Properties and Applications of Microperforated Panels

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Microperforated panels (MPP) are acoustic absorbers that are reclaimable, noncombustible, and environmentally friendly. Sound is attenuated due to viscous friction in the submillimeter size pores. The panels are typically spaced from a hard surface and are most effective when the acoustic particle velocity is a maximum in the pores. In this article, the theory of MPP absorbers is briefly reviewed, and their application to noise control problems is shown. We demonstrate that the sound absorption can be tuned to targeted frequency bands by adjusting the depth of the backing cavity and enhanced by partitioning the backing cavity. In many cases, the performance is comparable to foam occupying the same volume in an enclosure.

Traditional sound absorbing materials like glass fiber and foam deteriorate over time and are non-renewable. Small particles become dislodged, travel through ventilation ducts, and pollute the air inside buildings. Though facings are often added to glass fiber and foam to prevent deterioration and to guard against dirt and oil being trapped, the facings are combustible and diminish the performance of sound absorption at high frequency.

One of the more attractive alternatives to fibers and foams are microperforated panel (MPP) absorbers. For ordinary perforates such as those used in mufflers and silencers, hole diameters are on the order of millimeters or even centimeters and have little acoustic resistance. MPP absorbers have pore diameters that are submillimeter in size. Due to the small pores, MPP absorbers provide acoustic resistance, which enhances sound attenuation. Compared to traditional sound-absorbing materials, MPP absorbers are unique, because they are reclaimable, cleanable, noncombustible, rugged, fiber free, and light weight. They have been used successfully in the German Parliament Building[1] and are commercially used in construction equipment, building interiors, and mufflers. For example, Figure 1 shows a MPP absorber used in a reception area. Note that the absorber can be painted and is aesthetically pleasing. Figure 2 shows an MPP absorber used in the engine compartment of a boat.

MPP absorbers are normally manufactured from plastic or metal. In the past, holes were circular in shape and were cut using a laser. Accordingly, MPP absorbers were more expensive than traditional materials and were considered too costly for commercial use. However, lower-cost MPP absorbers are now available. Instead of circular holes, slits are manufactured into metal or plastic. Slit-shaped perforations have a slightly smaller acoustic resistance but function similar to circular holes for all practical purposes.[2,3] Figure 3 compares photos of MPP absorbers with circular holes and slits.

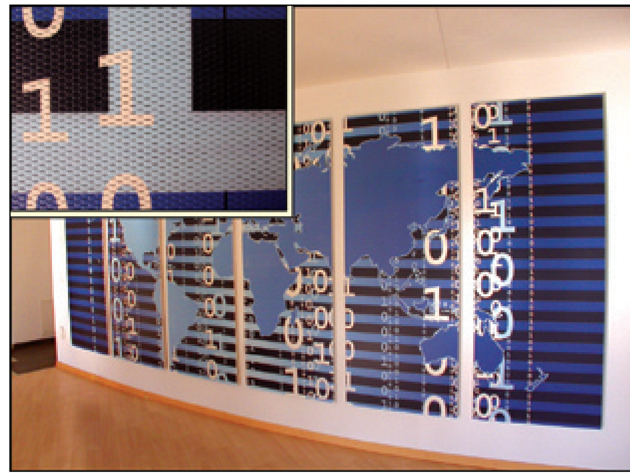

Figure 1. MPP used in reception area; inset shows perforations.

Figure 2. MPP absorbers used in engine compartment of a boat.

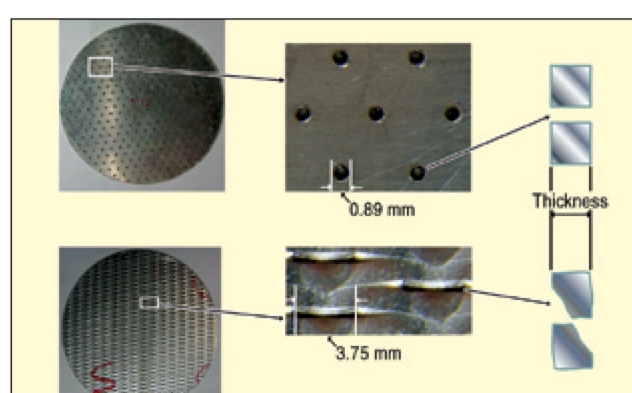

Figure 3. Photographs showing microperforated panels with circular and slit-shaped perforations.

Tuning Microperforated Panel Absorbers

MPP absorbers are tunable and can provide better sound absorption at low frequencies than typical foams and glass fiber. More than 35 years ago, Maa[4] developed a model to characterize the absorption properties of MPP absorbers having circular-shaped holes. The model describes the MPP absorber performance as a function of the pore diameter, porosity, thickness, and backing cavity depth.

A MPP absorber can be modeled as a transfer impedance (see Figure 4). The normalized transfer impedance can be expressed as:

$$Z_{tr} = \frac{p_1 - p_2}{\rho c v} \tag{1}$$

where p_1 and p_2 are the upstream and downstream sound pressure, respectively, v is the particle velocity in the pore, and ρc is the characteristic impedance of air.

An expression for the transfer impedance in terms of the pore diameter d, panel porosity σ, and thickness t, according to Maa[4] is:

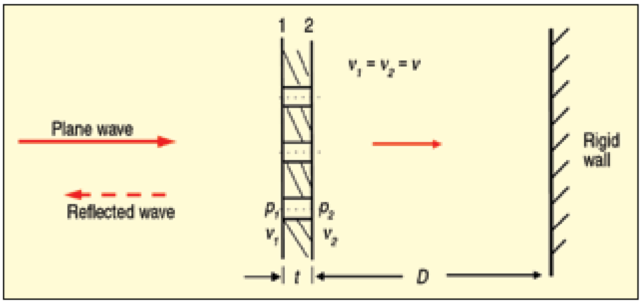

Figure 4. Schematic showing MPP and backing cavity.

$$Z_{tr} = \frac{\Delta p}{\rho c v} = \frac{32\eta t}{\sigma \rho c d^2}\left(\left(1+\frac{\beta^2}{32}\right)^{1/2} + \frac{\sqrt{2}}{8}\beta\frac{d}{t}\right) + \left(\frac{\omega t}{\sigma c}\left(1+\left(3^2+\frac{\beta^2}{32}\right)^{-1/2} + 0.85\frac{d}{t}\right)\right) \quad (2)$$

where ω is the frequency, c is the speed of sound, η is the viscosity, and β is a perforate constant dependent on the properties of the fluid. β is given as:

$$\beta = d\sqrt{\omega\rho / 4\eta} \quad (3)$$

where ρ is the mass density of air. Note that Eq. 2 is only directly applicable to circular-shaped pores. The transfer impedance for slit-shaped perforations should be measured in an impedance tube.

Though cavity depth does not affect transfer impedance, it governs the total acoustic impedance of the MPP plus cavity. The total acoustic impedance Z is a series combination of the MPP plus the cavity and can be expressed as:

$$Z = \frac{p_1}{\rho c v_1} = Z_{tr} - j\cot\frac{\omega d}{c} \quad (4)$$

where D is the depth of the backing cavity. The normal incident absorption can be expressed as:

$$\alpha_n = \frac{4r_n}{(1+r_n)^2 + (x_n)^2} \quad (5)$$

where r_n and x_n are the real and imaginary parts of the normalized impedance, respectively.

Notice that changing the backing cavity depth modifies only the imaginary part of Z via the cotangent term. MPP absorbers are most effective when the backing cavity depth is approximately one-quarter acoustic wavelength. In this case, the particle velocity in the pores is a maximum (the cotangent term in Eq. 4 is zero). Therefore, the cavity depth dictates the frequency at which the acoustic particle velocity is a maximum. The absorber is best thought of as a system comprised of both the MPP and the backing cavity.

Figure 5 illustrates the effect of changing the cavity depth on the absorption coefficient for an MPP absorber while holding porosity and hole diameter constant at 1.5% and 0.25 mm, respectively. The contour plot was created using Eqs. 2-5. Notice that the frequency bands exhibiting high absorption decrease in frequency as the cavity depth is increased. Therefore, absorption performance is most easily tuned by adjusting the depth of the backing cavity.

Figure 6 compares the normal incidence acoustic absorption coefficient of an MPP absorber with a backing cavity depth of 70 mm to open-cell foam (flow resistivity of 5000 rayls/m) occupying the same volume. Notice that the MPP absorber performs as well as foam in certain frequency bands and is more effective at lower frequencies. This is particularly advantageous, because many noise sources (engines and pumps, for example) are dominated by low-frequency sound. On the other hand, the MPP absorber is ineffective in certain frequency bands. Nevertheless, broadband absorption can be achieved by strategically varying the depth of the backing cavity behind the MPP.

Partitioning the Backing Cavity

MPP absorbers perform best when the backing cavity is partitioned.[5,6] Reference 7 documents research by the authors examining the performance of an MPP absorber inside a wooden box. The box is intended to represent either a small enclosure or a silencer. A 1 × 0.5 × 0.5-meter wooden box was constructed as shown in

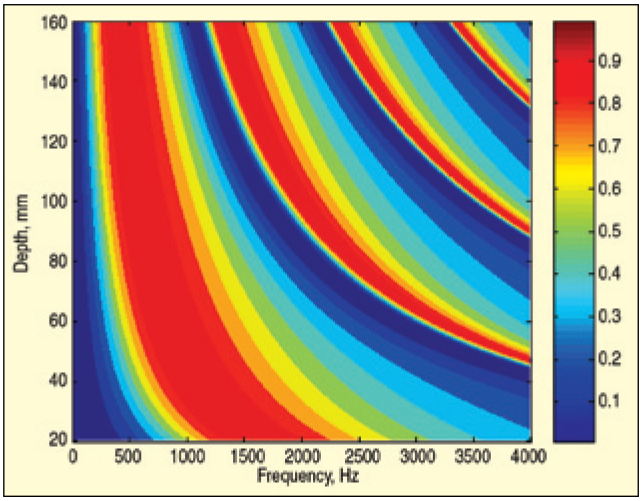

Figure 5. Effect of varying cavity depth on sound absorption coefficient.

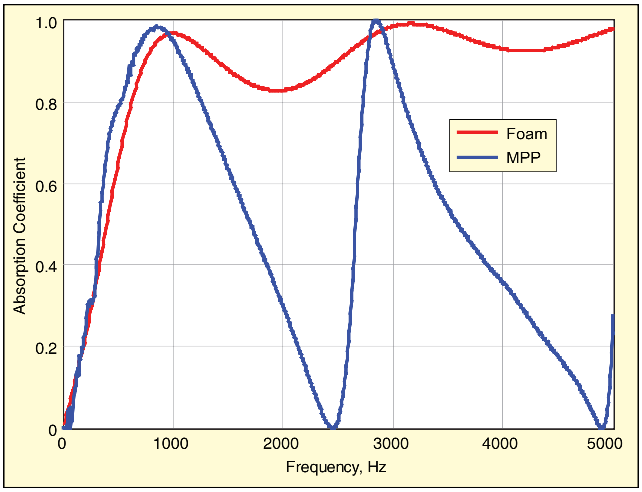

Figure 6. Comparison of normal incidence absorption between MPP absorber and open-cell foam.

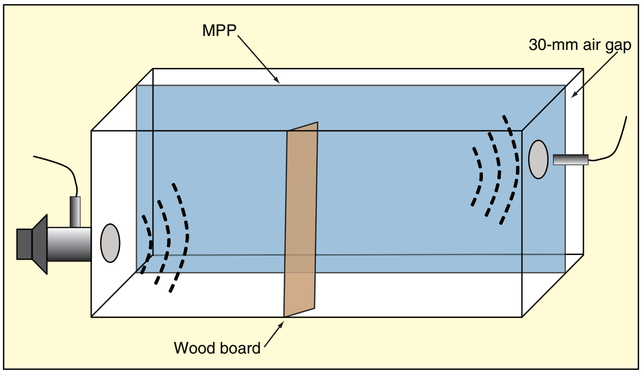

Figure 7. Schematic showing enclosure and experimental setup.

Figure 7. A panel of wood was inserted into the middle to obstruct the line-of-sight sound path between inlet and outlet ducts. A 1 × 0.5-meter MPP absorber with slit-shaped perforations (2.5% porosity and 1.2 mm thickness) was attached to one side of the box. The depth of the air cavity was set to 30 mm, corresponding to a maximum attenuation at 1500 Hz.

Three different treatment options were considered and are shown in Figure 8.

- 30-mm-thick, open-cell foam (foam occupied the same volume as the MPP absorber plus air cavity)
- MPP absorber and no partitioning in the backing air cavity
- MPP absorber with partitioning in the backing air cavity

The partitioning was made of cardboard with each cell having dimensions 40 × 40 mm. The noise reduction (difference between the inlet and outlet sound pressure level) is compared in Figure 9

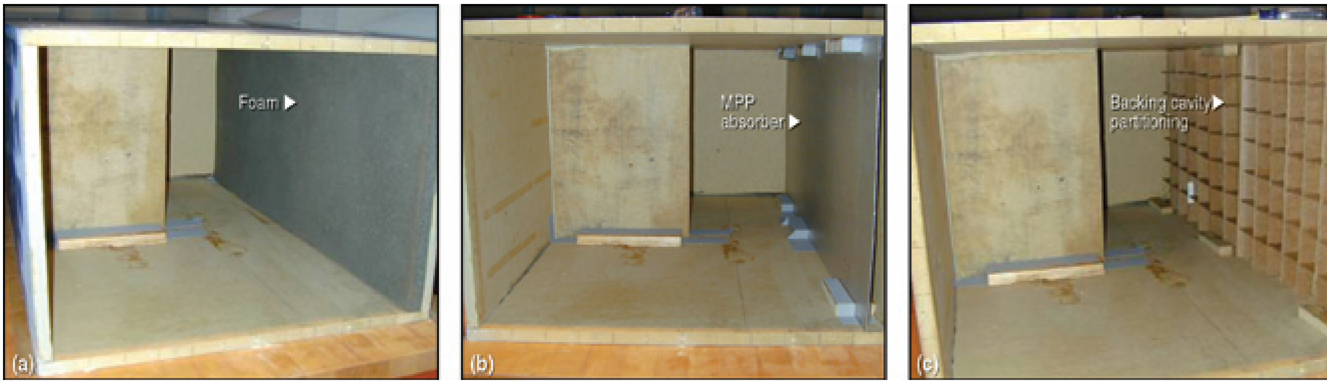

Figure 8. Three treatment options: a) 30-mm-thick, open-cell foam; b) MPP absorber with no partitioning; c) cardboard partitioning behind MPP absorber.

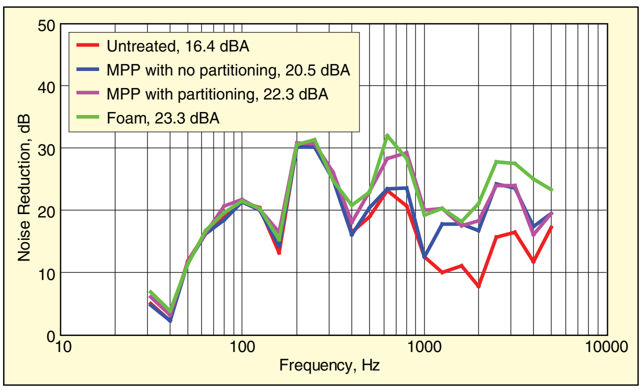

Figure 9. Comparison of noise reduction in dB for different treatment options; overall noise reduction in dBA indicated in legend.

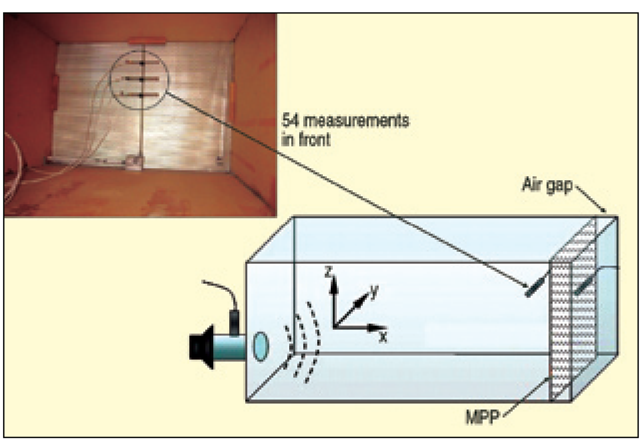

Figure 10. Schematic showing experimental setup for closed enclosure case.

for the three treatment options. Additionally, the noise reduction for the enclosure alone is shown.

Notice that the MPP with no partitioning improves upon the baseline configuration, especially at frequencies above 1000 Hz. However, the noise reduction accomplished using a foam absorber having the same thickness is approximately 3 dB higher than that with the MPP alone. If partitioning is added in the backing cavity, the noise reduction was improved by close to 2 dB. As expected, the honeycomb structure by itself (i.e., without an MPP facing) provided almost no additional noise reduction.

In a follow-up study, we investigated the mechanism for this improved performance with partitioning. The same enclosure was used, but the enclosure was closed, the wooden panel was removed, and the MPP absorber was placed at the end of the box, as shown in Figure 10. Acoustic waves that propagate normal to the panel were attenuated almost equally well with or without a partitioned substrate. However, the sound pressure due to grazing waves (propagating parallel to the MPP absorber) was reduced by close to 8 dB. (See Reference 8 for more information on the experiment and results.)

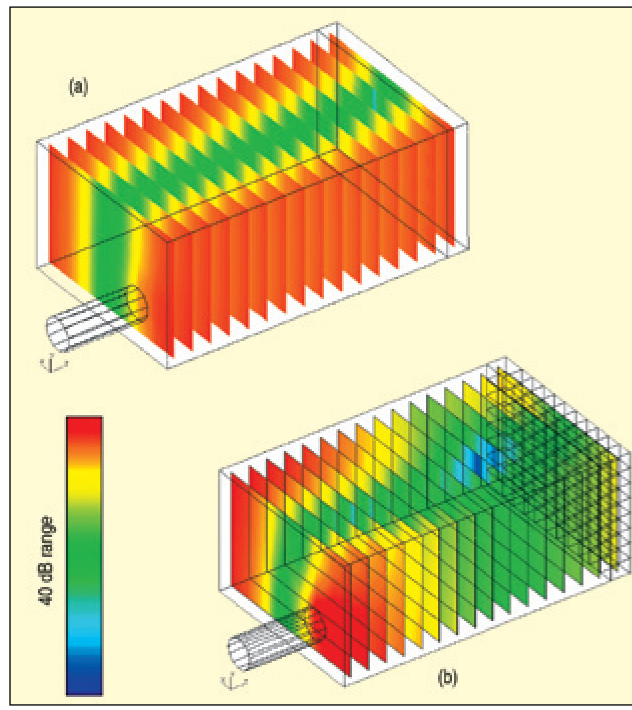

Figure 11. Sound pressure contour plots without partitioning (a) and with partitioning in the backing cavity (b).

To understand the results, the experiment was simulated using the boundary-element method (BEM). In Figure 11, contour plots of the interior sound pressure are shown both with and without partitioning for an acoustic mode propagating in the Y direction. The results indicate that partitioning improves the performance of the absorber by disrupting wave propagation in the cavity behind the MPP. Particle velocity normal to the panel is shown in Figure 12, both with and without partitioning. Note that the particle velocity normal to the panel is negligible without partitioning. If this is the case, the high acoustic resistance in the panel is ineffective. Once partitioning is added, an acoustic pressure difference is produced, and the particle velocity is increased substantially. As a result, the high acoustic resistance of the panel becomes advantageous.

Measuring Transfer Impedance

The model in Eq. 2 is limited to MPP absorbers having circular holes. For manufacturing and cost reasons, most MPP absorbers consist of slits or openings having irregular geometry. For irregularly shaped slits, a theoretical model is unlikely to be sufficiently accurate to predict the acoustic transfer impedance. Instead, it is preferable to measure the acoustic transfer impedance. Recently, a number of methods have been used to measure the transfer impedance of perforates[9-12] or can be adapted[13-15] for such a measurement. Most of these methods use an impedance tube and a pair of microphones.

Figure 13 shows a 35-mm diameter impedance tube (www.spectronics.net) that has been designed to measure impedance and

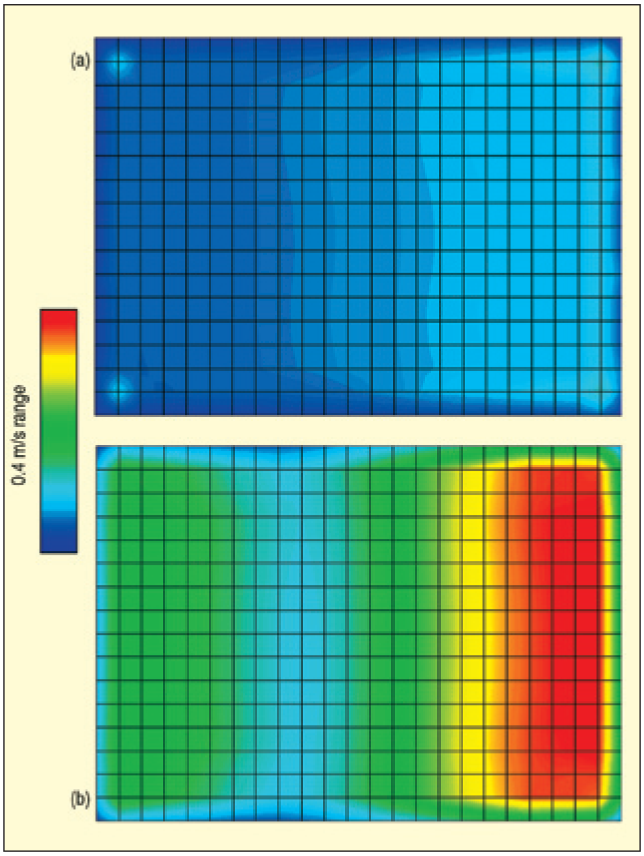

Figure 12. Particle velocity normal to the MPP absorber without partitioning (a) and with partitioning (b).

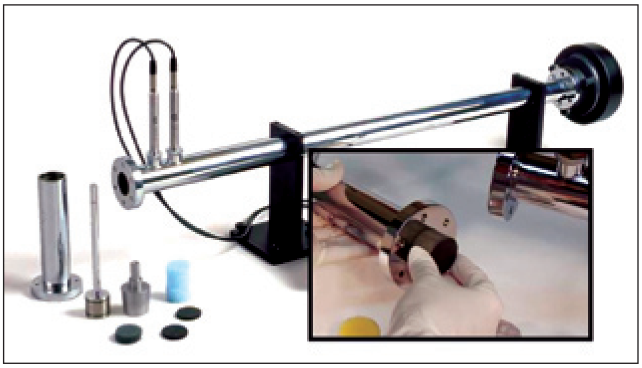

Figure 13. Impedance tube used for measuring transfer impedance (from Spectronics, Inc.).

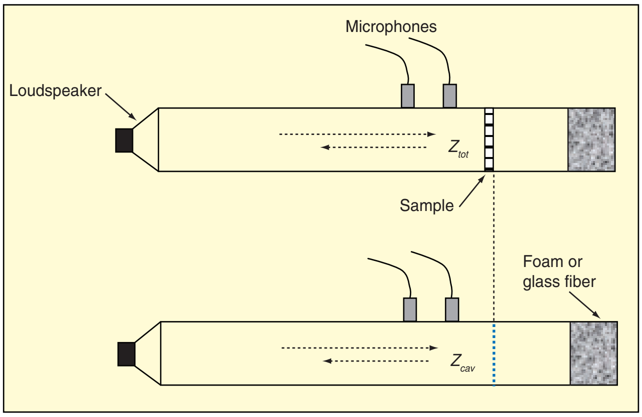

Figure 14. Schematic illustrating measurement approach for determining transfer impedance.

absorption over the range 50-5500 Hz using the two-microphone method (ISO 10534-2, ASTM E-1050). By using a single impedance tube designed for the frequency range of interest, preparation and measurement of a single sample is sufficient. Furthermore, this avoids the discontinuities that necessarily appear when multiple tubes are used for different frequency ranges.

For the results reported in this article, the transfer impedance was measured using the subtraction method.[9,10] In this method, the MPP is placed inside the tube with a short cavity behind it, as shown in Figure 14. The total impedance is a series combination of the transfer impedance of the MPP and the cavity impedance, expressed as :

$$Z_{tot} = Z_{MPP} + Z_{cav} \tag{6}$$

In this arrangement, a measurement of the total impedance (MPP + cavity) is made. The MPP is then removed from the impedance tube, and a second impedance measurement of the cavity alone is made. The transfer impedance of the MPP is then found by subtraction, as indicated in Eq. 6. The measured transfer impedance was used to simulate the sound field inside the enclosure shown in Figure 10; results are shown in Figures 11 and 12.

Conclusions

MPP absorbers are rugged, cleanable, and reclaimable acoustic absorbers that have been successfully used in construction equipment, buildings, and silencers. Sound is attenuated as a result of the high acoustic resistance in the small holes or slits. The absorbers can be tuned by adjusting the depth of the backing cavity behind the MPP. Therefore, the absorbers are best thought of as a system comprising both the MPP itself plus the backing cavity. It has been shown that the attenuation is comparable to open-cell foam having the same thickness, provided that the cavity is partitioned.

Acknowledgments

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