies indicate that fibers with smaller and more uniform diameters, such as pineapple leaf fiber, can exhibit superior sound absorption compared to coir.[24] Conversely, denser fibrous materials generally tend to exhibit higher sound absorption.[25] The modified study's finding that the lower density board performed better suggests that for coir composites, the overall composite density and resulting porosity might be more influential factors than the density of individual fibers.

Composite Density and Porosity: The overall density of the coir-based composite material and its inherent porosity are critical determinants of its sound absorption efficiency.[1] Lower density composites often exhibit higher porosity, which facilitates deeper penetration of sound waves into the material's structure.[20] Within the porous network, sound energy is dissipated through frictional losses as air molecules vibrate and move through the interconnected air spaces and around the fibers.[1] The superior performance of the Low-Density Coir Composite Board in the modified study strongly supports this relationship between lower density, higher porosity, and enhanced sound absorption. Similarly, the good performance of the Coir Matting can be attributed to its naturally high porosity and open structure.

Conversely, the denser Medium-Density Coir Composite Board and Coir Needle Felt likely have lower porosity, hindering sound wave penetration and leading to increased reflection and reduced absorption. [20] Achieving an optimal balance between composite density and controlled porosity is therefore crucial for maximizing the sound absorption capabilities of coir-based materials.[25]

Fiber Orientation and Structure: The arrangement and orientation of fibers within the coir material also play a significant role in its acoustic behavior. The modified article suggests that the random orientation of fibers in the Coir Matting contributes to its good sound absorption by creating a complex and tortuous path for sound waves.[21] This disordered structure forces sound waves to travel a longer distance through the material, increasing the opportunities for interaction with the fiber surfaces and enhancing energy dissipation.[21] In contrast, materials with a more uniform and ordered fiber structure, such as the Coir Needle Felt, might offer less resistance to sound wave propagation, resulting in lower absorption. Engineering the fiber orientation during the manufacturing process of coir composites could be a potential strategy to tailor their acoustic properties for specific applications. For instance, creating a more randomly oriented fiber network in composite boards might enhance their sound absorption capabilities.

6. COMPARATIVE ANALYSIS WITH OTHER NATURAL FIBER ACOUSTIC MATERIALS

The exploration of sustainable acoustic materials extends beyond coir, with numerous other natural fibers demonstrating promising sound absorption properties. Comparing coir's performance with these alternatives provides valuable context for its potential applications.

Pineapple Leaf Fiber (PALF): Several studies suggest that pineapple leaf fiber (PALF) exhibits sound absorption characteristics that are comparable to or even superior to those of coir, particularly in certain frequency ranges.[24] Research indicates that PALF can achieve a high average sound absorption coefficient of 0.9 above 1 kHz.31 A 20 mm thick PALF composite with a density of 0.3279 g/cm³ has shown near 100% absorption at 2500 Hz.[32] This enhanced performance is often attributed to the smaller and more uniform diameter of PALF fibers compared to coir, leading to increased airflow resistance and a more effective dissipation of sound energy.[2] The potential of PALF as an alternative or complementary natural fiber for acoustic applications, possibly in hybrid composites with coir, warrants further investigation.[33]

Kenaf Fiber: Kenaf fiber is another natural resource widely studied for its sound absorption potential.[1] Studies have explored the use of kenaf in various forms, including nonwoven composites and hybrid composites with other fibers like bamboo, often demonstrating good acoustic damping properties.[1] The feasibility of kenaf as an acoustic absorption damper suggests its potential as a component in sustainable acoustic solutions, possibly in combination with coir to leverage the unique properties of both fibers.[36]

Hemp Fiber: Hemp fiber composites have also shown promising sound absorption properties, with some research indicating performance levels comparable to or even exceeding those of certain synthetic fibers.[2] A hemp-wool-hemp fiber sandwich composite achieved a peak sound absorption coefficient of 0.817 at 500 Hz.22 The good acoustic absorption reported for hemp fiber in acoustic panels highlights its potential as a high-performance natural sound-absorbing material.[38] Exploring the acoustic characteristics of coir-hemp hybrid composites could lead to the development of highly effective and environmentally friendly noise control solutions.[38]

Date Palm Fiber: Research on date palm fiber has revealed its potential as a sound-absorbing material, particularly in the intermediate to high-frequency ranges.1 Studies have shown sound absorption coefficients between 0.81 and 0.84 at 2000 Hz for a 40 mm thick sample.[26] Given its availability in certain regions, date palm fiber presents another viable option for sustainable acoustics, potentially in conjunction with coir to create hybrid materials with tailored acoustic performance across different frequencies.[40]

Other Natural Fibers: A wide array of other natural fibers, including jute, banana, sisal, rice husk, tea leaf, sugarcane bagasse, wood, and wool, have been explored for their sound absorption properties. [25] Hybridization of different natural fibers, such as sugarcane and banana fibers, has also shown improved sound absorption compared to individual fibers. [21]

7. STRATEGIES FOR ENHANCING THE ACOUSTIC PERFORMANCE OF COIR COMPOSITES

To further promote the use of coir-based materials in sustainable acoustics, ongoing research should focus on optimizing their sound absorption properties. Several promising strategies can be explored:

Optimizing Coir Fiber Properties: Modifying the inherent properties of coir fibers can significantly impact the acoustic performance of the resulting composites. As suggested in the modified article, investigating the influence of coir fiber density, diameter, and orientation within composite boards is crucial. For instance, reducing the average fiber diameter could potentially enhance sound absorption, especially at lower frequencies, by increasing the material's tortuosity and airflow resistance.[28] Additionally, controlling the orientation of fibers during the manufacturing process to create a more random network might improve sound energy dissipation. Furthermore, exploring various treatments for coir fibers, such as alkali treatment using NaOH, has been shown to remove impurities and reduce fiber diameter, leading to enhanced sound absorption across low and high-frequency ranges, achieving an average α coefficient of 0.9 and above.24

Hybrid Material Development: Combining coir with other materials known for their sound-absorbing capabilities offers a promising avenue for enhancing acoustic performance. As suggested in the modified article, incorporating locally available natural fibers like pineapple leaf fiber, which exhibits superior sound absorption in certain frequency ranges [24], into coir composites could lead to synergistic effects and improved broadband absorption. Similarly, the inclusion of recycled materials such as rubber [1] or vermiculite [44] within the coir matrix could modify the composite's density and porosity, potentially enhancing its sound absorption characteristics, particularly at lower frequencies. [42] The strategic introduction of air gaps behind coir-based panels in hybrid systems has also been shown to significantly improve sound absorption, especially in the low-frequency range.[2]

Structural Modifications: Altering the physical structure of coir-based acoustic materials can also be an effective way to enhance their sound absorption. The use of multi-layered designs, where layers with different densities or porosities are combined, could be tailored to absorb sound across a wider frequency spectrum.15 Varying the overall thickness of the composite boards can also influence their acoustic performance, with thicker materials generally exhibiting better sound absorption, especially at lower frequencies.1 Additionally, exploring the incorporation of perforated plates into coir-based acoustic panels could create Helmholtz resonance effects, enhancing sound absorption at specific target frequencies.[46]

Scope for future work:

Future work should focus on optimizing microstructural parameters, expanding hybridization strategies, enhancing environmental resistance, and demonstrating industrial scalability through lifecycle and performance-based assessments.

CONCLUSION

With increasing emphasis on sustainable construction, this study highlights the potential of Low-Density Coir Composite Boards (LDCCBs) as viable alternatives to synthetic sound absorbers. LDCCBs demonstrated an average Sound Absorption Coefficient (SAC) of 0.65 in the mid-frequency range (500–2000 Hz), verified through ASTM E1050–12 testing. This performance surpasses traditional coir matting (SAC: 0.56) and aligns closely with untreated coconut fiber (SAC: 0.66 at 2000 Hz), owing to the high porosity and fiber connectivity of the material.

When compared with kenaf, which achieved a higher peak SAC of 0.90 at 2000 Hz, LDCCBs offer greater durability, lower density (300–400 kg/m^3), and improved resistance to environmental degradation. While kenaf excels acoustically, its higher density (837.5 kg/m^3) and susceptibility to wear make LDCCBs more suitable for sustainable applications, especially when thermal insulation (0.098 W/m·K) and mechanical stability are also priorities.

Hybrid composites, such as coir-jute blends (70:30 ratio), extended the acoustic range into higher frequencies (SAC: 0.72 at 5000–6300 Hz), surpassing LDCCBs' mid-frequency focus. This suggests that the limitations of coir in high-frequency absorption can be effectively mitigated through hybridization and microstructural tuning—like reducing fiber diameter—to enhance performance in broader acoustic ranges.

Comparative analysis with other agro-residue panels confirms that increased density diminishes acoustic performance. A rise from 300 to 500 kg/m^3 caused a 15% SAC reduction, unlike LDCCBs which maintain favorable porosity without compromising strength. Furthermore, coir's regional availability, biodegradability, and lower environmental footprint offer distinct advantages over sugarcane bagasse and PALF composites.

This research establishes Low-Density Coir Composite Boards (LDCCBs) as highly effective and sustainable alternatives to conventional synthetic sound absorbers. The boards demonstrated strong acoustic performance, with an average Sound Absorption Coefficient (SAC) of 0.65 in the mid-frequency range (500–2000 Hz), attributed to their high porosity and interconnected fiber network. Compared to traditional coir matting and untreated coconut fiber, LDCCBs showed comparable or superior absorption while offering additional advantages in terms of durability and environmental resistance.

The study further confirmed that LDCCBs maintain favorable acoustic efficiency even at lower densities (300–400 kg/m^3), unlike other agro-residue panels where increased density reduces performance. With added thermal insulation capacity (0.098 W/m·K), LDCCBs offer multifunctional benefits for building applications. Their regional availability, biodegradability, and low carbon footprint strengthen their position as a practical solution for sustainable construction. Based on these findings, LDCCBs are highly suitable for diverse applications such as acoustic panels, insulation boards, ceiling tiles, and other green building components. .:

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