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A novel acoustic micro-perforated panel (MPP) based on sugarcane fibers and bagasse

Mohammad Hosein Beheshti[1], Ali Khavanin[2], Mostafa Jafarizaveh[3] and Akram Tabrizi[4*]

Abstract

Natural materials are becoming a reliable alternative to traditional artificial materials used in sound absorption insulation. The present study was conducted to investigate the acoustic insulation of micro-perforated panel (MPP) based on sugarcane fibers and bagasse as an available and environmentally friendly material. The absorption properties of single- and double-leaf natural micro-perforated panels (MPP) made of bagasse and also nonnatural MPPs made of Plexiglass were measured using an impedance tube based on ISO 10534–2. Then the effect of bagasse and sugarcane fibers composite on the air gap of MPP was investigated. The results showed the peak sound absorption of the bagasse composite is in the range of 1000 to 2000 Hz, and the sugarcane fiber composite has a higher sound absorption coefficient than the bagasse composite. Also, natural MPPs have a higher absorption coefficient than nonnatural MPPs at all frequencies, and as the panel thickness increases, the peak absorption coefficient shifts to lower frequencies. The peak sound absorption coefficient of double-leaf MPPs made of bagasse is 76%, in the range of 160 to 200 Hz. Using sugarcane fiber composite in the air gap of single- and double-leaf natural MPPs causes the absorption peak to shift to frequencies below 100 Hz. According to the results, natural MPPs have a high sound absorption coefficient at low frequencies. These panels can control sounds with much lower frequencies, especially in a double layer and along with cane fiber composite in their air gap.

Keywords Micro-perforated panel, MPP, Bagasse, Sugarcane, Sound, Adsorption

Introduction

Nowadays, noise control has become one of the major challenges of our time. This should be taken into account in the early stages of design and construction, as the low-frequency sound is usually transmitted through the structure rather than through the air. One of the structures that are used to solve the problem of sounds with a low-frequency band is perforated absorbers and micro-perforated plates.

Micro-perforated panels have been regarded as the most promising material for green sound absorption in the twenty-first century (Zha et al. 2002; Kang and Brocklesby 2005; Fuchs et al. 2001; Qian et al. 2018). This could be due to the durability, sensitivity, recyclability, and flexibility in design, as well as the high sound absorption characteristics of these materials. Unlike sound-absorbent materials, these panels have no chance of emitting powdered fibers and do not have undesirable health effects. The MPP absorber is a thin film or panel (plastic, metal, etc.) with a low thickness, submillimeter pores, and porosity ratio less than 1% with an air gap and rigid wall at the rear (Fig. 1) (Sakagami et al. 2009).

The presence of pores along with the air gap behind them generates a Helmholtz resonator, whose absorption

*Correspondence:
Akram Tabrizi
tabrizi9@gmail.com
[1] Department of Occupational Health and Safety Engineering, Faculty of Health, Social Determinants of Health Research Center, Gonabad University of Medical Sciences, Gonabad, Iran
[2] Department of Occupational Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran
[3] Department of Occupational Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
[4] Student Research Committee, Department of Occupational Health and Safety Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran

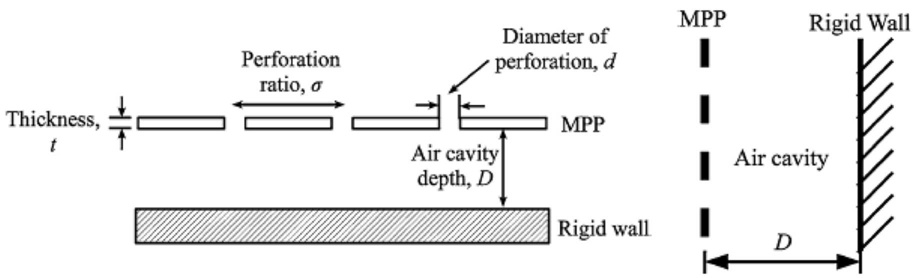

Fig. 1 Showing the schematic of an MPP adsorbent (Sakagami et al. 2009)

peak is within the resonant frequency range (Sakagami et al. 2010). As a general rule, the central mechanism of sound absorption is based on the Helmholtz resonance absorption (Toyoda et al. 2010; Ashour et al. 2011; Dowell 1975). One of the advantages of such a structure is the frequency resonance that can be adjusted and created depending on the purpose (Fahy 2000). These panels have been developed in succeeding years (Qian et al. 2013; Sakagami et al. 1996; Davern 1977; Okuzono 2015 and Sakagami 2015; Sagartzazu et al. 2008) and have been reviewed by many researchers in recent (Maa 1975, 1998; Sakagami et al. 2009; Fasllija and Yilmazer 2023; Alisah et al. 2023; Jiang 2024; Li and Choy 2024; Rezaieyan et al. 2024). Common MPPs have a higher peak absorption coefficient than traditional MPPs. They are more efficient at a wider frequency ranges; however, their sound absorption effect is limited to the resonant frequency range (Sakagami et al. 2010). In recent years, several attempts have been made to extend the bandwidth of MPP acoustic absorption. These include the use of multilayer perforated panels with air holes between them (Sakagami et al. 2009; Sakagami et al. 2014), two MPP installed in parallel (Sakagami et al. 2009) permeable membranes (Gai et al. 2018), and sound-absorbing materials (Toyoda et al. 2017). Several studies have revealed that the use of porous materials in the air gap of common MPPs can improve the peak and frequency range of sound absorption (Sakagami et al. 2011; Okano et al. 2015). On the other hand, in recent years, researchers have paid more attention to natural materials. Both natural fibers and their composites have a higher ability to reduce sound compared to synthetic fibers.

Numerous researchers have created sound-absorbing panels utilizing natural fibers like hemp, cotton, and coconut fibers. These materials are not only aesthetically pleasing but also cost-effective, renewable, readily accessible, and environmentally friendly, posing no harm to human health (Asdrubali et al. 2012). An examination of various natural fibers—including hemp, sugarcane, palm, coconut, kenaf, rice bran, rice husk, rice straw, Hanji (a traditional Korean paper), tea-leaf fiber, mandarin peel, pineapple-leaf fiber, corn husk, peanut shell, sugar palm trunk, *Yucca gloriosa* fiber, fruit stones, wood bark, flax fiber, and nettle fiber—as alternatives to synthetic fiber sound absorbers indicated that, in general, thicker materials provide improved sound absorption performance in the low- and mid-frequency ranges. Additionally, greater density correlates with enhanced sound absorption at the same thickness. Furthermore, increasing the distance between the sound-absorbing material and the air cavity behind it improves sound absorption at lower frequencies. Consequently, these physical characteristics, rather than the specific types of materials, are the primary factors affecting sound absorption performance (Jang 2023).

Since the common sound absorbers have been ineffective in the low-frequency range, in natural fibers, with the increase of material thickness, we can see significant sound absorption in low frequencies and improve it by adopting strategies such as using an air layer or perforated plates (Samaei et al. 2022).

Past research indicates that employing multilayer structures with varying properties, along with the careful selection of influencing parameters, can enhance the overall performance of the structure in the desired frequency range, compared to using each component individually (Asdrubali et al. 2012).

The majority of studies are related to the use of artificial porous adsorbents and fewer studies have investigated the arrangement of natural porous materials and MPP. On the other hand, sound control in the medium- and low-frequency range is still a problem and is not well known. Sugarcane is the largest crop in the world in terms of production and has a lot of agricultural waste and is planted in many countries including Iran. Bagasse is the pomade of sugarcane, which after being pressed and extracted from the sugarcane stalk remains in the form of wet and dense fibers (Beheshti et al. 2023). Because sugarcane production in Khuzestan province of Iran is between 2.5 and 3 million tons per year and it is abundantly available natively in the country, it was chosen to conduct the study.

Finally, the purpose of the present study was to design micro-perforated panels that used porous wood board made of cane bagasse in their structure. Bagasse composite and cane fibers were used in their air gap to improve the sound absorption coefficient of the panel.

Materials and methods

Preparation of materials and equipment

Bagasse is a cane-derived waste obtained in the form of dry and compact fiber pulp. The bagasse used in this study was obtained from one of the bagasse production companies in Khuzestan province of Iran and transferred to the acoustic laboratory of Tarbiat Modares University in Tehran. The specimens were dried and packed in plastic bags using a laboratory dryer. The dried bagasse was transformed into fine particles in two stages using crushing. The shredded bagasse was kept at laboratory ambient temperature for 4 days and then stored in a cylindrical dryer at 80 °C and then dried for 2.5 h until it reaches 3% moisture. Coarse wood chips were removed, and wood chips with appropriate dimensions were kept in a plastic bag (to prevent moisture absorption). Sugarcane fibers were also purchased from the Sugar Cane Research and Development Center in Khuzestan province. Then the specimens were incubated for 24 h at 70 °C, and the desired devices such as press machine and impedance tube were prepared according to the instructions of the manufacturing companies.

Manufacture of bagasse and sugarcane fibers composite

In this study, the sound absorption coefficient of bagasse was first examined. For this purpose, bagasse composite samples were prepared and tested using an impedance tube device. The amount of bagasse and fibers needed to make each sample was weighed and adhered with a laboratory adhesive. The prepared composite was placed inside molds with 10-cm and 3-cm diameters (according to the impedance tube dimensions) in uniform layers with thicknesses ranging from 1 to 5 cm. It was pressurized to the nominal thickness using a specially designed laboratory press machine. The adhesive used was polyvinyl alcohol (PVA), manufactured by Sigma Company. The adhesive content for all the samples was fixed at 6%.

Accordingly, the amount of adhesive (6% of the mass of dried bagasse), the mass density of the sample (150 kg/m^3), the type of adhesive (PVA), press time (45 min), and press pressure (30 bar) were determined (Feig et al. 2013). The steps of making a fiber composite are shown in Fig. 2.

Design and fabrication of natural micro-perforated panels

In this study, natural MPPs (using bagasse) and an artificial MPPs (using plexiglass) were constructed. As mentioned, the MPPs consist of a perforated plate, an air gap, and a rigid back wall. To enhance their sound insulation, sound-absorbing materials are placed in the air gap.

The perforated plate needed for constructing the natural MPP were made from bagasse, with a density of 500 kg/m^3. A sugarcane fiber composite, possessing a density of 150 kg/m^3, was utilized as an absorbent filler material within the air gap of the MPPs. The sound absorption coefficients were assessed in both single- and double-leaf configurations, as well as with and without absorbent materials in the air gap. Different types of MPPs were designed as described below, and their sound absorption coefficients were subsequently evaluated.

Natural single-leaf micro-perforated panel (without sound-absorbing materials in the air gap)

These panels are the most primitive MPPs comprising a perforated plate with submillimeter pores and a thick rear wall, creating an air gap between the perforated plate and the back wall. Based on various studies that identify a porosity ratio of 1% asnd a pore diameter of 0.5 mm as optimal for MPPs, this study adopted a pore diameter of 0.5 mm and a porosity ratio of 1% for the panels. Since measuring the sound absorption coefficient of a sample using an impedance tube necessitates the preparation of two circular specimens with diameters of 3 cm and 10 cm, respectively, a piece of each diameter was

Fig. 2 Making of sugarcane fiber composite and measurement of its sound absorption coefficient by tube impedance device (Beheshti et al. 2022)

Table 1 Physical parameters of perforated plate with 3-cm diameter

Sample no	Pore diameter (mm)	Radius of perforated plate (mm)	Thickness of perforated plate (mm)	Perforation ratio (%)	Density (kg/ m^3)	Weight of bagasse (g)
1	**0.5**	**30**	**2**	**1**	500	0.7065
2	**0.5**	**30**	**4**	**1**	500	1.413
3	**0.5**	**30**	**6**	**1**	500	2.1195
4	**0.5**	**30**	**8**	**1**	500	2.826
5	**0.5**	**30**	**10**	**1**	500	3.5325

Table 2 Physical parameters of samples with 10-cm diameter

Sample no	Pore diameter (mm)	Radius of perforated plate (mm)	Thickness of perforated plate (mm)	Perforation ratio (%)	Density (kg/ m^3)	Weight of bagasse (g)
1	0.5	100	2	1	500	7.85
2	0.5	100	4	1	500	15.7
3	0.5	100	6	1	500	23.55
4	0.5	100	8	1	500	31.4
5	0.5	100	10	1	500	39.25

fabricated from each sample.The physical parameters of the perforated plate are detailed in Tables 1 and 2.

Since the samples have the same density but vary in thickness, the amount of bagasse needed to produce them differs accordingly. MPPs were fabricated with perforated plates of varying thicknesses (ranging from 2 to 10 mm) and air gaps (ranging from 1 to 5 cm). The absorption coefficients were measured using an impedance tube device in accordance with the ISO 10534–2 standard. A laser device was employed to perforate the plates. The fabrication process for the samples is illustrated in Fig. 3.

The schematic of the single-leaf micro-perforated panel is shown below (Fig. 4).

Double-leaf natural micro-perforated panel (without absorbent substance)

These panels consist of two perforated panels with submillimeter pores, with an air gap situated between them. The key difference between this type of MPP and a single-leaf MPP is that, in the double leaf MPP, an additional perforated plate is positioned within the air gap, thereby creating a panel with two distinct air gaps. The schematic of the double-leaf MPP is shown in Fig. 5. Double-leaf MPPs were also made from bagasse's prepared in the previous steps, and a laser device was used to perforate them.

The dimensions of the MPP structure are presented in Table 3.

Natural single- and double-leaf micro-perforated panel (with absorbent substance)

In the present study, the effect of incorporating bagasse and sugarcane fiber composites (with a density of 150 kg/ m^3 and thicknesses ranging from 1 to 5 cm) into the air gap on the sound absorption of MPPs was investigated. The schematic representation of a single-leaf MPP including the sound-absorbing material within the air gap is shown in the following figure (Fig. 6).

Design and manufacture of nonnatural micro-perforated panels

This type of MPP was constructed for comparison with the natural MPP. Nonnatural MPPs were fabricated using plexiglass plates (Fig. 7). Both natural and nonnatural MPPs were manufactured with similar characteristics, including thicknesses of 2, 4, 6, 8, and 10 mm, pore diameters of 0.5 µm, and a porosity of 1%. The only difference between them was the material used to fabricate the perforated plate.

Measurement of sound absorption coefficient using impedance tube

Measurement of sound absorption coefficient was performed by an impedance tube device according to ISO 10534–2 standard. In this device, a large diameter tube (10 cm) is used to measure the sound absorption

Fig. 3 The steps of making natural MPP using bagasse

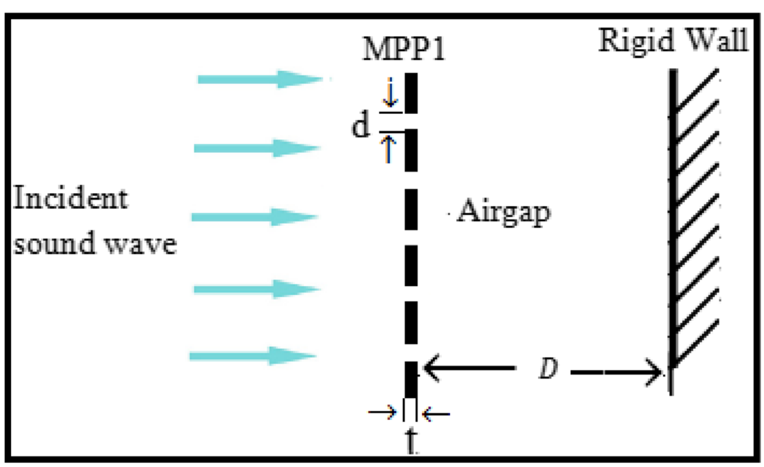

Fig. 4 Schematic of a single-leaf micro-perforated panel

coefficient at low frequencies (1600–100 Hz), and a small diameter tube (3 cm) is used to measure the sound absorption coefficient at high frequencies (1600–6300 Hz). The various parts of the tube impedance device and the sample position inside it are shown in the following figure (Fig. 8).

The experiments for the low-, mid-, and high-frequency bands were repeated separately, and the average

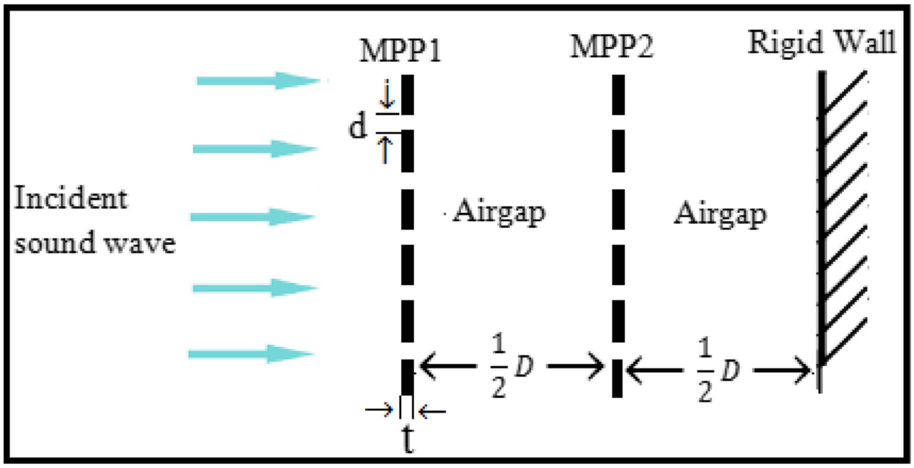

Fig. 5 Schematic of natural double-leaf micro-perforated panel (without absorbent substance)

Table 3 Dimension value of MPP structure

Sample no	Pore diameter (d)	Thickness of perforated plate (t)	Porosity ratio (%)	Air gap (D)
1	0.5 μm	2 mm	1	1 cm
2	0.5 μm	4 mm	1	2 cm
3	0.5 μm	6 mm	1	3 cm
4	0.5 μm	8 mm	1	4 cm
5	0.5 μm	10 mm	1	5 cm

sound absorption coefficient was calculated for each frequency range. Experimental trials were first done using a single-leaf MPP, and then the second leaf of an MPP with the same specification of the first leaf was added to the bottom of the filler composite and retested.

Results

In general, the results show that natural MPPs had higher absorption coefficients at lower frequencies (below 1000 Hz) than the nonnatural MPPs at all frequencies, and too that increasing the thickness of the perforated plate in natural MPPs causes the peak of absorption coefficient shifts to low frequencies. The application of cane fiber composite in the present study increased the sound absorption coefficient of natural double-leaf MPPs at low frequencies.

Comparison of the sound absorption coefficient of natural (bagasse) with nonnatural (plexiglass) MPP

Nonnatural materials such as spring steel (Yang et al. 2019) and metallic materials such as aluminum and steel (Herrin et al. 2011) are commonly used to manufacture

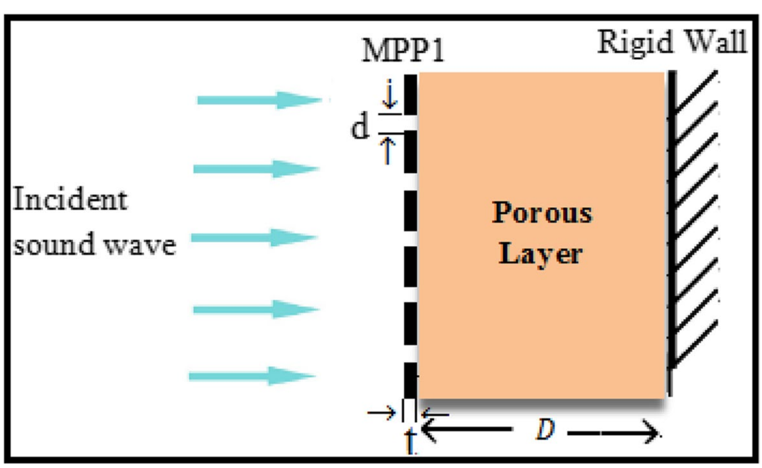

Fig. 6 Schematic diagram of MPP with the sound-absorbing material in the air gap

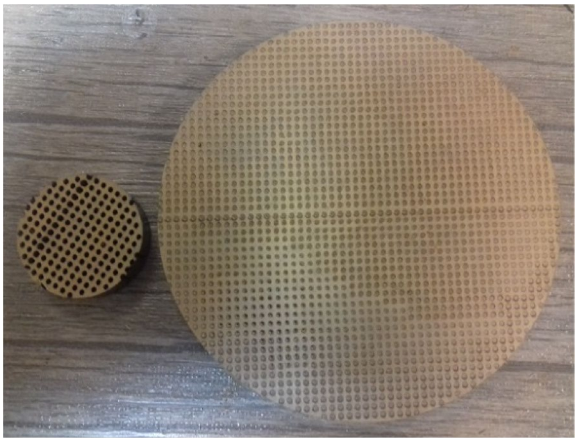

Fig. 7 Nonnatural MPP made of plexiglas (Beheshti et al. 2022)

MPPs. In the present study, natural MPPs made from bagasse and cane fibers were designed, and their sound absorption coefficient was studied for the first time. The results of comparing the sound absorption coefficient of natural MPPs with MPPs made of plexiglas are shown in Fig. 9.

Single-layer natural micro-perforated panels

Effect of thickness

Figure 10 shows the effect of perforated plate thickness on the sound absorption coefficient of the natural MPP.

Based on the results of Fig. 10, MPPs with 8- and 10-mm thicknesses compared to the lower thicknesses have a higher absorption coefficient at lower frequencies. However, the peak of the absorption coefficient is higher in MPPs with lower thickness.

Effect of absorbent substance in the air gap

In the present study, the effect of using sugarcane bagasse and fiber composite as an absorbent material on MPP air gap was investigated. For this purpose, bagasse and cane fiber absorption coefficients were first measured, and then composites with higher sound absorption coefficients were selected as the air gap filler. The results of the sound absorption coefficient of bagasse and cane fiber composite are shown in Fig. 11.

The results of using sugarcane fiber composite (density of 150 kg/m^3 and 5 cm thickness) on the sound absorption coefficient of natural MPPs with different thicknesses are shown in the following figure.

Based on the results of Fig. 12, using a cane fiber composite in the air gap of a single-leaf, natural MPP caused all MPPs to have a sound absorption peak at frequencies below 100 Hz. The results of the effects of a sugarcane fiber composite thickness (density of 150 kg/m^3) on the sound absorption coefficient of a single-leaf MPP made of bagasse (with a density of 500 kg/m^3 and 1-cm thick) are shown in Fig. 13.

Natural double-leaf micro-perforated panels

The sound absorption coefficient of natural double-leaf micro-perforated panels (1-cm thick, 2.5-cm overhead) is shown in Fig. 14.

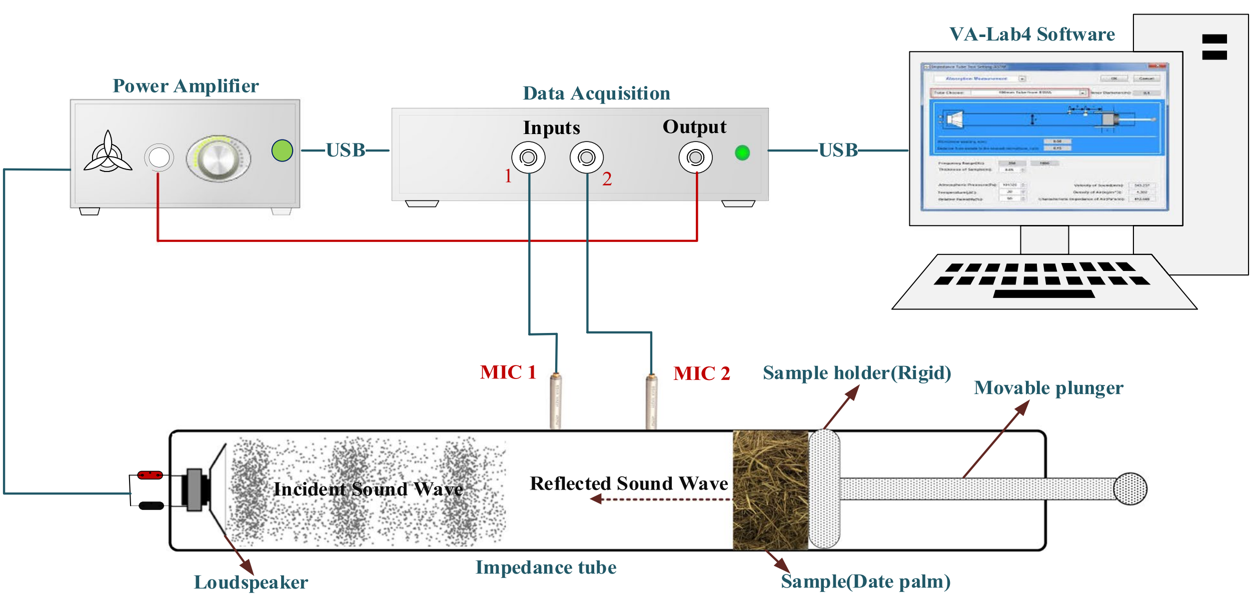

Fig. 8 Schematic diagram of the acoustical measurement system (BSWA, China) (Taban et al. 2019)

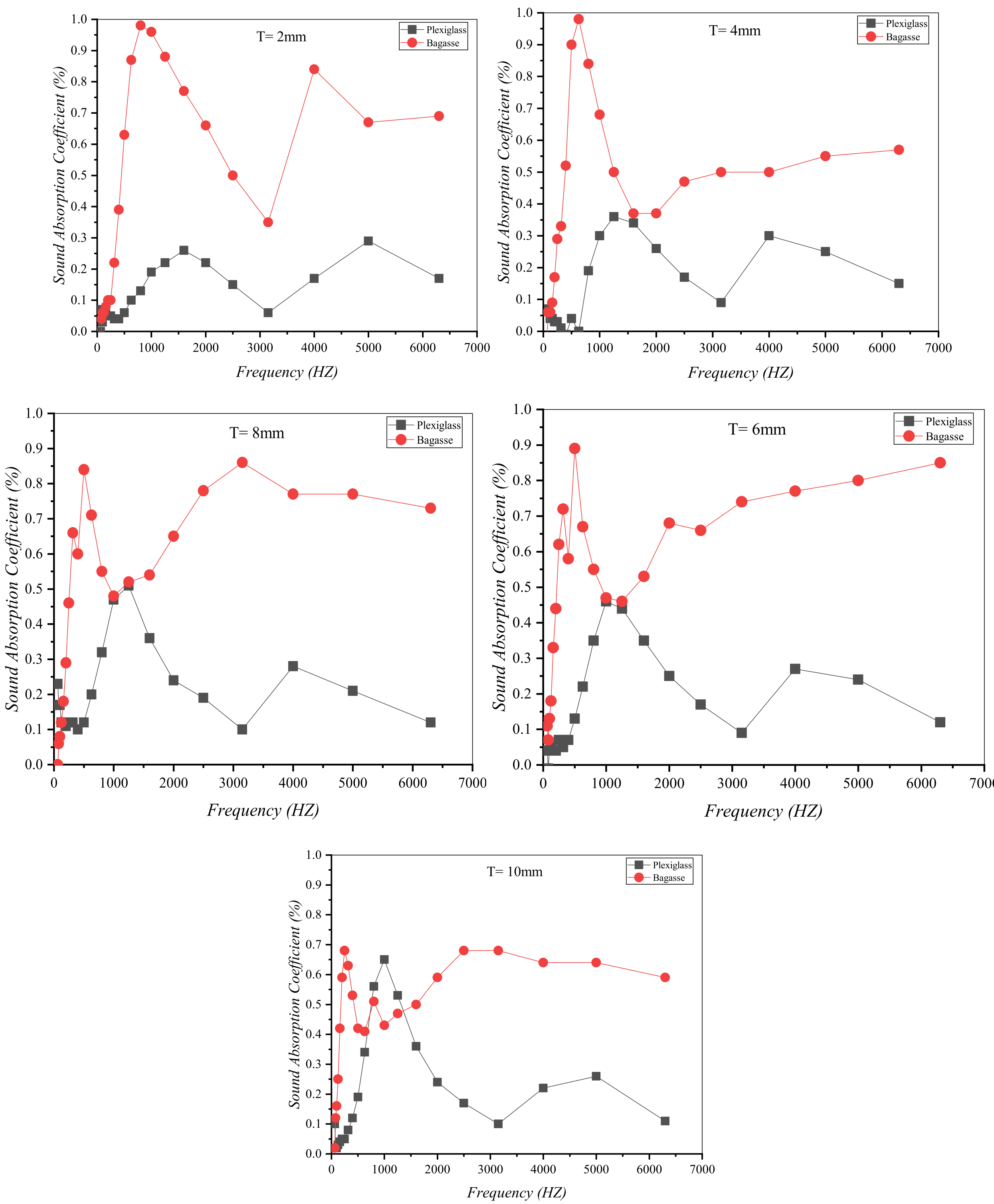

Fig. 9 Comparison of the sound absorption coefficient of bagasse-made MPPs with plexiglas-made MPPs

Also, the effect of using cane fiber composite in the air gap, on the sound absorption coefficient of a natural two-leaf micro-perforated, is shown below.

Discussion

In the present study, natural MPPs made from bagasse and cane fibers were designed, and their sound

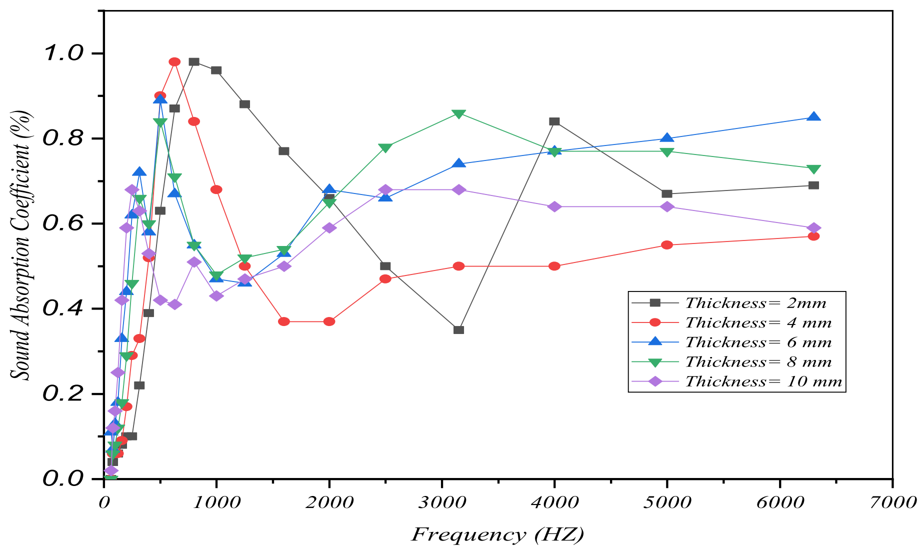

Fig. 10 The sound absorption coefficient of a single-leaf MPP made of bagasse (density 500 kg/m^3, 5-cm air gap, with different thicknesses)

absorption coefficient was studied for the first time. The results of the study showed that the combination of natural absorber and MPPs, with the correct selection of dimensional and macroscopic properties, can improve the performance of the absorber in the low-frequency range. The use of natural materials for the construction of MPP, the use of natural sound absorbers in the MPP air gap, the thickness of the acoustic absorber material, and the number of MPP layers were important factors affecting the sound absorption rate. The material used to make natural MPPs was cane fiber and bagasse. Based on the results of this study, the sound absorption peak of bagasse composite is in the range of 1000 to 2000 Hz, whereas the peak sound absorption of the cane fiber composite in the studied thicknesses is in the range of 100 to 2000 Hz. Sugarcane fibers have higher sound absorption coefficients than bagasse at mid and low frequencies. This can be due to the fact that bagasse is a waste derived from sugarcane and contains about 20–30% of the weight of cane fiber. However, the use of bagasse as a sound absorber has been used in various studies (Kazem and Abdullah 2012; Aziz and Sari 2021; Malawade and Jadhav 2020; Haghighat et al. 2023). The study by Mohit Gaur also suggested the use of bagasse as an alternative to glass wool for sound control (Gaur et al. 2018). In this study, natural MPPs were made from bagasse and cane fibers and sugarcane fibers, and their sound absorption rate was investigated and compared with common panels. In comparison to the sound absorption coefficient of natural (bagasse) with nonnatural (plexiglass) MPP, the results show that natural MPPs had higher absorption coefficients than the nonnatural MPPs at all frequencies. In addition, the sound absorption peak of natural MPPs is at lower frequencies (below 1000 Hz) than nonnatural MPPs. The sound absorption peak of nonnatural MPPs is at a frequency of 1000 to 2000 Hz. The results of the study conducted by Xiaocui Yang et al. showed that the peak sound absorption coefficients of spring steel MPPs were at frequencies above 1500 Hz, and their mean absorption coefficients for 1- to 4-layer MPPs were 57.45%, 70.85%, 71.99%, and 72.28%, respectively, at frequencies of 100 to 600 Hz (Yang et al. 2019).

As a result, using natural MPPs is more desirable to nonnatural MPPs with different sound frequencies. Probably one of the reasons that increased the sound absorption coefficient of natural MPPs is the higher porosity of its perforated plate. In natural MPPs, in addition to the Helmholtz mechanism, which plays an important role in the sound absorption coefficient of all MPPs, the sound absorption caused by perforated plates made of bagasse also adds to it which does not exist in plexiglass plates.

When installing a sound absorbent panel, the properties of the back layer significantly influence its acoustic performance. Research indicates that the back layer's state is crucial in the development of various sound absorbers (Bujoreanu et al. 2017). A common installation method involves positioning the absorber a few centimeters away from a hard surface, creating an air gap that functions similarly to a Helmholtz resonator. Such a method leads to an increase in material absorption at frequencies that previously had a low absorption coefficient (low frequencies) (Pieren 2012). Additionally, studies, including one by Beringare and colleagues, demonstrate that the air

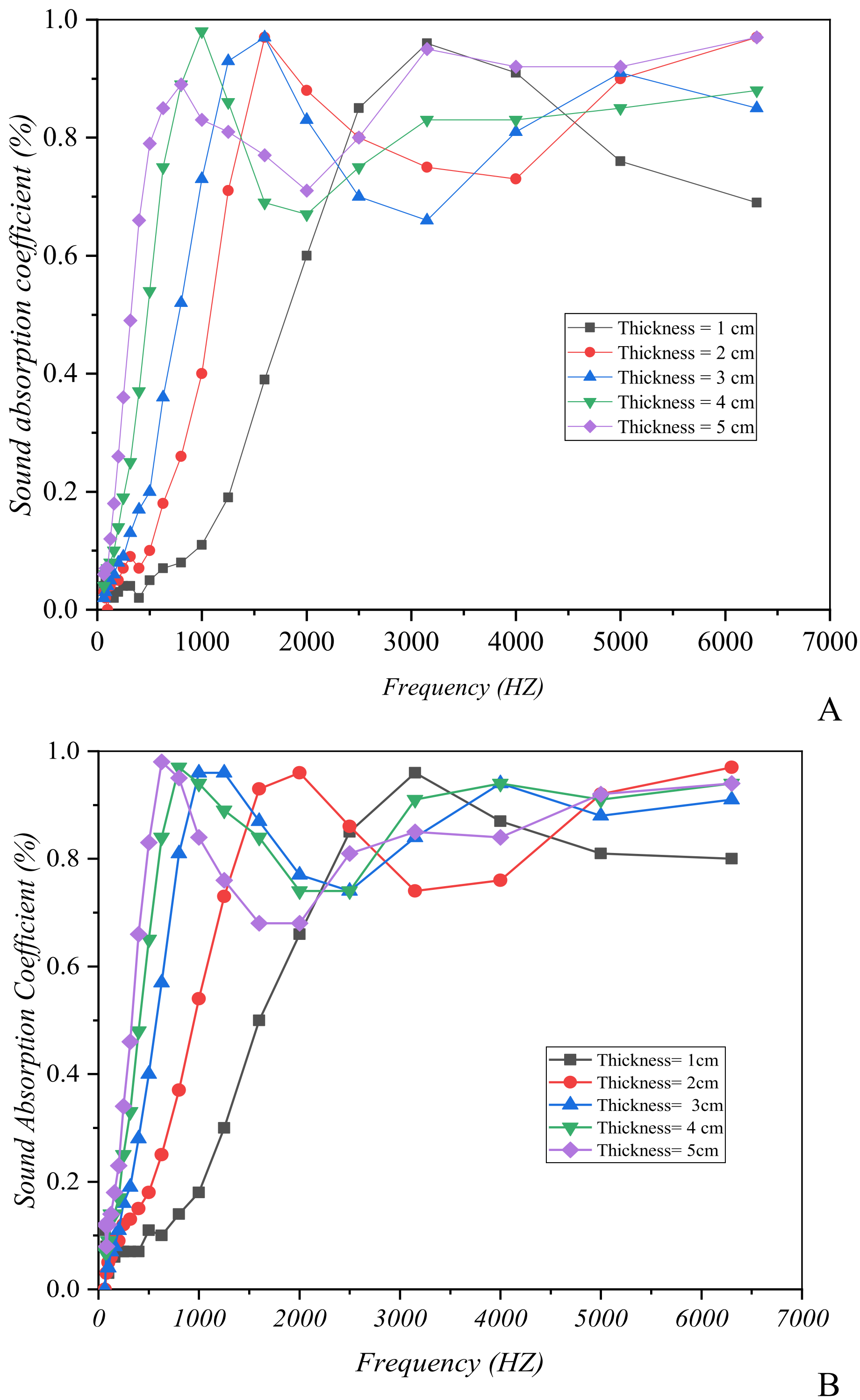

Fig. 11 The sound absorption coefficient of bagasse (**A**) and cane fiber (**B**) composite with a density of 150 and different thicknesses

layer behind the absorber improves sound absorption in natural materials like coconut, sugarcane, and hemp fiber (Bhingare et al. 2019).

Moreover, one disadvantage of MPPs is the limited range of sound absorption frequencies (Arenas and Ugarte 2016). For this purpose, various studies have

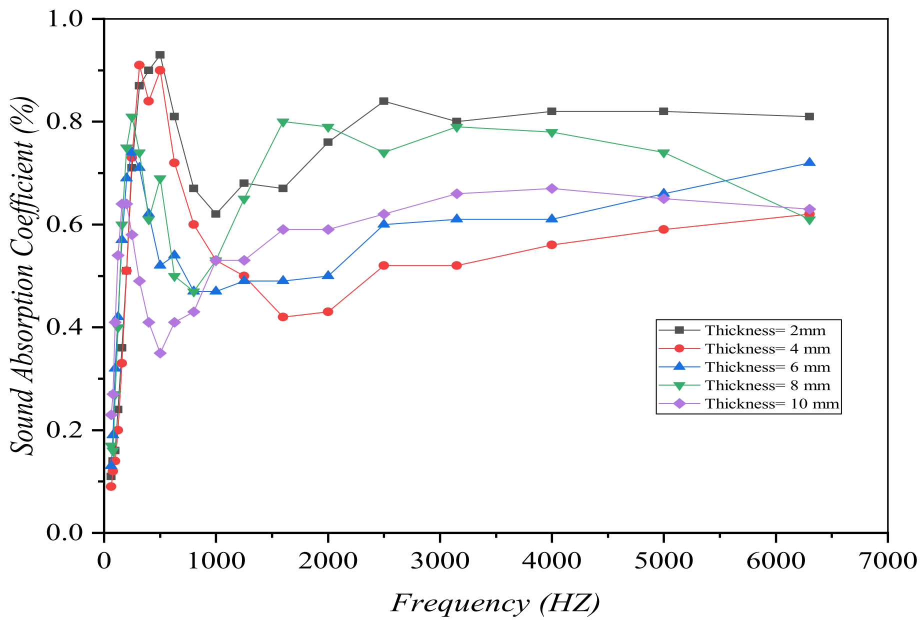

Fig. 12 Effects of using sugarcane fiber composite (density of 150 kg/m^3 and thickness of 5 cm) in air gap on the sound absorption coefficient of a single-leaf MPP made of bagasse with a density of 500 kg/m^3 and different thicknesses

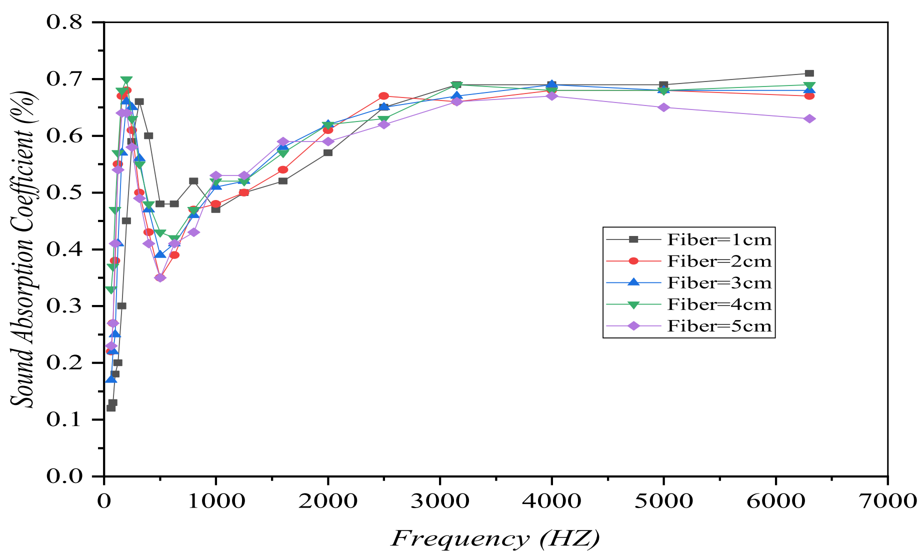

Fig. 13 Effects of a sugarcane fiber composite thickness (density of 150 kg/m^3) on the sound absorption coefficient of a single-leaf MPP made of bagasse (density of 500 kg/m^3 and 1-cm thickness)

investigated the effect of using adsorbent material in the air gap of MPP on their sound absorption coefficients and confirmed the positive effect of using of it (Gaur et al. 2018; Gai et al. 2016a, b; Rusli et al. 2020; Okano et al. 2014; Toyoda et al. 2017; Gai et al. 2018).

On the other hand, it has been shown in various studies that the thickness of acoustic absorbent materials significantly influences their effectiveness in diminishing the transmission of sound energy (Lima et al. 2016). Arenas and Ugarte (2016) showed that low-frequency resonances of MPPs with porous materials are dependent upon the clamping condition, the width of the air-back cavity, and the mechanical properties of the plate (Arenas and Ugarte 2016). In fact, increases in thickness result in a longer duration for thermal and viscous losses of sound energy, which accounts for the direct relationship between the thickness of absorbent materials and the enhancement of the absorption coefficient (Mamtaz et al. 2016).

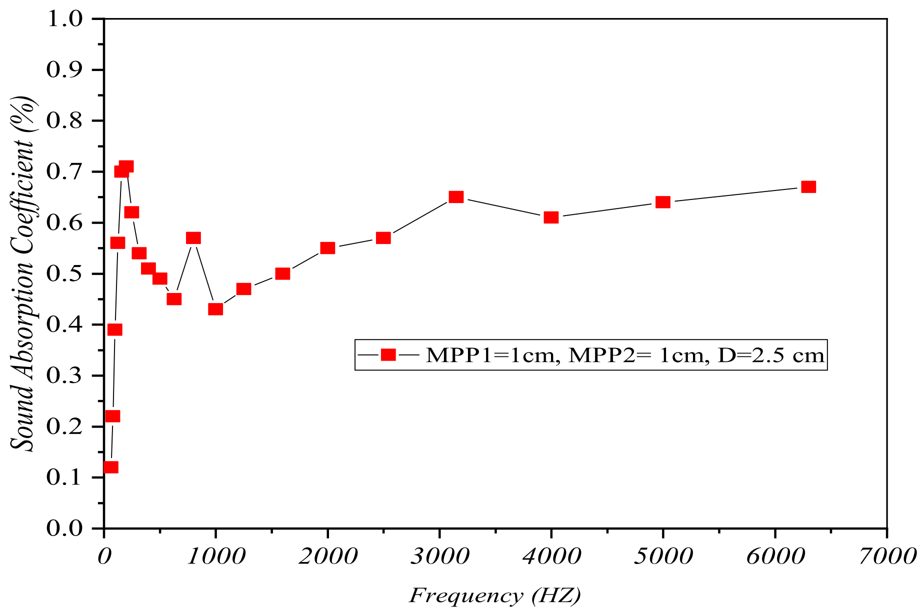

Fig. 14 The sound absorption coefficient of natural double-leaf micro-perforated panels made of bagasse with 2.5-cm air gap

Acoustic tests on date and palm tree fibers revealed that as thickness increases, the sound absorption coefficient improves, and the absorption peak shifts to lower frequencies (Abd ALRahman et al. 2014).

Among the various findings of the study, it was observed that the thickness of sugarcane fiber influences its absorption performance. As anticipated, an increase in the thickness of the sugarcane fiber, while the air layer depth was constant, resulted in a shift of the resonant frequency to lower values. In their study, Lim and colleagues examined how the thickness of the absorber, along with the density and thickness of the air layer, affects the sound absorption coefficient. They discovered that increasing both the density and thickness of the absorber leads to a rise in the sound absorption coefficient (Ying et al 2016).

Berardi and colleagues explored various natural fibers, including hemp, kenaf, cotton, coconut, wood fibers, and sheep wool, to assess their sound absorption coefficients. They also analyzed how fiber size impacts sound absorption in these natural materials. Their findings indicated that the density and thickness of the samples played a significant role in the sound absorption coefficient across all the natural fibers study (Berardi and Iannace 2015). Additionally, in another study, Brady and colleagues reported that thicker absorbers enhance sound absorption rates at lower frequencies (Berardi et al. 2017).

The results of this study show that increasing the thickness of the perforated plate in natural MPPs causes the peak of absorption coefficient shifts to low frequencies, but this factor decreases the absorption coefficient at other frequencies such as high frequencies. Accordingly, it is recommended that low-thickness MPPs (2 and 4 mm) could be used to control high-frequency sounds, and MPPs with a higher thickness (1 cm or more) could be used to control low-frequency sound. This is consistent with the results of the other studies (Beheshti et al. 2022).

Figure 13 shows that as the thickness of cane fiber composites used in MPPs air gap increases, the MPP sound absorption coefficient improves at lower frequencies. Using cane fiber composite on a natural single-leaf MPP caused all MPPs to have a sound absorption peak at frequencies below 150 Hz. Accordingly, using cane fiber in MPP air gap has a very important role in increasing MPPs' sound absorption coefficient at low frequencies. Studies by Kimihiro Sakagami et al. (2011) and Okano et al. (2015) showed that the use of sound-absorbing material in MPP air gaps improves sound absorption, which is consistent with the results of the present study. Also, a study by Xiao-Ling Gai et al. showed that cell membrane and mass block application in a single MPP made of aluminum plates increased sound absorption. This phenomenon is mainly due to the local resonance of the membrane and its mass (Gai et al. 2018). Another study by Xiao-Ling Gai et al. showed that the membrane had a significant effect on sound impedance and MPPs' sound absorption performance, which gradually increased by expanding membrane surface area (Gai et al. 2016a, b). Thus, combining MPPs with the membrane and mass can improve the structure's acoustic absorption properties, and by adjusting the membrane size, an MPP with wider sound absorption bandwidth and a higher sound absorption coefficient than single-leaf MPP can be created. So, it is recommended that future studies consider other effective strategies, including the effect of using a natural membrane, as well as the MPP mass changes on their sound absorption coefficient. The present study also shows that by increasing the thickness of the cane fiber composite used in the air gap, MPPs sound absorption coefficient increases at lower frequencies, but this increase is not very large.

Also, in this study, the effect of double-layered natural MPP was investigated. Figure 15 shows that the peak sound absorption capacity of two-layer natural MPP containing cane fiber composite is at 125 Hz, and as the composite thickness increases, the sound absorption coefficient improves distinctly at the following frequencies.

The peak sound absorption coefficient of the natural double-leaf micro-perforated panels is 76% and is in the range of 160 to 200 Hz. Therefore, natural double-leaf MPPs is more effective than other control strategies for controlling low-frequency sound. The results of other studies on double-leaf MPPs also suggest that this panel has a more sound absorption frequency range than the single-leaf panel (Rusli et al. 2020; Mosa et al. 2018), which is consistent with the results of the present study. The present study also shows that the use of sugarcane composite in the air gap of natural double-leaf MPs increases their sound absorption coefficient at lower frequencies. Also, as the composite thickness increases, the sound absorption coefficient improves distinctly at subsequent frequencies.

A study by Kimihiro Sakagami et al. showed that the application of permeable membranes, comparable with the use of sound-absorbing materials, enhances the sound absorption coefficient at high and mid frequencies (Sakagami et al. 2014; Sarja 1998). The application of cane fiber composite in the present study increased the sound absorption coefficient of natural double-leaf MPPs at low frequencies, and this effect may be due to the difference in the type of applied adsorbents.

The study by Xiao-Ling Gai et al. showed that MPP with an L-shaped structure has a better sound absorption performance compared to the MPP with a single-cavity structure (Gai et al. 2017). Therefore, it is suggested that the effect of the air gap shape of natural MPPs on their sound absorption coefficient be studied in the future. Moreover, the study conducted by Xiao-Ling Gai et al. showed that utilizing the Helmholtz resonators on the perforated plate enhances the absorption coefficient of these panels (Gai et al. 2016a, b). In future studies, examining the effect of natural Helmholtz resonators made from natural material on increasing the sound absorption frequency range of natural MPPs is recommended.

Conclusion

Although synthetic sound absorbers have been widely used in the field of acoustics, their environmental and health impacts are considered a prohibitive factor. In general, the results show that natural MPPs had higher absorption coefficients at lower frequencies (below 1000 Hz) than nonnatural MPPs at all frequencies, and furthermore, the application of cane fiber composites in the present study increased the sound absorption

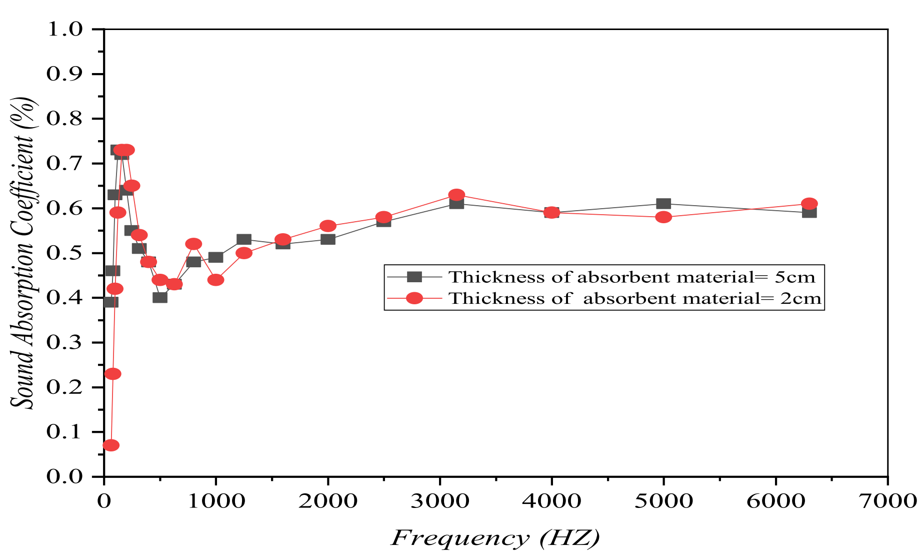

Fig. 15 The sound absorption coefficient of natural double-leaf micro-perforated panels made of bagasse (density of 500 kg/m^3) with absorbent materials in the air gap

coefficient of natural double-leaf MPPs at low frequencies. On the other hand, increasing the thickness of the perforated plate in natural MPPs causes the peak of absorption coefficient to shift to low frequencies. Therefore, in general, natural MPPs made of bagasse with sugarcane fibers composite in their air gap have a very high sound absorption coefficient at low frequencies. Therefore, they can be used to control low-frequency sounds. In the event that natural MPPs made of bagasse with sugarcane fibers composite in their air gap are used as double-leaf MPPs, these panels can be used to control very low-frequency sounds that are not regulated by other methods.

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Authors' contributions
All of authors contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript.

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Availability of data and materials
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Declarations

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The authors declare that they have no competing interests.

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References

Abd ALRahman L, Raja RI, Rahman RA, Ibrahim Z (2014) Comparison of acoustic characteristics of date palm fibre and oil palm fibre. Res J Appl Sci Eng Technol 7(8):1656–61
Alisah MI, Ooi LE, Ripin ZM, Yahaya AF, Ho K (2023) Evaluation of acoustic performance of cascaded cylindrical micro-perforated panel. Proc Inst Mechan Eng J Mater 237(5):1146–58
Arenas JP, Ugarte F (2016) A note on a circular panel sound absorber with an elastic boundary condition. Appl Acoust 114:10–7. https://doi.org/10.1016/j.apacoust.2016.07.002
Asdrubali F, Schiavoni S, Horoshenkov KV (2012) A review of sustainable materials for acoustic applications. Build Acoust 19(4):283–311
Ashour T, Heiko G, Wei W (2011) Performance of Straw Bale Wall: A Case of Study. Energy Build 43(8):1960–67. https://doi.org/10.1016/j.enbuild.2011.04.001
Aziz MA, Sari KA (2021) Comparison of sound absorption coefficient for natural fiber. Prog Eng Applic Technol 2(1):157–63
Beheshti MH, Khavanin A, Varyani AS, Yahya MNB, Alami A, Khajenasiri F, Talebitooti R (2022) Improving the sound absorption of natural waste material-based sound absorbers using micro-perforated plates. J Nat Fibers 19(13):5199–5210. https://doi.org/10.1080/15440478.2021.1875364
Beheshti MH, Firoozi A, Jafarizaveh M, Tabrizi A (2023) Acoustical and thermal characterization of insulating materials made from wool and sugarcane bagasse. J Nat Fibers 20(2):2237675
Berardi U, Iannace G (2015) Acoustic characterization of natural fibers for sound absorption applications. Build Environ 94:840–52. https://doi.org/10.1016/j.buildenv.2015.05.029
Berardi U, Iannace G, Di Gabriele M (2017) The acoustic characterization of broom fibers. J Nat Fibers 14(6):858–63
Bhingare NH, Prakash S, Jatti VS (2019) A review on natural and waste material composite as acoustic material. Polym Testing 80:106142
Bujoreanu C, Nedeff F, Benchea M, Agop M (2017) Experimental and theoretical considerations on sound absorption performance of waste materials including the effect of backing plates. Appl Acoust 119:88–93
Davern WA (1977) Perforated Facings Backed with Porous Materials as Sound Absorbers-An Experimental Study. Appl Acoust 10(2). https://doi.org/10.1016/0003-682X(77)90019-6
Dowell EH (1975) Radiation from Panels as a Source of Airframe Noise. AIAA Journal 13(11). https://doi.org/10.2514/3.7027
Fahy FJ (2000) Foundations of engineering acoustics. Elsevier. pp 443, ISBN 0080506836, 9780080506838.
Fasllija E, Yilmazer S (2023) Investigating the potential of transparent parallel-arranged micro-perforated panels (MPPs) as sound absorbers in classrooms. Int J Environ Res Public Health 20(2):1445
Feig DS, Shah BR, Lipscombe LL, Wu CF, Ray JG, Lowe J, Hwee J, Booth GL (2013) Preeclampsia as a risk factor for diabetes: a population-based cohort study. PLoS Med 10(4). https://doi.org/10.1371/journal.pmed.1001425
Fuchs HV, Zha X, Zhou X, Drotleff H (2001) Creating low-noise environments in communication rooms. Appl Acoust 62(12). https://doi.org/10.1016/S0003-682X(01)00008-1
Gai XL, Li XH, Zhang B, Xing T, Zhao JJ, Ma ZH (2016a) Experimental study on sound absorption performance of microperforated panel with membrane cell. Appl Acoust 110:241–7. https://doi.org/10.1016/j.apacoust.2016.03.034
Gai XL, Xing T, Li XH, Zhang B, Wang WJ (2016b) Sound absorption of microperforated panel mounted with Helmholtz resonators. Appl Acoust 114:260–65. https://doi.org/10.1016/j.apacoust.2016.08.001
Gai XL, Xing T, Li XH, Zhang B, Wang F, Cai ZN, Han Y (2017) Sound absorption of microperforated panel with l shape division cavity structure. Appl Acoust 122. https://doi.org/10.1016/j.apacoust.2017.02.004
Gai XL, Xing T, Li XH, Zhang B, Cai ZN, Wang F (2018) Sound absorption properties of microperforated panel with membrane cell and mass blocks composite structure. Appl Acoust 137. https://doi.org/10.1016/j.apacoust.2018.03.013
Gaur M, Muzammil M, Khan AA (2018) Bagasse—a replacement of glass wool as an acoustic material. In: Ergonomics in Caring for People. https://doi.org/10.1007/978-981-10-4980-4_14
Haghighat M, Samaei SE, Amininasab S, Faridan M, Mehrzad S, Sheikhmozafari MJ, Taban E (2023) The impact of fiber size on the sound absorption behavior of composites made from sugarcane bagasse wastes fibers. J Nat Fibers 20(1):2175760
Herrin D, Liu J, Seybert A (2011) Properties and applications of microperforated panels tuning microperforated panel absorbers. Sound Vib 45:6–9
Jang E-S (2023) Sound absorbing properties of selected green material—a review. Forests 14(7):1366
Jiang C (2024) Investigation on acoustic performance of distributed periodic micro perforated panel. Noise Control Eng J 72(2):131–149
Kang J, Brocklesby MW (2005) Feasibility of applying micro-perforated absorbers in acoustic window systems. Appl Acoust 66(6). https://doi.org/10.1016/j.apacoust.2004.06.011
Kazem DH, and Abdullah A (2012) Investigating the possibility of using bagasse in making soundproof chipboard
Li Y, Choy YS (2024) Acoustic behaviour of micro-perforated panel backed by shallow cavity under fully developed grazing flow. J Sound Vib 569:117985

Lima KF, Barbieri N, Barbieri R, Grossl VA (2016) Determination of the acoustical properties of sisal and coconut fiber samples based on the flow resistivity experimental assessment. J Acoust Soc Am 140(4_Supplement):3141
Maa DY (1975) Theory and Design of Microperforated Panel Sound-Absorbing Constructions. Scientia Sinica
Maa D-Y (1998) Potential of Microperforated Panel Absorber. J Acoust Soc Am 104(5). https://doi.org/10.1121/1.423870
Malawade UA, Jadhav MG (2020) Investigation of the acoustic performance of bagasse. J Market Res 9(1):882–89. https://doi.org/10.1016/j.jmrt.2019.11.028
Mamtaz H, Fouladi MH, Al-Atabi M, Namasivayam SN (2016) Acoustic absorption of natural fiber composites. J Eng 2016(1):5836107
Mosa AI, Putra A, Ramlan R, Esraa AA (2018) Micro-perforated panel absorber arrangement technique: a review. J Adv Res Dyn Control Syst 10(7). ISO 690
Okano M, Sakagami K, Yairi M (2014) Effect of a porous absorbing layer on absorption characteristics of a double-leaf MPP space sound absorber. Memoirs Graduate Sch Eng Syst Inform Kobe Univ No. 6, pp. 7–12. https://doi.org/10.5047/gseku.e.2014.005
Okano M, Sakagami K, Yairi M (2015) Effect of a porous absorbing layer on absorption characteristics of a double-leaf MPP space sound absorber. Memoirs Graduate Sch Eng Syst Inform Kobe Univ. https://doi.org/10.5047/gseku.e.2014.005
Okuzono T, Kimihiro S (2015) A Finite-Element Formulation for Room Acoustics Simulation with Microperforated Panel Sound Absorbing Structures: Verification with Electro-Acoustical Equivalent Circuit Theory and Wave Theory. Appl Acoust 95. https://doi.org/10.1016/j.apacoust.2015.02.012
Pieren R (2012) Sound absorption modeling of thin woven fabrics backed by an air cavity. Text Res J 82(9):864–74
Qian YJ, Kong DY, Liu SM, Sun SM, Zhao Z (2013) Investigation on Micro-Perforated Panel Absorber with Ultra-Micro Perforations. Appl Acoust 74(7). https://doi.org/10.1016/j.apacoust.2013.01.009
Qian YJ, Zhang J, Sun N (2018) A Strategy for extending the effective application of micro-perforated panel absorbers to high sound intensity. Appl Acoust 130. https://doi.org/10.1016/j.apacoust.2017.09.014
Rezaieyan E, Taban E, Berardi U, Mortazavi SB, Faridan M, Mahmoudi E (2024) Acoustic properties of natural fiber reinforced composite micro-perforated panel (NFRC-MPP) made from cork fiber and polylactic acid (PLA) using 3D printing. J Build Eng 108491
Rusli M, Rahman F, Gusriwandi HD, Bur M (2020) Sound Absorption Characteristics of a Single Micro-Perforated Panel Backed by a Natural Fiber Absorber Material. In: Solid State Phenomena, vol. 307. SSP. https://doi.org/10.4028/www.scientific.net/SSP.307.291
Sagartzazu X, Hervella-Nieto L, Pagalday JM (2008) Review in Sound Absorbing Materials. Archives of Computational Methods in Engineering 15(3). https://doi.org/10.1007/s11831-008-9022-1
Sakagami K, Motoki Y, Masayuki M (2010) Multiple-Leaf Sound Absorbers withMicroperforated Panels: An Overview.Acoustics Austral
Sakagami K, Yoshiki N, Masayuki M, Motoki Y (2009) Pilot Study on Wideband-Sound Absorber Obtained by Combination of Two Different Microperforated Panel (MPP) Absorbers. Acoust Sci Technol 30(2). https://doi.org/10.1250/ast.30.154
Sakagami K, Kobatake S, Kano KI, Morimoto M, Yairi M (2011) Sound absorption characteristics of asingle microperforated panel absorber backed by a porous absorbent layer. Acoust Austr 39:95–100
Sakagami K, Fukutani Y, Yairi M, Morimoto M (2014) Sound absorption characteristics of a double-leaf structure with an MPP and a permeable membrane. Appl Acoust 76:28–34
Sakagami, Kimihiro, Masakazu Kiyama, Masayuki Morimoto, and Daiji Takahashi (1996) Sound Absorption of a Cavity-Backed Membrane: A Step towards Design Method for Membrane-Type Absorbers. Applied Acoustics 49(3). https://doi.org/10.1016/S0003-682X(96)00025-4
Samaei SE, Taban E, Berardi U, Mousavi SM, Faridan M, Hassan AM (2022) Optimization and modeling of sound-absorption properties of natural fibers for acoustical application. J Nat Fibers 19(13):7157–73
Sarja A (1998) Integrated Life Cycle Design of Materials and Structures. In: CIB World Congress, Gävle, Sweden, June, 8:13
Taban E, Tajpoor A, Faridan M, Seyed ES, Beheshti MH (2019) Acoustic Absorption Characterization and Prediction of Natural Coir Fibers. Acoustics Australia 47 (1). https://doi.org/10.1007/s40857-019-00151-8
Toyoda M, Rui LM, Daiji T (2010) Relationship between Helmholtz-Resonance Absorptionand Panel-Type Absorption in Finite Flexible Microperforated-Panel Absorbers. Appl Acoust 71(4). https://doi.org/10.1016/j.apacoust.2009.10.007
Toyoda M, Sakagami K, Okano M, Okuzono T, Toyoda E (2017) Improved sound absorption performance of three-dimensional MPP space sound absorbers by filling with porous materials. Appl Acoust 116:311–6. https://doi.org/10.1016/j.apacoust.2016.10.006
Yang X, Chen L, Shen X, Bai P, To S, Zhang X, Li Z (2019) Optimization of geometric parameters of the standardized multilayer microperforated panel with finite dimension. Noise Control Eng J 67(3):197–209. https://doi.org/10.3397/1/376718
Ying LZ, Putra A, Nor MJ, Muhammad N, Yaakob MY (2016) Sound absorption of multilayer natural coir and kenaf fibers. In: 23rd International Congress on Sound and Vibration, p 1–7
Zha X, Fuchs HV, Drotleff H (2002) Improving the acoustic working conditions for musicians in small spaces. Appl Acoust 63(2). https://doi.org/10.1016/S0003-682X(01)00024-X

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