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Research Article

An Analysis of Acoustical Absorption Characteristics of Agro-Waste Materials

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Sound level, agro-waste materials, sound attenuation panel, sound absorption coefficient, noise

Abstract: Acoustical materials play several important roles in acoustic engineering, such as industrial noise control, room noise control, studio and automotive acoustics. This study presents research on the sound attenuation properties of recycled agro-waste composite materials. The raw materials used to prepare these composite panels are wastes generated from rice, sugar cane, groundnut, oil palm, and corn. Starch was the matrix material, thereby making the composite fully green. Five sound absorption composite panels were produced for the five categories of agro waste by compression molding method. The sound attenuation capacity of the produced composite panels relayed a quality sound absorption coefficient α ranging from 0.72 – 0.86. An increase in the thickness of the composite panels resulted in a lowering sound absorption coefficient, which indicates that thickness is an important factor in determining the sound attenuation capacity of agro-waste-based composites. The agro-waste material approach in sound control was effective, cost beneficial and offers an environmentally friendly solution to sound control.

1. Introduction

Noise emanates from different sources, such as household devices, residential generators, machines, automobiles, aircraft, and commercial and industrial activities [1-4]. Technological innovations, industrial growth and urban development are continually adding to the variety of noise-polluting devices and activities with an increase in the recorded acoustic problem [1][5]. Studies showed that exposure to noise affects people more than other environmental stimuli [5]. The impact is being intensified daily, leading to the increasing need for noise prevention and control [6-10]. Many studies have identified the sources of noise pollution, the causation factors and the effects on human populations and the environment [11-14]. Once noise levels are measured, the identification and rank order of the noise sources responsible for the high-intensity noise level is determined, and the required reductions are afterwards ascertained [15]. Noise reduction to create a healthy acoustic environment is crucial for human psychological well-being and quality of life [16][17]. Acoustical materials play vital roles in acoustic engineering, such as industrial noise control, room control, studio and automotive acoustics.

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Noise transmission loss or reduction is an approach to absorbing sound spontaneously by converting part of the sound energy to a small amount of heat in the intervening object (the absorbing material) rather than transmission or reflection of the sound [18-20]. The absorbing material attenuates the sound pressure incident on it and reduces the amplitudes of the transmitted and reflected sound pressure waves, resulting in a reduced sound pressure level on the opposite side of the absorbing material [3-4][21]. The sound attenuation capacity of any material depends on the material impedance - determined by knowing the attenuation coefficient [21-24]. A material that can absorb and relay more sound waves than it reflects is considered a quality sound-absorbing material [25].

Synthetic materials widely used in sound attenuation processes are sourced from petrochemical sources, thus producing significant carbon footprints [26]. A high temperature associated with the manufacturing processes of synthetic materials releases hazardous substances into the environment, consumes more energy and has a higher global warming potential from cradle-to-site installation based on life cycle assessment [26][27]. Synthetic materials, such as mineral wool, glass wool, rock wool, asbestos, polymer foams, fabric filler, polymer fibres, and glass fibre used as sound attenuation panels, are hazardous as such can affect human health in the short-term period and pollute the environment in the long run [28-36]. In addition, the financial implication involved in the handling and processing of sound attenuation panels from synthetic materials is high [31].

Of late, natural materials are becoming alternative quality materials to synthetic materials as they provide good health to a greener environment [31] [37-38]. Zhu et al. [2] added that synthetic materials have a higher environmental impact than natural fibres. Natural fibre materials are directly obtained from animal, mineral, or vegetable sources [37]. Natural fibre materials are bio-degradable, non-harmful and less hazardous to human health and the environment, including low safety risk in their process [22]. Advantages of natural materials in the fabrication process of sound attenuation panels include their renewable nature, non-abrasive, low-cost, abundance, lower carbon footprint, very low toxicity, low density, lightweight, good biodegradability and of less health and safety concerns [4][39-42].

Natural materials are sourced either in their raw, refined or waste state. Research has revealed that wastes are not wasted because they can become sources of natural fibres [31]. The natural fibres obtained from the wastes can be modified into useful products with technologies [31]. Plenty of agricultural waste, such as coconut trunks, rice straw, rice husks, oil palm trunks, empty fruit bunch, corn cob, rice husks, sugar cane bagasse, oil palm fibre and groundnut husk, abound in Nigeria. The sound attenuation property of some of these wastes has been researched. Agricultural waste materials used in noise attenuation found in the works of literature include waste industrial tea-leaf [43], palm oil male flower spikes fibre [44], waste corn husk fibres [45][46], rice straw [47], coconut fibres [29][48], oil palm frond fibre [42] oil palm mesocarp [36], bamboo fibres [49], natural jute [50], tea-leaf fibres [43] and corn cob [51].

From the foregoing literature, it is recommended that more studies be conducted in this research area for alternatives in the different areas of the applications. Additionally, synthetic matrix material was used in most of the previous researches. Thus, there is a need to investigate fully green-environmentally friendly composite materials for sound attenuation. The above background knowledge instigated this study as it was conducted to investigate the properties of recycled agro-waste material green composites in sound attenuation.

2. Materials and method

The agro-waste materials used for producing sound attenuation panels in this research work were corn cob, rice husks, sugar cane bagasse, oil palm fibre and groundnut husk (Figure 1). Starch was used as the matrix material to produce a fully green composite material. Water was used for making the starch pasty (Figure 2).

Corn cob

Rice husk

Groundnut husk

Sugarcane bagasse

Oil palm fibre

Figure 1. Agro-waste materials

Figure 2. Starch

Three sound attenuation panels of thickness 20, 40 and 60 mm were produced from the five agro-waste materials considered in this study. Table 1 shows the proportion composition of the raw materials used to fabricate the sound attenuation panels. The variation in the agro-waste and the starch quantity depended on the materials' mould thickness.

Table 1. The size of each sample for each mould size and the gram of starch added

Agro-waste material	Size of mould (cm)	Agro-waste material (g)	Starch (g)
Corn cob	2	140.13	25
	4	272.24	45
	6	366.81	55
Rice husks	2	223.92	25
	4	435.95	45
	6	631.25	55
Groundnut husk	2	128.15	35
	4	229.47	55
	6	370.36	80
Sugar cane bagasse	2	108.01	45
	4	163.07	65
	6	194.08	70
Oil palm fruit fibre	2	248.41	35
	4	477.05	55
	6	528.05	85

Steps in the production of sound attenuation panel

Materials sourcing: The agro-waste materials were sourced at their disposed point (dumpsites and waste bins), where they have been dumped as waste.

Sun drying: The materials were sundried for one week. Sun drying is a traditional drying method for reducing the moisture content of agro-waste by spreading the material under the sun [52].

Cleaning: Each of the agro-waste materials was winnowed to remove dirt, sand and other foreign materials in the agro-waste

Grinding: This involves breaking large particles of raw materials into small pieces by mechanical means [53].

Sieving: This process involves separating fine particles from larger particles using a sieve of 2.00 mm manually. Sieving gave the same pore size distribution for the materials selected.

Batching: This is the process of weighing the materials and preparing them for mixing. This involves weighing different agro-waste materials and starch to make up the batch composition for the different sound attenuation panels [53].

Molding: This involves the slurry preparation and casting process. The different batches for each of the materials composition of the slurry are the agro-waste, starch and water. Water is added to the batches gradually to avoid over-softening of the contents. The sound attenuation panels were fabricated using compression molding methods.

Drying: The produced sound attenuation panels were dried for some days and later sintered at a temperature of 80°C in an oven [52]. The difference in the weight of the sound attenuation panels before and after drying is presented in Table 2.

Table 2. The mass of composite panels before and after oven drying

Agro-wastes	Size of mould (cm)	Before oven drying (g)	After oven drying (g)
Corn Cob	2	147.59	146.20
	4	290.00	289.71
	6	385.64	384.53
Rice Husks	2	227.70	227.22
	4	442.54	440.81
	6	624.89	623.37
Groundnut Husk	2	150.49	150.34
	4	252.71	252.36
	6	419.18	418.53
Sugar cane Bagasse	2	106.46	105.93
	4	203.63	203.03
	6	265.67	266.37
Oil palm fruit fibre	2	266.63	268.45
	4	512.37	510.80
	6	698.48	698.32

The processing step of the sound attenuation panel is displayed in Figure 3.

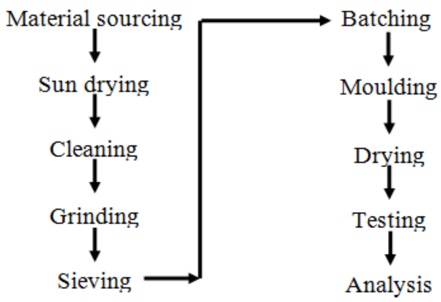

Figure 3. The acoustic panel production process

Characterization of agro waste materials in sound reduction

The agro-waste minerals compositions of all sound attenuation panel samples were determined using a fabricated acoustic transmission loss tube set-up with two sound level meters in the Department of Pure and Applied Physics, Federal University Wukari, Taraba state of Nigeria. The acoustic transmission loss tube has two chambers on either side of the chamber with a cushioned interior to avoid noise and vibration transmission in and out of the chambers. At the top of each chamber is a sound level meter set to dBC frequency weighting and slow mode for slow weighting time (1s for each reading). In between the two chambers is the acoustical attenuation panel holder adapted with bolt and nut for firm fixation of the produced panels during the testing process. The acoustic attenuation panel tested is the separation layer between the two chambers. The sound was generated using an MP3 player through a Bluetooth application connection to a mobile phone. The Mp3 player was accommodated inside one of the chambers, while the other chamber was left empty for the acoustic attenuation assessment. The sound generated and the absorbed sound levels were concurrently measured from the sound level meter on either acoustic transmission loss tube chambers. For the varied thicknesses of the sound attenuation panel composites samples produced, a total of ten readings were taken at intervals of one minute with different volumes and sounds to ascertain the level of sound attenuation of the acoustic panel. The experimental setup is shown in Figure 4. Due to the frequency of the vibration of the sound source, the sound levels were noted using a digital stopwatch at three intervals, five minutes apart from each reading.

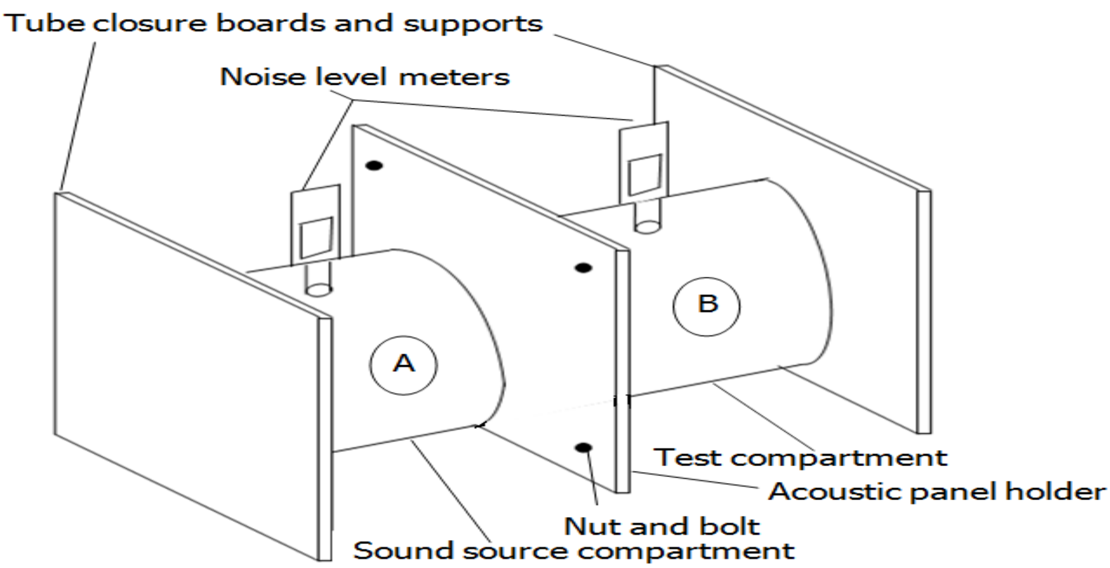

Figure 4. A *set*-up of an acoustic transmission loss tube

Evaluation of the sound absorption coefficient

The sound absorption coefficient used to evaluate the sound attenuation capacity of agro-waste materials was the ratio of the absorbed energy to the incident energy and is represented by α [4][54]. The sound absorption coefficient of the agro-waste materials α is calculated using the following equations;

$$\alpha = \frac{E_a}{E_I} \quad \text{(I)}$$

Where E_a absorbed wave energy and
E_I incident wave energy [55]

$$\alpha = 1 - \frac{E_r}{E_I} \quad (2)$$

Where E_R reflected wave energy, and
E_I incident wave energy [55]

$$\alpha = 1 - |R|^2 \quad (3)$$

Where R is sound reflection coefficient [55]

$$\alpha = \frac{I_{Abs}}{I_{Inc}} \quad (4)$$

Where I_{Abs} sound intensity absorbed, W/m^2,
I_{Inc} incident sound intensity, W/m^2 [55]

Analysis of data

The data obtained from testing the sound attenuation composite panel in this study were analyzed using SPSS version 20.0 and Microsoft Office Excel version 2016 software. Descriptive and inferential statistics analysis was carried out on the data obtained.

Results and discussion

Fifteen sound attenuation composites were produced. Three (20, 40, and 60 mm thicknesses) from each of the natural waste materials, corn cob, rice husks, sugar cane bagasse, oil palm fibre and groundnut husk. The sound attenuation composites' lengths and breadths were approximately equal dimensions. According to studies, the thickness of any sound attenuation composites is one of the parameters used in assessing the sound attenuation capacity [18][56]. Table 3 summarises the measured incident sound level produced from the source and the absorbed sound level across the 20, 40 and 60 mm thickness for the agro-waste-based sound attenuation panels. The average value for each agro-waste-based sound attenuation panel, the corn cob, rice husks, sugar cane bagasse, oil palm fibre and groundnut husk showed that the incident sound level was higher as compared to the absorbed sound level (Table 3).

Table 3. Summary of sound attenuation properties of agro waste materials

Agro waste materials	Thickness (cm)	Incident sound pressure level (decibel)				Absorb sound pressure level (decibel)			
		1st	2nd	3rd	Average	1st	2nd	3rd	Average
Oil palm fruit fibre	2	107.10	107.90	107.20	107.40	87.60	86.90	87.50	87.30
	4	107.30	107.70	107.90	107.60	84.90	84.20	84.40	84.50
	6	107.10	107.10	107.50	107.20	81.00	80.90	80.70	80.90
Groundnut husk	2	107.80	107.90	108.20	108.00	93.70	93.20	93.00	93.30
	4	107.40	107.50	107.30	107.40	87.50	87.60	87.30	87.50
	6	106.30	106.30	106.30	106.30	83.70	83.80	83.30	83.60
Bagasse	2	106.40	107.00	106.40	106.60	89.70	88.90	88.90	89.20
	4	107.20	106.80	107.10	107.00	84.60	85.00	83.60	84.40
	6	106.80	107.10	107.10	107.00	80.60	81.30	81.90	81.30
Rice husk	2	106.90	106.90	107.10	107.00	90.50	91.40	90.90	90.90
	4	107.00	106.70	106.10	106.60	80.90	79.60	80.00	80.20
	6	106.70	107.10	107.30	107.00	77.90	76.10	76.40	76.80
Corn cob	2	106.60	106.50	106.70	106.60	89.70	89.30	88.70	89.20
	4	106.60	106.50	106.70	106.60	82.10	82.40	83.70	82.70
	6	106.30	106.20	106.70	106.40	79.60	80.60	79.20	79.80

The quality of sound attenuation waste material composite panels produced in this study was determined by the sound absorption coefficient [21][25]. From the literature, the sound absorption coefficient is expressed as a single value format ranging from 0.0 (reflects sound energy but does not attenuate mid-frequency sounds) to 1.0 (attenuates mid-frequency sounds completely). The sound absorption coefficient obtained using Bai et al. [55] expression for the five sound attenuation waste material composites produced is presented in Table 4. The sound pressure level in this study was determined at a frequency range of 31.5 Hz to 8 kHz (from the specifics of the research instrumentation used). The maximum sound absorption coefficient recorded was 0.86 against a groundnut husk of 60 mm thickness, while the minimum was 0.72 against rice husk of 20.0 mm. Therefore, the sound absorption coefficient range obtained in this study was found to be of good quality. The ranges of the sound absorption coefficient obtained in this study considering the thicknesses of sound attenuation waste material composites produced are similar (Ismail et al., 2010). The sound absorption coefficient for the panels is 0.72 - 0.79 for 20.0 mm, 0.75 - 0.81 for 40.0 mm and 0.81 - 0.86 for 60.0 mm sound attenuation panels with rice husk of 20.0 mm thickness, recording the lowest and groundnut husk of 60.00 mm of thickness recording the highest sound absorption coefficient.

Table 4. Sound reduction percentage (%) and sound absorption coefficient (α) of the agro waste materials

Materials	Thickness (mm)	SLS (Decibel)	ASL (Decibel)	SAC (α)
OPF	20.00	107.40	87.30	0.81
	40.00	107.60	84.50	0.79
	60.00	107.20	80.90	0.75
GH	20.00	108.00	93.30	0.86
	40.00	107.40	87.50	0.81
	60.00	106.30	83.60	0.79
SG	20.00	106.60	89.20	0.84

	40.00	107.00	84.40	0.79
	60.00	107.00	81.30	0.76
RH	20.00	107.00	90.90	0.85
	40.00	106.60	80.20	0.75
	60.00	107.00	76.80	0.72
CC	20.00	106.60	89.20	0.84
	40.00	106.60	82.70	0.78
	60.00	106.40	79.80	0.75

Table 5 shows the comparative analysis using independent-sample t-test analyses of the incident and absorbed sound. The sound pressure levels were measured using the transmission loss tube. This was done to ascertain the sound attenuation property of five categories of the sound attenuation panels produced from oil palm fruit fibre, groundnut husk, sugar cane bagasse, rice husk and corn cob. Independent-sample *t*-test analyses on the incident and absorbed sound pressure levels were measured using the transmission loss tube. The independent *t*-tests showed statistically significantly higher mean sound level values of incident sound pressure (107.42 ± 0.34) when compared to absorb sound pressure level (84.89 ± 2.70) for oil palm fruit fibre with $p = 0.00$ (Table 5). For the other four materials, similar trends were observed. The groups' means are significantly different as the p-value is less than 0.05. The statistically significant difference between the mean sound level values of incident sound pressure and absorbed sound pressure level for each composite panel produced implies that the panels are effective sound absorbers as they reduced sound level (Table 5).

Table 5. Independent sample *t*-test for sound level between sound level from the source and the absorb sound level

Agro waste material	Sound level	Descriptive statistics			Paired samples test		
		Mean	SD	SEM	*t*	*df*	*p*-value
Oil palm fruit fiber	SLS	107.42	0.34	0.11	24.78	8	0.00
	ASL	84.89	2.70	0.90			
Groundnut husk	SLS	107.22	0.74	0.25	15.10	8	0.00
	ASL	89.19	4.19	1.40			
Bagasse	SLS	106.88	0.30	0.10	18.03	8	0.00
	ASL	85.88	3.33	1.11			
Rice husk	SLS	106.87	0.35	0.12	10.25	8	0.00
	ASL	84	6.73	2.24			
Corn cob	SLS	106.53	0.18	0.06	15.69	8	0.00
	ASL	85.06	4.16	1.39			

One-way analysis of variance (ANOVA) test was used to determine the effect of the thickness of the produced sound attenuation composite panel variables on the sound level. The analysis of variance (ANOVA) for sound attenuation level is shown in Table 6. *F*-value is the ratio of variance group means to the mean within-group variances used to decide whether to accept or reject the null hypothesis. The *p*-values were used as a tool to check the significance of each of the coefficients, which is necessary to understand the pattern of the mutual interactions between the test variables. A significance level of 5% was used, implying that all terms with *p*-value less than 0.05 were considered significant. The sound absorption coefficient significance from the effect of the thickness of the produced sound attenuation composite panel variables dataset is observed at a larger *F*-value and a smaller magnitude of *p*-values. The model regression *F*-values of 64.06 imply that the model is significant, validated by the *p*-value is less than 0.05. Therefore, the ANOVA indicates that the thickness of the produced sound attenuation composite panel has a significant effect on the sound attenuation of the composites (p-value < 0.05) (Table 6).

In summary, the study observed that the higher the thickness of the sound attenuation of the composites the higher the sound attenuation capacity represented in its sound absorption coefficient. The optimal sound attenuation panel thickness on the sound absorption coefficient observed in this study is similar to the findings of Masrol *et al.* [44]. Furthermore, the sound attenuation panels attenuated the sound pressure level with its sound absorption coefficient ranging from 0.72 – 0.86, similar to the findings of Masrol *et al.* [44], who obtained a sound absorption coefficient ranging from 0.76 – 0.86. in this study and that of Masrol *et al.* [44], the research goes that the higher the thickness of the composite material, the higher the sound attenuation capacity of the panel.

Table 6. Analysis of variance (ANOVA) for thickness effect on sound attenuation level

	Sum of squares	*Df*	Mean square	*F*-value	*p*-value
Between Groups	699.63	2	349.81	64.06	0.00
Within Groups	229.34	42	5.46		
Total	928.97	44			

3. **Conclusion**

The low-cost sound attenuation panels (eco-friendly, biodegradable and economical) were fabricated from agro waste as an alternative to synthetic sound-absorbing materials. The analysis of the acoustic characteristics of the produced materials showed that sound attenuation panels attenuated the sound pressure level with its sound absorption coefficient ranging from 0.72 – 0.86. Furthermore, the analysis of the acoustic characteristics of agro-waste materials with regard to the thickness of the materials showed that the higher the thickness of the sound attenuation waste material composites, the lower the sound absorption coefficient of the material composites. Thus, it is recommended that the produced and analyzed green composite should be used to substitute synthetic materials in sound attenuation where applicable.

Author Contribution

Conflict of Interest

The authors confirm that there is no known conflict of interest or common interest with any institution/organization or person.

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