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Utilisation of Indigenous Resources for Acoustical Applications

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Abstract

This paper presents the development of novel sound absorbing materials based on natural indigenous resources particularly that of fibrous nature. Coir fiber in the form of stitched mat, which is porous and fuzzy, was utilized as the main sound absorbing component. Composite panels support the coir mat laterally. The panels were made from oil palm frond fibre (OPF) and rice husk (RH) bounded in either unsaturated polyester (UP) or polypropylene (PP) matrix. The acoustical properties of the composite structures were determined in an impedance tube based on the two-microphone transfer function method in the frequency range of 125Hz to 4000Hz. Overall results indicate that the coir mat-composite panel structure is a potential absorbent-barrier with not less than 50% of sound absorption. General improvements were achieved in the absorption properties over the entire frequency range using the more flexible RH-PP panel while superior low frequency absorption was attained using panel made of 50% volume fraction of OPF/RH mixture in UP. The product of this research offers exceptional cost-performance balance to the existing, relatively expensive noise control industry while reducing waste disposal problems in the plantation industry.

Keywords: *Indigenous material; sound absorption; impedance tube; noise control*

INTRODUCTION

Engineering problems related to noise and vibration control are often tackled using four major classes of materials i.e. absorbing materials, barrier materials, vibration damping materials and silencers [1]. The utility of these structures is determined by specific treatment strategies that might involve any or all element of the noise transmission chain. (Refer Figure 1).

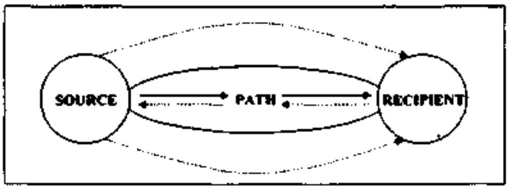

Figure 1: Noise transmission chain (——→) and interactions between elements of the sound transmission (- - - - - -→)

Most sound absorbing materials are naturally porous and allow sufficient sound energy transmission into them to be dissipated. At present, almost any commercially available sound absorptive material utilizes mineral or glass fibre as the base material. Rockwool and fibreglass are the common choice of materials used in architectural and industrial noise control applications today. However, these materials do have their limitations too. Some intrinsic features of conventional sound absorbers, especially asbestos, pose risks concerning health and skin irritation [2]. Furthermore, they are often imported from major exporters abroad for a very high cost. Alternative approaches are being diligently researched to design and develop proxy materials that are specifically aimed at eliminating the health impact caused by the commercial materials but possess equally good sound absorption properties.

The continuous effort to reduce and recycle waste residues predominantly from the plantation related sectors have contributed significantly towards development of various sophisticated agro-based products such as biodegradable plastics [3] automotive components such as engine covers and composite boards [4]. Of these, utilization of naturally occurring materials in acoustical applications has been increasingly explored.

Shoshani and Rosenhouse have tried using woven fabrics made of cotton and wool as sound absorbing materials [5]. These materials were found to be effective when applied as the covering surface to other noise absorbers such as perforated metal plate or rockwool. Wassilieff have developed a novel sound absorber using loose wood fibres and shavings packed into a sample holder or compressed using PVA as the binder [6]. The main difficulty that was encountered in developing the compressed panels is related to the production of a low density, homogeneous sample with relatively pervious front surface. Ballagh proposed wool as a potential substitute for the traditional materials [2]. Woollen materials that were experimented show increment in transmission loss of stud walls up to 6 dB besides possibilities of achieving high absorption coefficients for control of room reverberation.

In the case of indirect transmission path from the noise source to the recipient, sound absorbing material can be effectively used to attenuate noise and suppress multiple reflections in an enclosed space. The mechanism of sound energy dissipation via frictional energy losses inside a porous absorptive material is understood. One obvious constraint of any efficient sound absorber is its functionality merely as a noise absorbing utensil with virtually no restriction posed to the possible transmission of sound through it. Therefore, special acoustic material designated as absorbent-barrier, which consists of thin, semi-rigid panel backing the principal absorptive material component, is sometimes chosen for critical applications. The added mass functions as a barrier to prevent transmission of sound through the absorptive component. Moreover, the transmitted sound is reflected back to the absorbent to be further dissipated.

The aim of this work was to develop novel sound absorbing materials utilizing entirely local agro-based resources. The absorbing material is designed to be a composite structure where prefabricated coir mat is used as the main absorptive component backed by thin composite panels in various compositions of fibres extracted from indigenous, natural resources. Besides varying the fibre volume fraction, $\%v_f$, of the composite panels, two types of binder matrixes were utilised to determine their specific effects on the acoustical properties of the composite absorptive materials. The acoustical properties of the fabricated materials were determined experimentally. The information gained will be particularly useful to establish suitable applications for these novel as well as inexpensive materials.

THEORY

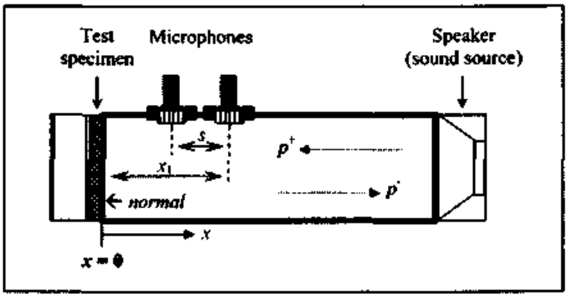

Figure 2: The impedance tube set-up

Referring to Figure 2 above, pure tone harmonic acoustic waves are generated by the speaker at the right edge. This produces one-dimensional acoustic field inside the tube. The sound wave will propagate towards the test specimen that is mounted on the left end. Upon impinging the surface of the material, some portion of the acoustical energy will be reflected while the rest will be absorbed. This is, of course, assuming that there is nearly no energy being transmitted across the material i.e. structure borne sound radiation. Assuring that the specimen is snugly mounted on the specimen holder fulfills this assumption. The phase interference between the incident and reflected sound wave produces a complex standing wave pattern that can be decomposed. This is achieved by using two microphones to obtain the transfer function of the complex acoustic pressure signals, H_{12} between the two microphones. H_{12} represents the ratio of the Fourier transform of acoustic pressure measured at the microphone nearer to the test specimen (microphone 2), p_2, to that measured by the microphone closer to the sound source (microphone 1), p_1, at discrete frequencies, i.e. $H_{12} = \frac{p_2}{p_1}$.

Impedance mismatch between the propagating medium i.e. air inside the tube and the material surface causes reflection of the sound energy. Determination of the amount of sound absorption by a plane surface is often based on a local reaction model. In this model, it is assumed that the normal component of the particle velocity, $\vec{v}_n$, at any defined points on the material surface is linearly related to the local sound pressure, p [7]. In other words, the acoustic field at given point of the surface is determined only by the properties of the surface at this point. Normal acoustic absorption coefficient, a_n, is related to the reflection coefficient, $|R_n|^2$ as follows:

$$\alpha = 1 - |R_n|^2 \tag{1}$$

R_n can be deduced from the measurement of H_{12} [8],

$$R_n = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} e^{2jk_o x_1} \tag{2}$$

where x_1 is the distance between the specimen surface to the further microphone and s is the microphone separation distance.

EXPERIMENTAL METHOD

Test Material

1. Design

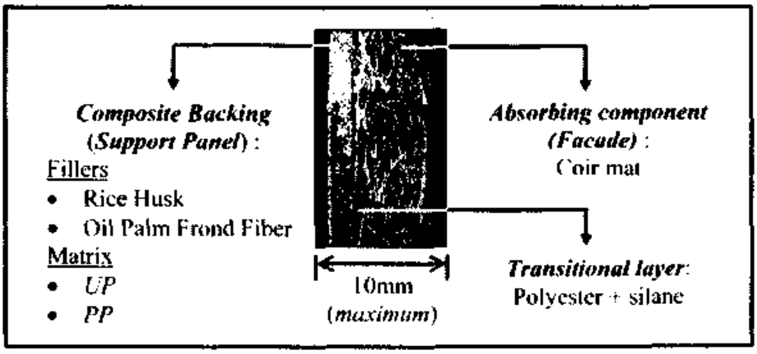

Figure 3: Design of the composite absorbing structure

The design of the composite absorbing structure is shown in Figure 3. The overall nominal thickness of the test materials is 10mm. The facade of the material is a factory-produced coir fibre mat (CF mat) made from long coconut fibre and sprayed with latex to keep the fibres intact. This fibrous and fuzzy makeup will function as the main sound-absorbing component. The support panel is a composite material itself that is bonded to the coir mat by a fine transitional layer of polyester and silane mixture. Three different composite systems were fabricated using high $\%v_f$ of crushed oil palm frond fibre (OPF) and rice husk (RH). Unsaturated polyester (*UP*) and polypropylene (*PP*) were chosen as the binding agents. Thus, three test materials were developed based on the specifications listed in Table 1 below.

Table 1: The composite systems for supporting panel

Sample	Absorbing Component	Support Panel		$\%v_f$
		Fibre	Matrix	
1	CF mat	(OPF + RH)	UP	70 (50 + 50)
2	CF mat	(OPF + RH)	UP	70 (70 + 30)
3	CF mat	RH	PP	50

2. Fabrication

The composite backing panels were fabricated employing suitable processing techniques for the types of matrix used i.e. thermoset (*UP*) and thermoplastic (*PP*) polymers. Hand lay-up coupled with compression molding technique was utilized to fabricate the *UP* based samples. OPF and RH were initially dried at 333 K for 24 hours. Appropriate amount of OPF and RH were then thoroughly mixed and dispersed in *UP*. The cross-linking process of *UP* is initiated using 1% methyl-ethyl-ketone-peroxide. The mixture was discharged and carefully suffused into a cylindrical cavity mold of 3 mm thickness. This preparation was placed on a manual compression molding unit and compacted at room temperature (302 K) for at least 8 hours. Pressure ranging 30 - 50 MPa was applied according to the $\%v_f$ level. Hot pressing method was used to fabricate the *PP* based sample. RH and *PP* were originally mixed using an extruder at 453 K and compressed by an automatic hot press machine. The processing temperature and pressure was 453 K and 15 MPa, respectively. A mixture of polyester and 1% silane coupling agent was finely applied to the support panel surface to bond the CF mat against it.

Procedure

The normal incidence absorption coefficients, a_n, at selected octave band center frequencies were determined in an impedance tube using the two-microphone transfer function method. Transfer function method was used since it is proven to be a rapid and accurate technique which do not need large sample sections as required by the reverberation room method [7, 8, 9]. The properties were measured as a function of incident sound frequency at six discrete, octave band centre frequencies ranging from 125 Hz to 4000 Hz. Two impedance tubes, which differ in internal diameter (ID), were fabricated. The maximum measurement frequency for the bigger tube with ID = 90 mm is 1000 Hz while the smaller tube with ID = 25 mm works up to 4000 Hz. The cut-off frequencies were also used as a basis to calculate the appropriate microphone separation distance, D*r*, based on the finite different approximation principles. Sound pressure signals from the two microphones were acquired using 01dB-SYMPHONIE®, a 32bit PC-based digital acquisition unit, and processed by dedicated software namely, dBFA32® to determine the transfer function of the pressure signals with an accuracy of 0.01%. The entire process of signal acquisition and processing was accomplished in real time mode. Transfer function data obtained from the dBFA32® were then transferred to a specially written MATLAB® program to calculate the acoustical properties.

Effect of the support panel rigidity on the sound absorption properties of the CF mat was investigated. Support panel of sample 3 that contains *PP* matrix (thermoplastic) is more flexible than the support panels for sample 1 and sample 2, which are based on *UP* matrix (thermoset). Effect of increment of RH content in samples 1 and 2 on the sound absorption properties was also investigated. Besides this, a reference sample i.e. CF mat of 10mm thickness (without the support panel) was tested for comparison purposes. Noise Reduction Coefficient (*NRC*), that is the arithmetic mean of a_n at 250 Hz, 500 Hz, 1 kHz and 2 kHz, is used as a rating index to evaluate the sound absorption performance of the samples with regard to the reference sample.

RESULTS AND DISCUSSION

Normal incidence sound absorption coefficient for both sides of the absorptive composite structure was determined individually. Figure 4 and Figure 5 below show the absorption coefficient curve as a function of test frequency for the facade (CF mat component) and support panels, respectively. The entire test samples show similar trend as the reference sample i.e. CF mat. However, the values of a_n at the resonance frequency, 2 kHz is slightly greater for sample 1 and sample 2 as summarized in Table 2. Samples 1, 2 and 3 have the same thickness as CF mat and therefore a comparative analysis can be made in terms of the effect of different support panels on the absorption properties of the porous CF mat. The analysis will involve critical comparison of the effect of varying panel rigidity on the sound absorption performance of the CF mat with specific reference to the test frequency and the panels' reflection properties. The basis for argument revolves around the panels' stiffness properties, which depends on the filler content and type of matrix.

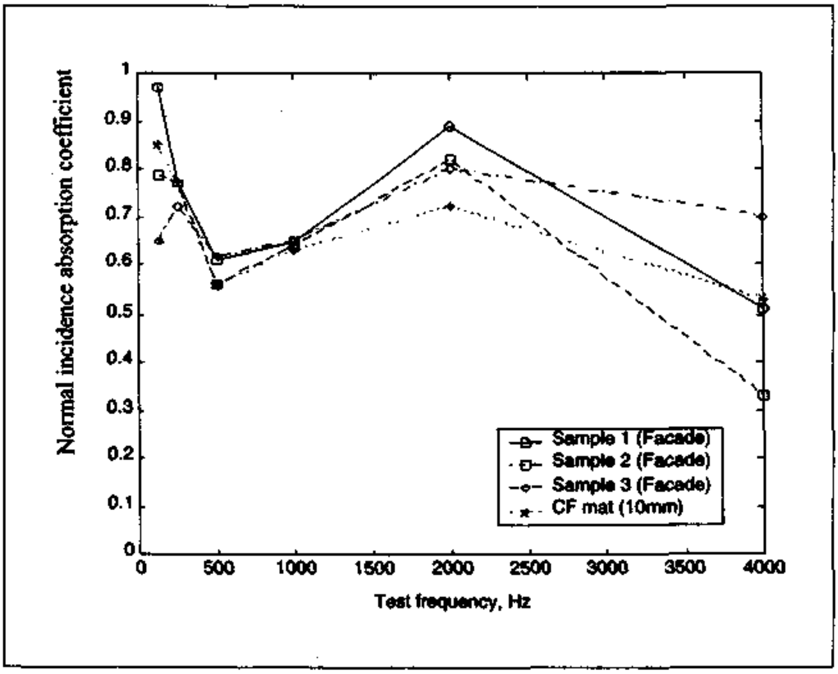

Figure 4: Normal incidence sound absorption coefficient plot of the CF Mat Components

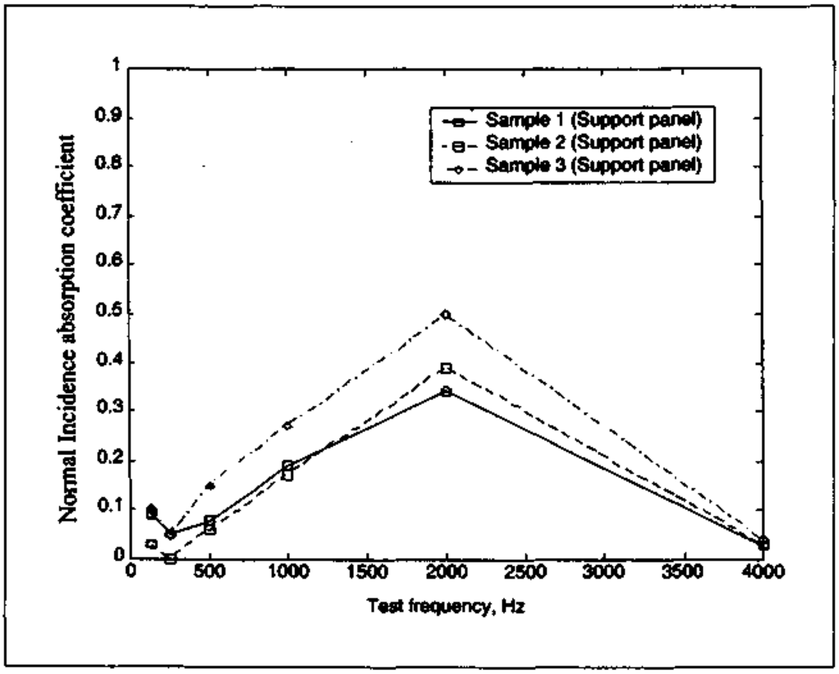

Figure 5: Normal incidence sound absorption coefficient plot of the support panels

Table 2: The NRC values of the test samples

Sample	Thickness, mm	α_n						NRC
		125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	
1	10	0.97	0.77	0.61	0.65	0.89	0.51	0.73
2	10	0.79	0.77	0.56	0.64	0.82	0.33	0.70
3	10	0.65	0.72	0.62	0.65	0.80	0.70	0.70
CF Mat	10	0.85	0.77	0.56	0.63	0.72	0.53	0.67

Table 2 shows that sound absorption, especially at 125 Hz and 2 kHz has improved significantly. Sample 1 is capable of absorbing 97% of incident sound energy at 125 Hz. Panel absorption also plays crucial part in this superior low frequency performance. Although the decrement at 250 Hz and 500 Hz is present, it is controlled by sample 1. One apparent drawback that persists in both samples is the low absorption at 4 kHz. The overall performance of coir mat can be improved by introducing a semi-rigid backing panel. The improvement is evident from the increment of the *NRC* indicator for sample 1 compared to that of CF mat alone.

The support panel of sample 1, on the other hand, is relatively a reflective material. This is because the CF mat component is a porous material that allows the transmission of incidence sound energy more readily to be dissipated while the hard, solid surface of the support panel hinders sound transmission through it. High reflections occur at 250 Hz and 4 kHz. Hence, sound energy transmission into the material is rather restricted causing the absorption mechanism to be insignificant or stalled.

The overall trend of sound absorption for sample 2 is similar to sample 1 but in a smaller magnitude. At 125 Hz, only 79% of the incident energy is absorbed. This is equivalent to a reduction of about 20%. The reduction vaguely indicates the lack of the backing panel's function to provide sufficient flexibility to absorb low frequency sound. Greater amount of fine RH inclusion compared to OPF i.e. 70%v_f makes the panel more rigid, as observed in another experiment [10]. At 250 Hz, 500 Hz and 1 kHz, this sample performs almost competitively with the reference sample, CF mat. But the value of a_n is sufficiently lower at 4 kHz compared to sample 1 and CF mat alone.

The absorption trend of the support panel of sample 2 is similar to that of sample 1 but generally in a lower scale. The values of absorption coefficient at 125 Hz – 1 kHz range is almost inferior to the values of sample 1-support panel. Hence, sample 2-support panel is a better reflector in this frequency range. Nevertheless, the value of absorption coefficient at 2 kHz is higher. Zero absorption registered at 250 Hz cannot be entirely attributed to the panel's acoustical response but could also be due to other factors including execution of the test method or deficiency related to the impedance tube apparatus. This problem will be treated separately in another paper.

The maximum absorption of sample 3 occurs at 2 kHz but its value is slightly lower than sample 2. Sample 3 exhibits an apparent shift in low frequency absorption compared to sample 1 and sample 2, i.e. from 125 Hz to 250 Hz. Performance trend from 250 Hz onwards is akin to that of sample 1 and sample 2. The uniqueness of sample 3 is its high absorption of 72% at 4 kHz. Increased flexibility of the structure supported by a supple backing panel causes this augmentation of high frequency absorption.

Sample 3 is comparable to sample 1 in terms of RH content. Since the matrix is a flexible *PP*, the support panel of sample 3 is generally more absorptive than its counterpart in sample 1 and sample 2 at all frequencies. Increment of sound absorption at 250 Hz, 500 Hz and 1 kHz is observed for the sample 3-support panel. This is particularly useful to improve the high frequency absorption of the CF mat.

CONCLUSION

The novel acoustic materials that were developed in this research provide a convenient solution as absorbent barrier wherein one side of the material absorbs sound finely while the other reflects sound energy. Requirements pertaining to specific application and critical regions that have to be masked from intrusion of noise determines which part of the composite acoustic absorber to be exposed to the noise source. Functional optimization of the composite absorptive material is possible. Rigidity of the support panel can be altered by varying the $\%v_f$ or the type of polymer matrix used to enhance the sound absorption performance of CF mat at higher frequencies. Support panel made from *PP* is more flexible and reflect 50% of incident sound energy while panels based on *UP* is rigid and reflect more than 60%. The flexibility of thin composite panels can be utilized to design a sound absorbing system that yields efficient mid and high frequency absorption. It is anticipated that the utilization of abundant agricultural residues would reduce, to some extent, waste disposal problems faced by the plantation or its related sector. Exploitation of agricultural wastes in a large scale will most likely create new wealth generating and economical ventures in the rural plantation areas.

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