Investigation on Sound Absorption Characteristics of Nonwoven Coir Mats

G. Thilagavathi, A. Muralikrishnan, N. Muthukumar and S. Neelakrishnanan

Abstract Due to higher CO_2 and other environmental issues, many researchers are working in the production of insulating materials made of natural and bio-based materials. This paper investigates the sound absorption characteristics of porous nonwoven mat made from coir fibre. The produced nonwoven samples were combined with a perforated panel to have hybrid configurations and characterized for acoustic properties. It was found that the developed porous coir mats had good sound absorption values at high-frequency range compared to low-frequency range. When Micro perforated panel (MPP) was placed in front of porous coir mat, the sound absorption characteristic was improved at low frequencies and some samples exhibited good sound absorption characteristics in both low and high frequencies.

Keywords Coir fibre · Impedance tube · Needle punching · Sound absorption

1 Introduction

Various musical programmes are conducted in the multipurpose concert halls. But the quality of the musical programme mainly depends on the acoustic atmosphere which includes volume of the hall, the surface area of various surfaces (walls, ceiling, etc.) and the absorption coefficient of the surfaces. For example, the required reverberation time for the classical music is 1.5–2 s and rock music is 0.8–1.5 s for empty halls. Some special musical programmes have low-frequency sound energy which requires a specific acoustic atmosphere in order to provide quality programme. A bass guitar typically has a low E string tuned to E1 or about 41 Hz. So the acoustic design and measurement range could in fact extend down to the 40 Hz frequency band.

Porous absorbing materials like glass wool, polyurethane foam and mineral fibre composites are commonly used for sound absorption applications. These materials

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provide better performance for the sound having a medium and high frequency. Resonance absorbers like perforated plasterboard, perforated metal corrugated sheets and metal boxes provide better sound absorption for low-frequency sound. A single structure does not provide better sound absorption for a wide frequency range. Hence, sound-absorbing materials in the form of sandwich structure need to be constructed to provide sound absorption for a wide frequency range [1, 2].

Coir fibre is the natural organic fibre which is obtained from the outer shell of the coconut. The insulation characteristic of coir makes it an organic sound absorbent. Coir fibres are mixed with a binder to improve the functional and surface characteristics and used in building panels. Nonwoven fabrics have been widely used for acoustic applications and provide better performance for the sound having a medium and high frequency. The lower performance of nonwovens at low-frequency sound limits its applications in the automobile industry. Mohd et al. [3] experimented with coir-based samples both with and without binders and concluded that nonwovens made from raw coir fibres had better performance for both low- and medium-frequency sound waves compared to nonwovens made from coir fibres with binder. This behaviour is more remarkable with layer thickness. It was found that increasing coir fibre layer thickness increased the performance of sound absorption at low- and medium-frequency range. Also in another study, Mohd et al. [4] analysed the influence of compression on sound absorption performance of single layer coir panel and observed that the coir nonwoven panel made with higher compression rate had better sound absorption performance compared to uncompressed coir nonwoven panel.

Modern rhythmic music has a wide range of sound energy and requires good acoustic atmosphere to provide quality sound. Therefore, in recent years, multi-layer acoustic absorbers have been developed to absorb broadband noise. These materials are made by combining perforated plates and porous materials with airspace. The sound absorption performance of multi-layer acoustic absorbers depends on their manufacturing process [5–7]. Zulkifi et al. [8] studied the performance of coir fibre with perforated panel and results showed that coir fibre with perforated panel has higher sound absorption at low-frequency range. Increasing the sound absorption at low frequency can be a great contribution to noise control engineering [9]. Ayub et al. [10] developed a panel composed of coir fibre layer in different thicknesses 20, 35 and 50 mm with air gap backed by a rigid wall. Zulkifli et al. [11] studied the performance of sound absorber consisting of a perforated plate with porous coir backing.

The aim of present work is to develop hybrid fibrous panel from porous nonwoven coir mat and perforated panels for controlling low-frequency sound. The samples are planned to have various configurations like porous nonwoven coir mat, perforated panel with air gap, perforated panel backed by porous fibrous matt and perforated panel backed by porous fibrous mat and air cavity. The developed samples are characterized for its acoustic performances.

2 Materials and Methods

2.1 *Fabrication of Nonwoven Coir Mats*

Coir fibre is sourced from coir industries in Tamil Nadu, India. The opened fibres are passed through a needle punching machine where the fibres are made to entangle to form as a sheet. In order to get the structural integration, natural rubber polymer latex of 22% was sprayed over the coir mat and cured. Totally, six nonwovens were developed and the specifications of the developed nonwovens are given in Table 1.

Plywood of 3.4 mm thickness was purchased from local market with density of 67.27 kg/m^3 and perforations were made using a hand drill. The specifications of the developed micro-perforated panel (MPP) are given in Table 2. Porous coir mat samples, MPP and air gap are considered for making effective experimental set-up. Figure 1 shows the representation of various configurations of samples followed during measurements.

Table 1 Physical properties of porous nonwoven coir samples

Sample ID	Thickness (mm)	Weight (g/m^2)	Density (kg/m^3)	Porosity (%)
P1	6	900	150	86.9
P2	15	1650	110	90.4
P3	15	2625	175	84.8
P4	15	3150	210	81.8
P5	20	2200	110	90.4
P6	25	2750	110	90.4

Table 2 Physical properties of perforated panel

Sample ID	Material type	Thickness (mm)	Hole diameter (mm)	Hole spacing (mm)	Open area (%)
MPP1	Plywood	3.4	0.6	4	1.76
MPP2	Plywood	3.4	2	12	2.18
MPP3	Plywood	6.0	2	12	2.18
MPP4	Plywood	6.0	4	12	8.72
MPP5	Plywood	3.4	8	12	34.89
MPP6	Plywood	3.4	2	18	0.97
MPP7	Plywood	3.4	8	18	15.51
MPP8	Plywood	3.4	2	8	4.90
MPP9	Acrylic sheet	1.0	2	4	19.63

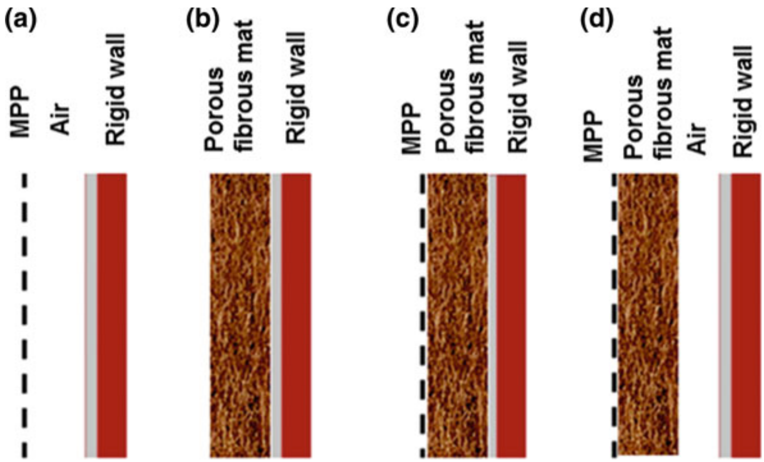

Fig. 1 Representation of various configurations, **a** MPP backed by air cavity (MPP+A), **b** porous absorber (P), **c** MPP backed by porous absorber (MPP+P) and **d** MPP backed by porous and air cavity (MPP+P+A)

2.2 Sound Absorption Characterization

The acoustic performance of the developed samples was evaluated using an impedance tube as per ASTM E 1050 standards. The impedance tube is made of a hollow cylinder consisting of loudspeaker and sample holder. Figure 2 indicates the positions of the microphone ports in the tube. The system of data acquisition and processing takes into account of these microphones as matched ones along with the other devices such as two analog signal conditioners and a two-channel Fast Fourier Transform (FFT) analyser. The microphones are connected to the individual channel

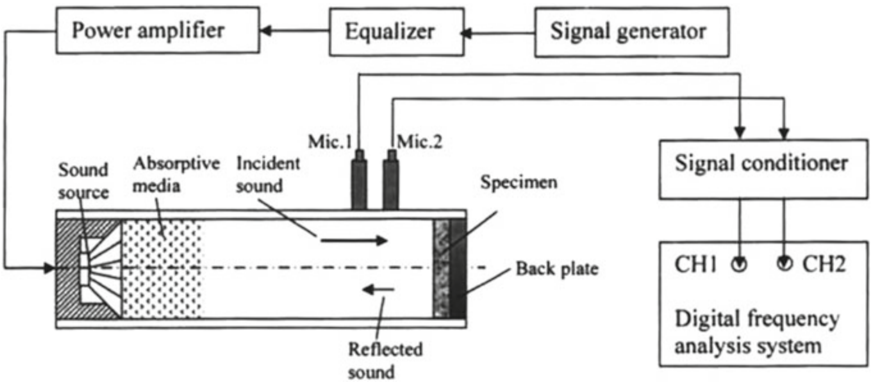

Fig. 2 Schematic diagram of an impedance tube set-up

of the analyser. The sound absorption coefficient is determined through the measured transfer function data using a microprocessor computer.

The sound absorption performance of a material is represented by Noise Reduction Coefficient (NRC) value which is an index obtained through as an average of sound absorption values at 250, 500, 1000 and 2000 Hz frequencies. The NRC values range from 0 (perfect reflection) to 1 (perfect absorption) to the nearest accuracy of 0.05.

3 Results and Discussion

3.1 Sound Absorption Characteristics of Porous Absorber

Figure 3 shows sound absorption characteristics of the developed porous absorber samples. The NRC values of porous samples (P1 to P6) are 0.08, 0.08, 0.11, 0.13, 0.12 and 0.18, respectively. In general, porous materials have minimum sound absorption characteristics at low frequencies (<1000 Hz) and have good sound absorption characteristics at higher frequencies. The maximum sound absorption coefficient among the samples is 0.13 for lower frequency (f < 1000 Hz) and 0.69 for higher frequency (f > 1000 Hz). This is the reason for the reduction in NRC values of porous materials.

The density of material plays a major role in sound absorption characteristics of any material. It was observed that the NRC values of the sample P2, P3 and P4 are 0.08, 0.11 and 0.13, respectively, and maximum absorption coefficient is 0.38 at

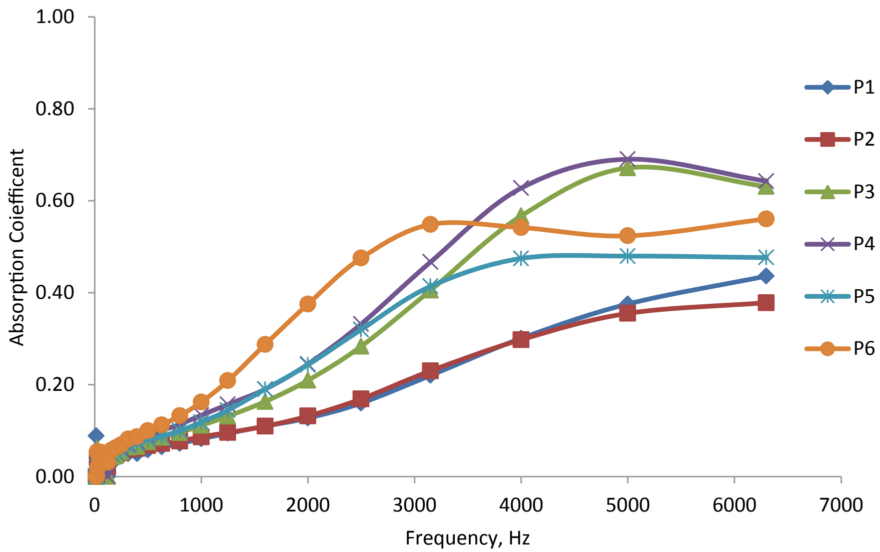

Fig. 3 Sound absorption characteristics of porous absorbers

6300 Hz, 0.67 at 5000 Hz and 0.69 at 5000 Hz, respectively. It was also observed that porous coir mat with density of 110 kg/m^3 (P2) has lowest sound absorption and porous coir mat with the density of 210 kg/m^3 (P4) has higher sound absorption for the entire frequency range. This is due to the presence of more number of coir fibres in the porous coir mat with the density of 210 kg/m^3 (P4). The loss in energy of sound wave is more when more number of fibres present in the porous layer. But there is no significant difference noticed in the absorption coefficient between the porous coir mat with the densities of 175 and 210 kg/m^3; this may be due to the lesser difference in porosity which results in minor difference in the air flow resistivity.

Thickness of the material is another factor which influences the sound absorption characteristics of any material. It was observed that the porous coir mat of thickness 25 mm (P6) has higher sound absorption coefficient values at low- and medium-frequency range compared to others. Low-frequency sound absorption has a direct relationship with thickness of material. When thickness of the material increases, the sound absorption characteristics increase and absorption curve also shifts towards lower frequencies. It is a well-known fact that if the porous absorber has thickness of one-tenth of the wavelength of the incident sound then it will have maximum sound absorption.

3.2 *Sound Absorption Characteristics of Porous Absorber with MPP+Air Configuration*

MPP backed by 50 mm air gap (MPP1+50 mm Air) has sound absorption only at low-frequency range of 630–1500 Hz and has the maximum sound absorption

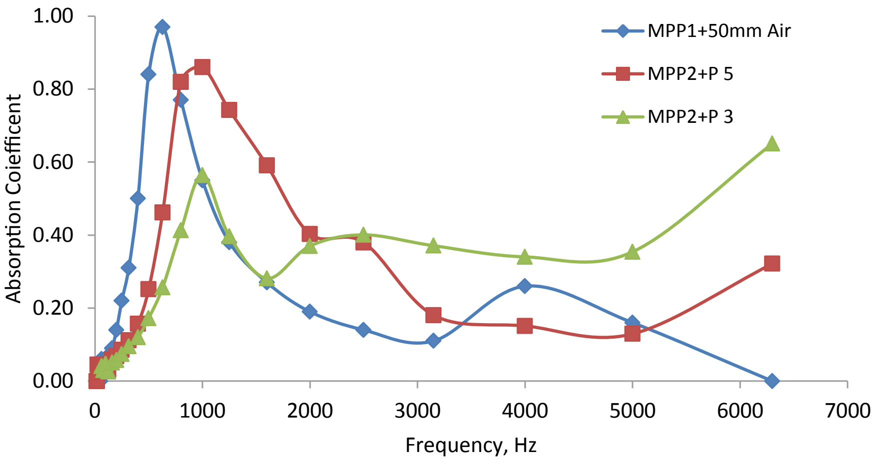

Fig. 4 Effect of porous absorber in MPP+Air configuration

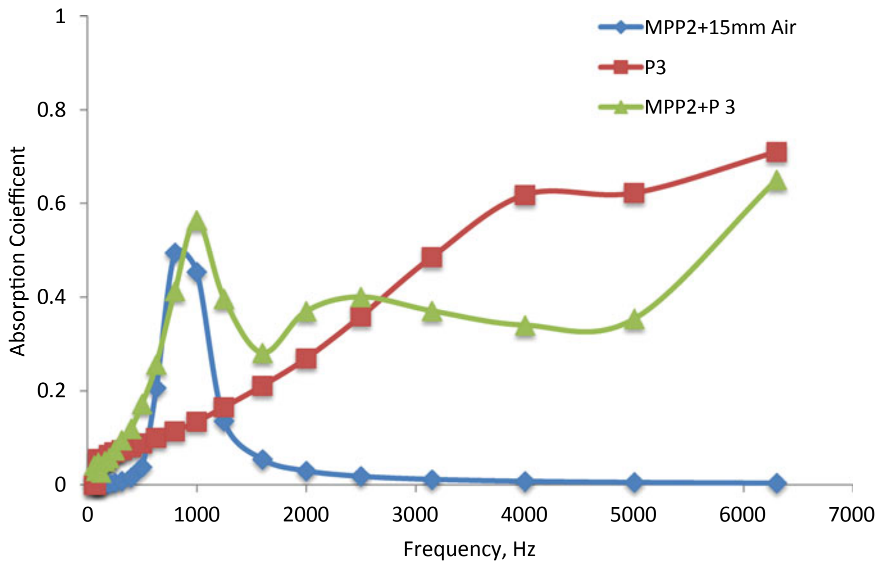

Fig. 5 Effect of MPP and porous absorber in MPP+Air configuration

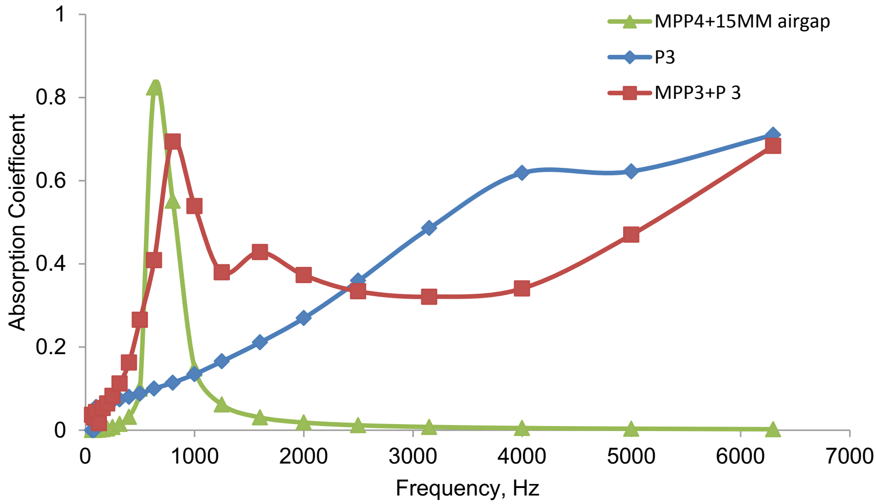

Fig. 6 Effect of MPP and porous absorber in MPP+Air configuration

coefficient value of 0.97 at 630 Hz. This configuration does not have any absorption characteristics at higher frequencies. While inserting porous nonwoven coir mat in between MPP and rigid wall, the absorption characteristics of MPP backed by porous material was improved.

The effect of porous absorber in MPP+Air configuration is shown in Fig. 4. The NRC values of perforated panel backed by air (MPP1+50 mm Air), perforated panel backed by porous coir mat MPP2+P3 and MPP2+P5 are 0.45, 0.30 and 0.4, respectively. MPP2+P5 have higher absorption coefficients at lower frequencies when compared to MPP2+P3; this is due to the increased thickness of porous coir mat P5 (20 mm) compared to P3 (15 mm). At the same time, MPP2+P3 has higher absorption coefficient at higher frequencies than MPP2+P5. This is due to higher density of porous coir mat P3 (175 kg/m^3). Hence, the absorption coefficients of porous materials may well be modified by adding MPP in front of it and by varying the significant parameters of porous material such as thickness and density.

In general, MPP backed by air has sound absorption only at low-frequency range and MPP backed by porous absorbers have sound absorption only at high-frequency range. In some cases, MPP backed by porous absorber showed good sound absorption at both low and high frequencies. This trend is shown in Figs. 5 and 6. It was observed that MPP2+P 3 and MPP3+P 3 have absorption trend of MPP2 backed by 15 mm air and MPP3 backed by 15 mm air gap at low frequencies, respectively, and have common absorption trend of porous absorber (P3) at higher frequencies. In this case, the acoustic impedance of MPP and porous absorber is just added in both low and high frequencies and act like wide-band absorber. Hence, it is clear that by selecting suitable parameters of MPP and porous absorber, the wide-band sound absorption characteristics would be obtained.

4 Conclusion

In this work, hybrid fibrous panel was developed by combining porous nonwoven coir mat and perforated panels and characterized for low-frequency sound absorption application. It was found that the sound absorption coefficient increases with the density of porous coir mat. The porous coir mats of 175 and 210 kg/m^3 density were having higher sound absorption coefficient than others. When MPP was backed with porous coir mat, the sound absorption characteristics improved as it combined both low-frequency and high-frequency absorption in some cases. The sound absorption characteristic of MPP backed by porous coir mat had two different behaviours. It had absorption characteristics of MPP backed air cavity for the low frequencies and absorption characteristics of porous coir mat for high frequencies. But the above trend was noticed only with high-density porous materials. The same configuration such as MPP backed with low-density porous coir mat did not have two-stage sound absorption characteristics. It had the resonance-type absorption curve, but the bandwidth of absorption was found to be wider. The results indicated that the developed coir fibrous mats can be used as sound-absorbing panels in auditorium and conference halls.

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