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EVALUATION OF ENVIRONMENTALLY FRIENDLY SOUND ABSORPTION MATERIALS MADE FROM AGRICULTURAL WASTE FIBERS

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Abstract. Agriculture, the world's largest industry, significantly contributes to the GDP of many developing countries, employing over a billion people and producing 1.3 trillion dollars' worth of food annually. Despite its economic impact, agriculture generates a substantial 140 billion metric tons of waste globally, necessitating sustainable waste management to reduce CO_2 emissions. Natural agricultural waste fibers like coconut fiber, groundnut shell, and sugarcane fiber are explored as eco-friendly alternatives for sound insulation to combat noise pollution. The research investigates their application as sustainable sound-absorbing materials, determining sound absorption coefficients based on the ISO 10534-2 standard. Results indicate coefficients ranging from 0.55 to 0.95 within the 160 Hz to 5000 Hz frequency range. Sugarcane fiber exhibited the most favorable coefficients, reaching 0.95 at 1600 Hz and 0.46 at 800 Hz, followed by coconut fiber with a range of 0.84 at 4000 Hz to 0.57 at 160 Hz. This research highlights the potential of agricultural waste fibers in addressing environmental concerns associated with agricultural waste while providing sustainable solutions for sound absorption.

Keywords: sound absorption, agricultural waste, natural fiber, noise pollution.

1. Introduction

In recent years, rapid urbanization, transportation, and industrialization have become the prime sources of noise pollution in the world. Noise pollution has become a serious environmental problem and causes different types of health problems such as hearing loss, cardiovascular diseases, and sleep disorders (Malawade et al., 2022). As noise problems intensify, there is a growing demand for improved environmental conditions and a more varied lifestyle. There is a need for advanced sound-absorbing materials with broader frequency absorption capabilities (Samsudin et al., 2016).

Growing public concern about noise pollution has led to an increased demand for sound absorption materials as effective noise barriers (Jariwala et al., 2017). These materials play a crucial role in softening the acoustics of enclosed spaces by diminishing sound wave energy and reducing the amplitude of reflected waves. The widely used sound absorption materials in the market, such as glass-fiber or mineral fiber, possess low thermal conductivity and high sound absorption coefficients but have negative environmental impacts during production and potential effects on human health (ALRahman et al., 2013). Natural fibers have received a lot of interest mostly because they have ecological benefits and acoustical qualities. Acoustic absorbers made of natural material are consequently appealing because of their biodegradability and sustainability to help the "Green environmental movement". As an alternative, natural fibers derived from agricultural wastes, coconut fiber, sugarcane fiber, and groundnut shell, can be utilized as affordable, biodegradable, and recyclable sound absorption materials (Gboe & Grubliauskas, 2023).

Over the past 50 years, agricultural production has more than tripled due to expanded soil use, technological advancements from the green revolution, and population growth. The global output is now approximately 23.7 million tons of food per day, placing significant strain on the environment and adversely affecting soil, air, and water resources. This environmental impact poses risks to population health and ecosystem sustainability, with agriculture accounting for 21% of greenhouse gas emissions. Recognizing this crisis, a shift toward more sustainable development in the agricultural production system has emerged in recent years, necessitating substantial changes (Duque-Acevedo et al., 2020). Agricultural Waste Management is installed to manage and control the use of byproducts of agricultural production in a manner that sustains or enhances the quality of air, water, soil, plant, and animal resources (Obi et al., 2016).

Coconut waste, a byproduct of coconut cultivation, is abundant globally, with an annual production of 62.5 million tons in over 90 countries, particularly in tropical regions like Thailand, India, Nigeria, and other African nations (Hosseini Fouladi et al., 2010). The large cultivation and expansion of coconut contribute to the higher generation of coconut waste such as coconut husk, shell, frond, fiber, and pulp (Azeta et al., 2021). The sugar industry generates approximately 279 million metric tons of sugarcane waste each year worldwide, with South Africa contributing over 1.353 million metric tons annually, more than 50% of which is recovered in cogeneration facilities (Putra et al., 2013). Improper disposal of sugarcane waste poses environmental and health risks due to its solid, semi-solid, and liquid nature (Ungureanu et al., 2019). Groundnut shells, a byproduct of groundnut processing, represent about 30% of the total weight of the legume, processing, represent about 30% of the total weight of the legume, producing around 11 million tons of waste annually worldwide (Mandala et al., 2023). Despite ongoing development in their utilization, groundnut shells, rich in cellulose, hemicellulose, and lignin, hold promise as a source of cellulosic, hemicellulose, and lignin, hold promise as a source of cellulosic biomass for energy production (Rubino et al., 2019) The research aims to investigate the sound absorption coefficient of agricultural waste fiber materials, namely coconut fiber, groundnut shell, and sugarcane fiber. The goal is to present these materials as eco-friendly alternatives for building acoustic sound-absorbing panels. These panels, when utilized, will reduce noise levels in various settings such as offices, libraries, cafes, etc., contributing to a more acoustically comfortable environment.

2. Materials and methods

2.1. Materials preparation

Groundnut shell material was sourced from a groundnut farm in Liberia's central area (Bong County). To ensure cleanliness, the raw materials underwent a cleaning process using pressured water, removing dust and contaminants. Hand crushing was employed to convert the shells into chips, and subsequent sorting through sieves was done to achieve the desired size. Sugarcane fiber material was obtained from a local kin juice production site in Liberia after extracting the juice and nutritious elements from sugarcane stalks. The fibers were separated and trimmed to a shorter length. Coconut fiber was acquired from coconut husks at a local coconut farm, where street vendors purchase coconut for selling in different parts of the city.

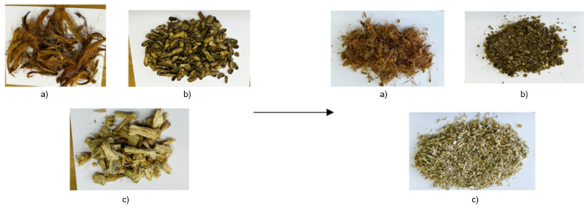

Figure 1. Raw agriculture wastes materials used in the study: a – coconut fiber; b – groundnut shell; c – sugarcane fiber

The materials were exposed to the sun for 8 hours for two days to dry at 25 °C temperature and then they were heated at low temperatures (165 °C) to track the moisture content and frequently record the weight of materials, the moisture content was monitored to ensure the materials were dry. Determining the sound absorption coefficient using the impedance tube method, three sample types of each of the materials (coconut fiber, groundnut shell, and sugarcane fiber) were prepared. The samples were prepared as follows:

- Sample 1: Density of 2.39 kg/m^3 and thickness of 5 cm.
- Sample 2: Density of 3.19 kg/m^3 and thickness of 5 cm.
- Sample 3: Density of 3.99 kg/m^3 and thickness of 5 cm.

The systematic variation in the mass and thickness of the samples provides a comprehensive exploration of the sound absorption characteristics of agricultural waste fiber materials.

2.2. Determination method of sound absorption coefficient in impedance tube

In this study, the sound absorption coefficient was determined according to the ISO 10534-2 standard, utilizing the transfer function method and the two-microphone technique specified by the International Organization for Standardization (ISO, 1998). The research utilized a tube with a 30 mm inner diameter and rigid backing for samples, measuring impedance in the range of 160 to 5000 Hz and presenting results in 1/3 octave bands. Microphones No. 1 and No. 2 were used for low frequencies (160–1000 Hz), and No. 2 and No. 3 for high frequencies (1000–5000 Hz), with specific distances between microphones. Data was collected using a data acquisition device connected to a computer interface in a controlled laboratory environment of 25 °C and 50% relative humidity (Ružickij & Grubliauskas, 2023).

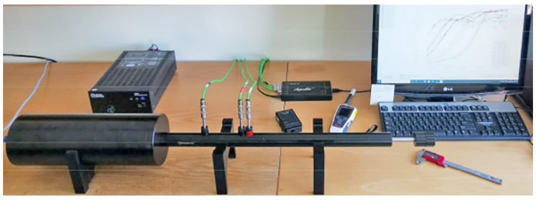

Figure 2. Sound absorption coefficient measurement impedance tube setup

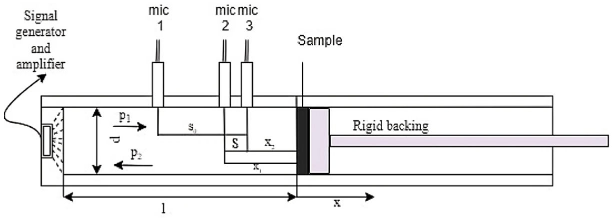

Figure 3. Schematic diagram of impedance tube

As per the procedure, the initial step involves establishing the transfer function. The transfer function, namely H_{12}, and H_{23}, are derived by calculating the ratio of pressure captured by microphone pairs No. 1 and No. 2, and No. 3, across the entire frequency spectrum (ISO, 1998; Ružickij & Grubliauskas, 2023).

$$H_{12} = \frac{P_{2(f)}}{P_1(f)},\quad H_{23} = \frac{P_{3(f)}}{P_2(f)}; \tag{1}$$

$$H_{I(160-1000\,Hz)} = \frac{P_2 I}{P_1 I} = e^{-jk_o(x_{12}+x_{23})}; \tag{2}$$

$$H_{I(100-5000\,Hz)} = \frac{P_3 I}{P_2 I} = e^{-jk_o(x_{23})}; \tag{3}$$

$$H_{R(160-1000\,Hz)} = \frac{P_{2R}}{P_{1R}} = e^{-jk_o(x_{12}+x_{23})}; \tag{4}$$

$$H_{R(100-5000\,Hz)} = \frac{P_{3R}}{P_{2R}} = e^{-jk_o(x_{23})}. \tag{5}$$

Afterwards, the sound reflection coefficient is determined from Eq. (2) and Eq. (3) (ISO, 1998)

$$R_{(160-1000Hz)} = \frac{H_{12} - H_{I(160-1000\,Hz)}}{H_{R(160-1000\,Hz)} - H_{12}}\, e^{2jk_o(x_{12}+x_{23}+x_{35})}; \tag{6}$$

$$R_{(1000-5000Hz)} = \frac{H_{23} - H_{I(1-5\,kHz)}}{H_{R(1-5\,kHz)} - H_{13}}\, e^{2jk_o(x_{23}+x_{35})}, \tag{7}$$

where P_1, P_2, and P_3 represent the pressures captured by the microphones in pascals (Pa); H_I stands for the incident wave transfer function; H_R denotes the reflected wave transfer function; x_{12} signifies the distance between microphones No. 1 and No. 2 in millimeters (mm); x_{23} represents the distance between microphones No. 2 and No. 3 in mm; x_{35} is the distance between No. 3 and the sample in mm; R signifies the sound reflection coefficient; j represents the complex number, and k_o stands for the wave number. In the last step, the sound absorption coefficient is determined (Eq. (5) (ISO, 1998)):

$$\propto = 1 - |R|^2, \tag{8}$$

where R – sound reflection coefficient.

The sound absorption coefficient range is from 0 to 1, without dimensions.

3. Experimental results and discussion

The experiment generated a thorough report, data on sound absorption coefficients for raw materials, along with information on the density, thickness, and frequency range. An examination of the findings was conducted to understand how these factors influence the sound absorion properties demonstrated by natural fiber materials. The goal of this research was to uncover the comex interplay between material composition, physical characteristics, and acoustic performance of the raw material, offering valuable insight into the determinants of sound absorption in natural fibers.

3.1. Coconut Fiber (CF)

– Coconut Fiber (CF 75 kg/m^3, 100 kg/m^3 & 125 kg/m^3 in 5 cm mold)

Figure 4 displays the experimental outcomes for coconut fiber specimens at three distinct densities: 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3. The measurement was carried out across the frequency spectrum ranging from 160 Hz to 5000 Hz.

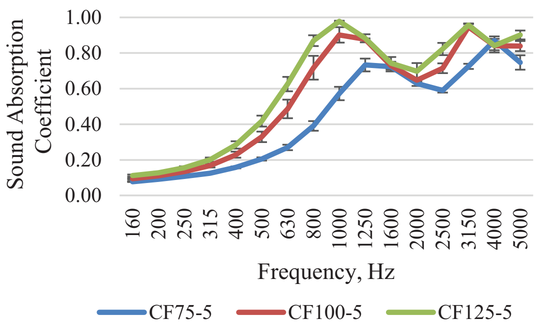

Figure 4. Results of experimental impedance tube measurement coconut Fiber (CF 75 kg/m^3, 100 kg/m^3 & 125 kg/m^3 in 5 cm mold)

Three samples with densities of 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3 demonstrate varied sound absorption coefficient behaviors across different frequency ranges. For the 75 kg/m^3 sample, the absorption coefficient peaks at 0.57 at 1000 Hz for lower frequencies, 0.73 at 1250 Hz for medium frequencies, and 0.84 at 4000 Hz for higher frequencies. For the 100 kg/m^3 sample, maximum absorption occurs between 2000 Hz and 3150 Hz, peaking at approximately 0.79 at 2500 Hz. In the lower frequency range, absorption peaks at 0.72 at 800 Hz, while in the medium frequency range, it peaks at 0.90 at 1000 Hz and in the higher frequency range, absorption reaches its maximum at 0.96 at 3150 Hz.

For the 125 kg/m^3 sample, maximum absorption occurs between 2000 Hz and 3150 Hz, with the highest coefficient of approximately 0.98 at 1000 Hz. Peak absorption remains constant at 0.98 at 1000 Hz for lower frequencies, while in the medium frequency range, it peaks at 0.88 at 1250 Hz. In the higher frequency range, absorption peaks at 0.96 at 3150 Hz. Each sample shows unique frequency-dependent absorption characteristics, with varying peak absorption values and frequencies across the tested density ranges.

3.2. Groundnut Shell (GS)

– Groundnut Shell (GS 75 kg/m^3, 100 kg/m^3 & 125 kg/m^3 in 5 cm mold)

Figure 5 shows experimental results for groundnut shell samples with three different densities: 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3. The measurements were conducted within the frequency range of 160 Hz to 5000 Hz.

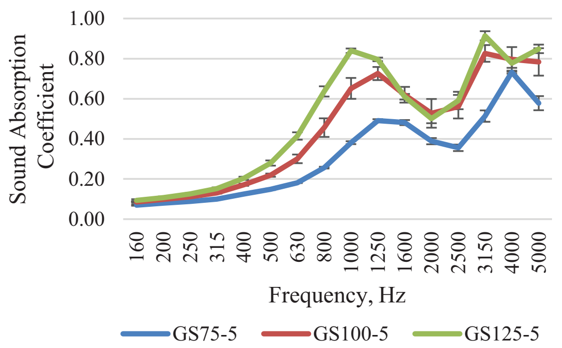

Figure 5. Results of experimental impedance tube measurement Groundnut Shell (GS 75 kg/m^3, 100 kg/m^3 & 125 kg/m^3 in 5 cm mold)

For three samples with densities of 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3, the sound absorption coefficient peak in the frequency range 3150 Hz to 5000 Hz.

For the 75 kg/m^3 sample, the highest absorption value is 0.73 at 4000 Hz, with varying peals across different frequency ranges: 0.38 at 1000 Hz for lower frequencies and 0.49 at 1250 Hz for medium frequencies. For the 100 kg/m^3 sample, the maximum absorption is approximately 0.83 at 3150 Hz, with peaks of 0.46 at 800 Hz for lower frequencies and 0.73 at 1250 Hz for medium frequencies. For the 125 kg/m^3 sample, the highest absorption value at 0.91 at 3150 Hz, with peaks of 0.84 at 100 Hz for lower frequencies and 0.80 at 1250 Hz for medium frequencies. In the higher frequency range, all samples exhibit maximum absorption, with values of 0.73 at 4000 Hz for the 75 kg/m^3 sample, 0.83 at 3150 Hz for the 100 kg/m^3 sample, and 0.91 at 3150 Hz for the 125 kg/m^3 sample.

3.3. Sugarcane Fiber (SF)

– Sugarcane Fiber (SF 75 kg/m^3, 100 kg/m^3 & 125 kg/m^3 in 5 cm mold)

Figure 6 shows experimental results for Sugarcane Fiber samples with three different densities: 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3 in 5 cm mold. The measurements were conducted within the frequency range of 160 Hz to 5000 Hz.

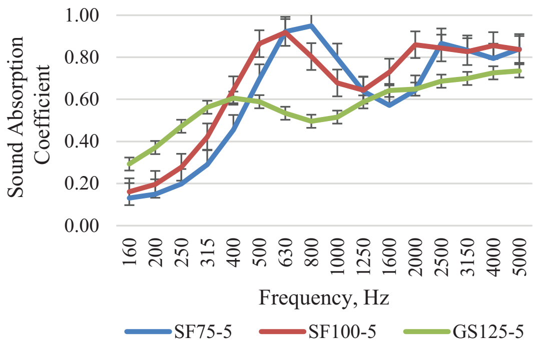

Figure 6. Results of experimental impedance tube measurement Sugarcane Fiber (SF 75 kg/m^3, 100 kg/m^3 & 125 kg/m^3 in 5 cm mold)

For three samples with densities of 75 kg/m^3, 100 kg/m^3, and 125 kg/m^3, the sound absorption coefficients exhibit different patterns across frequency ranges.

For the 75 kg/m^3 sample, maximum absorption occurs in the range of 630 Hz to 800 Hz, reaching approximately 0.95 at 800 Hz. Peak absorption is consistent across lower frequencies, with 0.95 at 800 Hz, while in the medium frequency range, it peaks at 0.64 at 1250 Hz. In the higher frequency range, absorption peaks of 0.87 at 2500 Hz. For the 100 kg/m^3 sample, maximum absorption occurs between 500 Hz to 800 Hz, with a peak of approximately 0.92 at 630 Hz. Peak absorption remains consistent across the lower frequency range at 0.92 at 630 Hz, while in the medium frequency range, it peaks at 0.86 at 2000 Hz. In the higher frequency range, absorption peaks at 0.86 between 4000 Hz. For the 125 kg/m^3 sample, maximum absorption occurs in the range of 2500 Hz to 5000 Hz, reaching about 0.74 at 5000 Hz. Peak absorption in the lower frequency range is at 0.61 at 400 Hz, while in the medium frequency range, it peaks at 0.68 at 2500 Hz. In the higher frequency range, absorption peaks at 0.74 at 5000 Hz. Each sample exhibits unique frequency-dependent absorption characteristics, with different peak absorption values and frequencies across the tested density ranges.

4. Conclusions

The study examined the sound absorption coefficient of natural agricultural waste fiber materials (coconut fiber, groundnut shell, and sugarcane fiber), finding promising results. Sugarcane fiber with a density of 75 kg/m^3 showed the highest average absorption coefficient (0.86) at 800 Hz, primarily in the low-frequency range. Coconut fiber with a density of 125 kg/m^3 ranked second, with an average coefficient of 0.81 at 4000 Hz, mainly in the high-frequency range. Groundnut shell exhibited the lowest coefficient (0.73) at medium frequencies. These findings suggest this material could serve as an alternative to synthetic ones for sound absorption.

The result evaluates the sound absorption coefficient of the raw material without binder. To explore the sound absorption potential further, using an eco-friendly binder in the sample preparation process with an appropriate mixing ratio is crucial. Adding an eco-friendly binder could enhance the sound absorption properties. Future research aims to conduct a Life Cycle Assessment to comprehensively understand the environmental impact of these materials. understanding of the environmental impact of these materials.

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APLINKAI NEKENKSMINGŲ GARSĄ SUGERIANČIŲ MEDŽIAGŲ, PAGAMINTŲ IŠ ŽEMĖS ŪKIO ATLIEKŲ PLUOŠTO, ĮVERTINIMAS

N. A. GBOE, R. GRUBLIAUSKAS

Santrauka. Žemės ūkis, kaip didžiausia pasaulio pramonė, reikšmingai prisideda prie daugelio besivystančių šalių BVP, įdarbinant daugiau nei milijardą žmonių, ir kasmet pagamina maisto už 1,3 trilijono dolerių. Nepaisant jo ekonominio poveikio, žemės ūkis pasaulyje generuoja 140 milijardų tonų atliekų kiekį, reikalaujantį tvaraus atliekų tvarkymo, siekiant sumažinti CO_2 emisijas. Natūralūs žemės ūkio atliekų pluoštai, tokie kaip kokoso pluoštas, žemės riešutų kevalai ir cukranendrių pluoštas, tyrinėjami kaip ekologiškos alternatyvos garso izoliacijai kovojant su triukšmo tarša. Tyrime nagrinėjama jų, kaip tvarių garsą sugeriančių medžiagų, taikymo galimybė, nustatant garso sugėrimo koeficientus, remiantis ISO 10534-2. Rezultatai rodo koeficientus, kurie kinta nuo 0,55 iki 0,95, 160–5000 Hz dažnių diapazone. Cukranendrių pluošto bandiniai pasižymėjo aukščiausiomis vertėmis (0,95), esant 1600 Hz dažniui, kokoso pluoštas (0,84), esant 4000 Hz dažniui. Šis tyrimas rodo žemės ūkio atliekų pluoštų potencialą sprendžiant su žemės ūkio atliekomis susijusias aplinkosaugines problemas, kuriant tvarius sprendimus garso sugerčiai.

Reikšminiai žodžiai: garso sugertis, žemės ūkio atliekos, natūralus pluoštas, triukšmo tarša.