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Acoustic Study of Reinforced Coconut Fiber Wall Panels

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Abstract

Studies in acoustics began with microscopic air pressure waves that are perceptible to the human ear. In modern acoustics, structural vibrations are often taken into consideration. This paper explores a sustainable approach to reducing noise pollution in buildings by incorporating coconut fiber into reinforced wall panels. The study examines the acoustic performance of these panels, which employ coconut fiber as a partial replacement for sand. Composite materials were made by blending coconut fiber with traditional construction materials, maintaining a cement-to-sand ratio of 1:2.75 and a water-cement ratio of 0.6. The study investigates panels with 0%, 3%, 6%, and 9% coconut fiber content to determine their mechanical qualities and sound absorption capacities. Different reinforcing techniques were also investigated to improve structural integrity while retaining acoustic efficiency. The process consists of material testing and acoustic measurements. The findings illustrated the viability of employing coconut fiber in building construction materials for noise reduction purposes, promote sustainable practices in the construction sector, and contribute to environmental preservation and resource efficiency. The method included ISO standard material testing and acoustic measurement, such as sound absorption coefficient and transmission loss evaluations. The study found that panels with 9% coconut fibre content produced improvement in sound absorption compared to 6%, 3% and 0% panels while maintaining appropriate mechanical strenght, indicating the potential of employing coconut fibre in construction material for noise reduction.

1. Introduction

Noise pollution can lead to increased stress, sleep disruption, decreased productivity, and even long-term health issues [1]. To mitigate the adverse effects of noise pollution, traditional noise barriers have been employed, often constructed from materials such as concrete, steel, or wood. However, these conventional materials have limitations, including environmental concerns, high production costs, and a lack of sustainability [2]. Natural fiber materials have gained attention for their potential to address these concerns. Due to its fibrous and porous nature, coconut fiber exhibits distinct acoustic properties.

Current noise reduction measures in Malaysian structures frequently rely on standard materials, which may not provide enough acoustic insulation [3]. Despite Malaysia's abundance of coconut fiber, there has been little systematic investigation and practical implementation of its potential as a reinforcing material in building, particularly in the context of noise reduction. This underutilization of a locally accessible, sustainable resource represents a missed opportunity to address both environmental and acoustic issues in the building industry [4].

Coconut fibers possess acoustic qualities that make them suitable for sound absorption applications, such as acoustic panel manufacturing. Coconut fibers are hydrophilic, which means they can absorb and hold water. Due to these mechanical qualities, coconut fiber-reinforced mortar offers improved flexural behavior and more impact resistance than ordinary mortar [5].

Acoustic partition wall panels are specifically designed to provide sound absorption and noise control within a space [6]. The thickness and density of the acoustic material employed in the panels determine their efficacy. Thicker and denser panels generally provide better sound absorption [7]. Acoustic partition walls usually have a Noise Reduction Coefficient (NRC) value. The NRC evaluates a material's ability to absorb sound at various frequencies. Acoustic walls aim for higher NRC values, which indicate improved absorption.

The sound absorption coefficient for coconut fiber varies with frequency. Sound absorption coefficients are usually reported for frequencies of 125, 250, 500, 1000, and 2000 Hz [8]. The bigger the number of coefficients, the higher the absorbance. This study examines the optimal method for producing reinforced wall panels from coconut fiber. This study investigates the acoustic properties of a coconut fiber composite for sound insulation in reinforced wall panels. This research focuses on coconut fiber material, which was investigated in the lab utilizing ASTM E1050-98. Acoustic testing was conducted to evaluate the noise absorption and insulation capabilities of the coconut fiber-reinforced wall panels.

Coconut fiber has a cylindrical structure which has diameters ranging from 10 μm to 460 μm. Coconut fiber structure has a hollow section that attaches a range of 200 to 300 elementary fibers. Mostly, the hollow cylindrical structure for individual fiber cells must have a diameter of 10 μm to 20 μm, and the length must be in a range of 1 mm [9]. Coconut fibers offer acoustic qualities that make them suitable for sound absorption applications, such as acoustic panel manufacturing, as they are categorized in the hydrophilic group. Coconut fiber is among the finest natural fibers because it contains up to 30% lignin, which makes it more durable and elastic by providing compressive properties to plant tissue and its separate fibers to defend itself from physical and chemical destruction. Table 1 shows the chemical properties of coconut fiber [10].

Coconut fiber has excellent thermal insulating characteristics. It is used to provide insulation in construction and other uses in a variety of items. Furthermore, coconut fiber has the highest strength of any natural fiber. Due to these mechanical qualities, coconut fiber-reinforced mortar offers improved flexural behavior and more impact resistance than ordinary mortar [11]. Composites containing more than 9% coconut fiber cannot create adequate workability due to a shortage of water and the absorbent nature of natural fiber [12]. Flexural strength and water absorption in a coconut fiber-reinforced mortar may reach up to 50% and 33% respectively [13]. For the term' durability,' it may be advantageous to use less coconut fiber. Table 2 displays the physical properties of coconut fiber [14].

The objectives of this study are to (1) identify the optimal mix proportion in terms of cement and sand ratio, (2) to determine the physical properties of the mix proportion following the substitution of coconut fiber, and (3) to analyze the viability of coconut fiber for sound absorption material.

2. Material and Method

2.1 Material Preparation

Fig 1 displays the approach for developing acoustic panels using coconut fiber, along with testing results. Fig 2 illustrates the development of composite samples using coconut fiber in varying amounts. The samples were created with 0% coconut fiber, 3%, 6%, and 9% coconut fiber. The sample used was 100 mm in diameter in the form of a cylinder mould, as in Fig. 2. The samples underwent physical, thermal, and acoustic testing to assess scanning electron microscopy, thermal conductivity, sound absorption, and noise reduction.

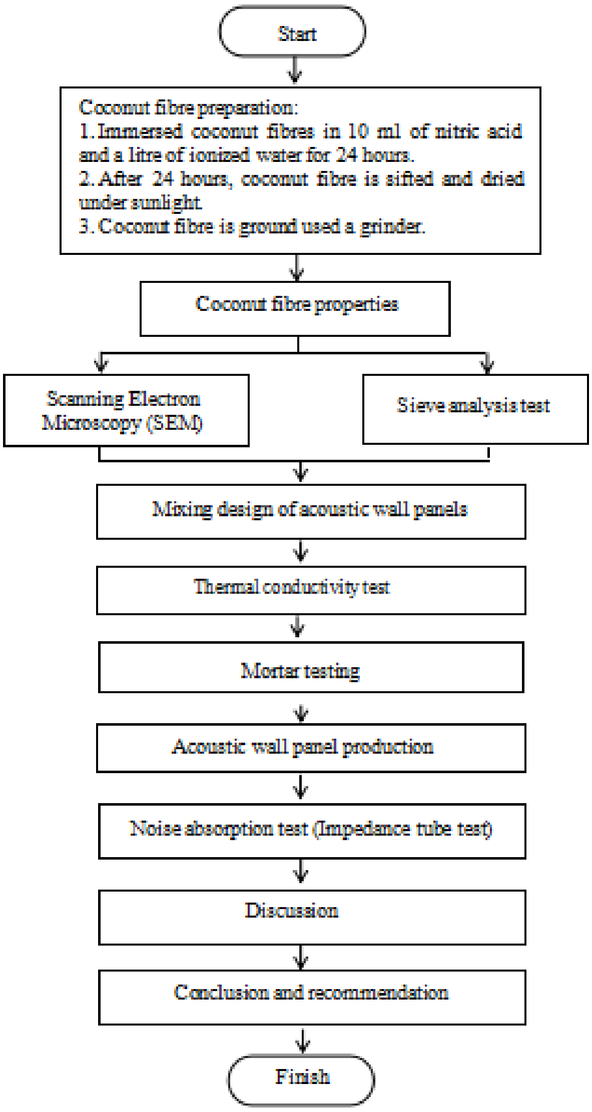

Fig. 1 *Research of flowchart*

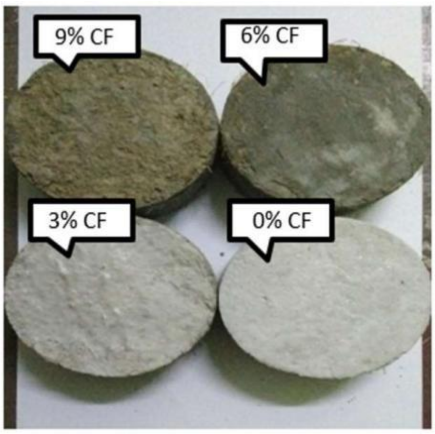

Fig. 2 *The size of the samples of 100 mm in diameter*

2.2 Mixing Design on Acoustic Wall Panel

The mixing design for acoustic wall panels is designed to achieve the desired acoustic performance by utilizing specific materials and proportions. According to Malaysian standards, the mortar mix is made using the

Department of Environment's regular mixing design process, adhering to ASTM C109 methods [15]. The materials used include Ordinary Portland Cement (OPC), coconut fiber (CF), sand, and water. The cement-sand ratio is 1:2.75, and the water-cement ratio is 0.6. Four types of mortar mixes are created with varying CF content: 0%, 3%, 6%, and 9%. The proportions are detailed in Table 1.

Table 1 *Division of mixture proportion*

Percentage coconut fiber replaced (%)	Fine aggregate (g)	Coconut fiber (g)	Cement (g)	Water (g)
0	1925	0	700	420
3	1867	58	700	420
6	1809	116	700	420
9	1751	174	700	420

2.3 Scanning Electron Microscopy Test

After the sample has been prepared, the Scanning Electron Microscopy (SEM) experiment is conducted. Scanning Electron Microscopy (SEM) is a sophisticated technique that examines the surface appearance and structure of materials at high magnification. SEM provides extensive information on the fibre's surface properties, arrangement, and other structural traits when applied to the coconut fibre.

2.4 Thermal Conductivity Test

A thermal conductivity test measures a material of their ability to conduct heat, crucial for assessing the thermal performance of construction materials. This study used SOLTEQ thermal conductivity equipment, which features a hot plate on top and a cold plate below with cooling water to maintain a temperature gradient. A clamping tool ensures proper specimen contact for accurate heat transfer measurements. The heat flux reading and temperature differential data are used to calculate thermal conductivity. This test is crucial in the building industry for evaluating heat transfer through materials [16]. Tests were conducted on a sample with a size of 300 mm x 300 mm x 30 mm [17]. The thermal conductivity coefficient may be computed using the following equations:

$$Thermal\ Conductivity, k = \frac{qx}{A\ (\Delta T)}\ [W/m°C] \quad (1)$$

Where, k is thermal conductivity, q is amount of heat transferred, x is thickness of material, A is area of the surface, ΔT is the difference in temperature.

2.5 Noise Absorption Test

Sound coefficients for the absorption are measured using an impedance tube in compliance with BS EN ISO 10534-Part 2 regulation [18]. This approach displays the fraction of sound energy absorbed by a material, with values ranging from 0 (no absorption, total reflection) to 1 (complete absorption, no reflection) [19].

3. Results and Discussion

3.1 Scanning Electron Microscopy (SEM) Test

The study examines the microstructure of coconut fiber-reinforced mortar samples using Scanning Electron Microscopy (SEM) at a magnification of 1000x with a 100 µm scale bar. From Fig 3, treated coconut fiber exhibits elongated, fibrous structures. The control sample, which contains 0% coconut fiber, exhibits irregular surface textures with sharp edges, as no coconut fiber was added. For 3% coconut fiber, the microstructure shows fibers embedded within the cement and sand matrix, providing reinforcement. For the 3% coconut fiber sample, the concentration of coconut fibers is higher, resulting in a more densely packed appearance within the matrix, which may potentially improve mechanical properties. Lastly, the 9% coconut fiber sample exhibits even higher fiber content and tighter packing within the matrix compared to the 6% sample, suggesting further enhancement of its mechanical characteristics. The SEM results align with previous findings, indicating consistent microstructural features across various studies [15].

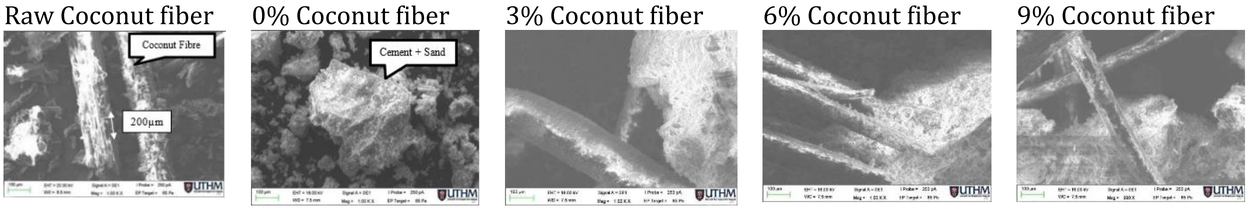

Fig 3. *SEM result for raw coconut fiber, and four different coconut fiber percentages*

3.2 Thermal Conductivity Test

The study investigates the effect of incorporating coconut fiber (CF) on the thermal conductivity of mortar. Pure mortar, which is 0% coconut fiber, has a thermal conductivity of 0.585 W/m°C, typical for dense, solid materials like cement, sand, and water. Adding 3% coconut fiber reduces thermal conductivity to 0.441 W/m°C. Coconut fiber's lower thermal conductivity disrupts heat flow, improving insulation. With 6% coconut fiber, the thermal conductivity further decreases to 0.356 W/m°C, thereby enhancing the insulating properties. At 9% coconut fiber, thermal conductivity drops significantly to 0.262 W/m°C, indicating a substantial improvement in insulation. The normal thermal conductivity for mortar wall panels is around 0.703 W/m°C [20]. The study's results align with previous findings, showing that increasing coconut fiber content decreases thermal conductivity, improving insulation [21] [22]. According to [23]. coconut fibers have lower heat conductivity than typical mortar materials, enhancing the composite's insulating properties, which is beneficial for thermal insulation applications.

3.3 Sound Absorption Test

The study investigates the effects of coconut fiber (CF) content on the density and sound absorption properties of mortar. Increasing CF content reduces the mix's density, replacing denser components with lightweight fibers. For the 0% coconut fiber, the lowest sound absorption coefficient across all frequencies, as measured by the NRC, is 0.45. For 3% coconut fiber, there is a moderate improvement, with an NRC of 0.48. Next, the percentage of 6% coconut fiber has further increased, with the NRC being 0.58. Lastly, 9% coconut fiber is the most prevalent sound absorption coefficient, with an NRC of 0.68. Higher CF concentrations improve sound absorption, especially at higher frequencies. The recommended NRC values for coconut fibre are 0.60 to 0.80 for noise reduction, speech intelligibility, and privacy enhancement [24]. The results align with previous findings, showing that increased CF content enhances sound absorption and correlates with lower density, making the material suitable for sound insulation applications [25].

4. Conclusion

In conclusion, this study examines the benefits of incorporating coconut fiber (CF) into cement mortar for use in building construction. The sample with 9% CF is deemed optimal, offering the best balance of properties despite reduced workability. It achieves the lowest thermal conductivity (0.262 W/m°C) and, based on previous research, the best water absorption performance. For the physical properties, decreases with increased CF content, improving insulation. The control sample (0% CF) has the highest thermal conductivity (0.585 W/m°C), while 9% CF has the lowest (0.262 W/m°C). Increases with CF content. For the sound absorption, it is improving with coconut fiber content. The control sample has the lowest NRC (0.45), while 9% CF has the highest (0.68), indicating enhanced acoustic performance. Incorporating coconut fiber into cement mortar enhances thermal insulation and sound absorption, addressing production costs and sand depletion while promoting sustainability and resource conservation. The 9% CF mix is optimal for energy-efficient and comfortable buildings.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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