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# Improving sound absorption bandwidth of micro-perforated panel by adding porous materials

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## ABSTRACT

Micro-perforated panel (MPP) has been widely used in acoustic treatments due to its wideband sound absorption coefficient. When the MPP is applied to absorb low frequency noise, more space is required, while at the same time sound absorption bandwidth becomes narrow. In this paper, a combined absorption structure containing the MPP, airspace and porous materials is proposed to improve the sound absorption bandwidth of MPP. The absorption coefficients of combined absorption structures were calculated and as well were measured in the impedance tube. The measured and predicted results are well agreed in the frequency of interest. When the porous materials are put in front of the MPP and there is an air layer between them, the sound absorption is much better in comparison with that of the porous materials are located behind the MPP.

Keywords: sound absorption, MPP, compound sound absorber

## 1. INTRODUCTION

Sound absorbers are widely used in noise control engineering. In general, these sound absorbers can be roughly classified as resonant sound absorbers and porous sound absorbing materials. The resonant sound absorbers, such as the Helmholtz resonator, the perforated panel and so on, are usually designed for absorbing low frequency noise. The porous materials are mainly used in the middle and high frequency noise absorption. Over the past few decades, much work has been devoted to improve the sound absorbing performance of sound absorbers at low frequency range [1~5]. The MPP, though has a relatively wide range absorption bandwidth [1~2], one single MPP is still not able to meet some engineering demands specifically for low frequency and wide absorption bandwidth [3]. To broaden the sound absorption bandwidth of MPP, many scholars tried to add porous material behind the MPP. Lee [4] established a theoretical model of MPP-porous composite sound absorber. Rostand [5] studied the sound absorption of micro-perforated panel backed by a porous material under high sound excitation. Wang [6] investigated a new bionic multi-layer sound absorber contained the porous material, micro-slit panel and micro-perforated membrane.

Although many results indicated that a porous absorbing layer located behind the MPP can improve the low frequency sound absorption, the total sound absorption bandwidth is still limited. The purpose of this paper is to compare the sound absorption of compound structures when porous material layers located at different distances from the MPP. As shown in Figure 1, seven types of compound absorber were investigated in order to find the better one. The results illustrate that putting the porous sound absorbing layer in front of the micro-perforated panel can get a better sound absorption. It is expected that the paper's results can provide some useful references for wideband sound absorber design.

## 2. THEORETICAL FORMULATION

### 2.1 Theory of Micro-perforated Panel

According to Maa's theory for the MPP, The relative specific acoustic impedance of the micro-perforated absorber is given as:

$$r_p = \frac{32\eta t}{p\rho c d^2} k_r, \quad k_r = \left(1 + \frac{k^2}{32}\right)^{1/2} + \frac{\sqrt{2}}{8} k \frac{d}{t} \tag{1}$$

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$$m_p = \frac{t}{pc} k_m, \quad k_m = 1 + \left(9 + k^2 / 2\right)^{-1/2} + 0.85 \frac{d}{t} \tag{2}$$

Where the perforate constant $k = \frac{d}{2}\sqrt{\frac{2\pi f \rho}{\eta}}$ , $t$ is the thickness of the panel (m), $r$ is the radius of the hole of the MPP (m), $p$ is the perforation ratio of the panel (%), $f$ is the frequency (Hz), $\rho$ is the density of the air ( $Kg/m^3$ ), and $\eta$ is the viscous coefficient of air ( $Kg/sm$ ).

### 2.2 Theory of Porous Sound Absorbing Materials

For fibers and foams of high porosity [7], the characteristic impedance and the specific propagation constant can be calculated as follows,

$$Z_c = \rho_0 c_0 \left[1 + c_1 (\rho_0 \frac{f}{\sigma})^{-c_2} - j * c_3 (\rho_0 \frac{f}{\sigma})^{c_4}\right] \tag{3}$$

$$k_p = \frac{\omega}{c_0}[1 + c_7 (\rho_0 \frac{f}{\sigma})^{-c_8} - j * c_5 (\rho_0 \frac{f}{\sigma})^{-c_6}] \tag{4}$$

Where $\rho_0$ is the density of the air ( $Kg/m^3$ ), and $c_0$ is the speed of sound ( $m/s$ ), $f$ is the frequency (Hz), $\omega$ is the angular frequency $(rad/s)$ , $\sigma$ is the air flow resistivity ( $Ns/m^4$ ). The eight parameters $c_1$ - $c_8$ for two kinds of materials are listed in Table 1.

Table 1 – Eight parameters of two kinds of materials

| Sample | $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | $c_6$ | $c_7$ | $c_8$ |
|---|---|---|---|---|---|---|---|---|
| fibers | 0.0571 | -0.7540 | 0.0870 | -0.7320 | 0.1890 | -0.5950 | 0.0978 | 0.7000 |
| foams | 0.1440 | -0.3690 | -0.0985 | -0.7580 | 0.1680 | -0.7150 | 0.1360 | -0.4810 |

### 2.3 Sound Absorption Coefficient of Compound Sound Absorbers

The sound absorption of compound sound absorbers can be calculated by the transfer matrix method. The transfer matrix of the MPP can be written as:

$$T_{MPP} = \begin{pmatrix} 1 & Z_p \\ 0 & 1 \end{pmatrix} \tag{5}$$

The transfer matrix of the porous sound absorbing layer is written as:

$$T_{Porous} = \begin{pmatrix} \cos(k_c d_{porous}) & jZ_c \sin(k_c d_{porous}) \\ j\sin(k_c d_{porous}) / Z_c & \cos(k_c d_{porous}) \end{pmatrix} \tag{6}$$

Where $k_c$ is the wave number in the porous materials and $d_{porous}$ is the thickness of the material, $Z_c$ is the acoustic impedance of the air.

For the air layer the transfer matrix is given by:

$$T_{Air} = \begin{pmatrix} \cos(k_a d_{air}) & jZ_a \sin(k_a d_{air}) \\ j\sin(k_a d_{air}) / Z_a & \cos(k_a d_{air}) \end{pmatrix} \tag{7}$$

Where $k_a$ is the wave number in the air and $d_{air}$ is the air cavity depth, $Z_a$ is the acoustic impedance of the air.

Once the matrices of each layer are obtained, the total transfer matrix of the compound absorber contained the air layer, MPP and the porous sound absorbing materials can be calculated as:

$$T = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \prod_{i=1}^{n} T_i \tag{8}$$

For the compound sound absorber type a, the total matrix is:

$$T = T_{porous} \cdot T_{Airlayer1} \cdot T_{MPP} \cdot T_{Airlayer2} \tag{9}$$

The surface impedance can be obtained as:

$$Z_s = \frac{T(1,1)}{T(2,1)} \tag{10}$$

The reflection coefficient $R$ is obtained as:

$$R = \frac{Z_s - Z_0}{Z_s + Z_0} \tag{11}$$

And the normal incidence sound absorption $\alpha$ is given as:

$$\alpha = 1 - |R|^2 \tag{12}$$

## 3. NUMERCIAL ANALYSIS

### 3.1 Calculation of Seven Types of Compound Sound Absorber

The seven types of compound absorber are shown in Figure 1. The sound absorption coefficients are shown in Figure 2. The total depth of the all absorbers is 20cm. The thickness of the porous layer is 3cm. For type b, c, e and g the depth of the air layer is 17cm. For type a and d the depths of the air layer1 and layer2 are 4cm and 13cm respectively. For type f, the depth of the air layer is 20cm. The porous layer is supposed as glass wool.

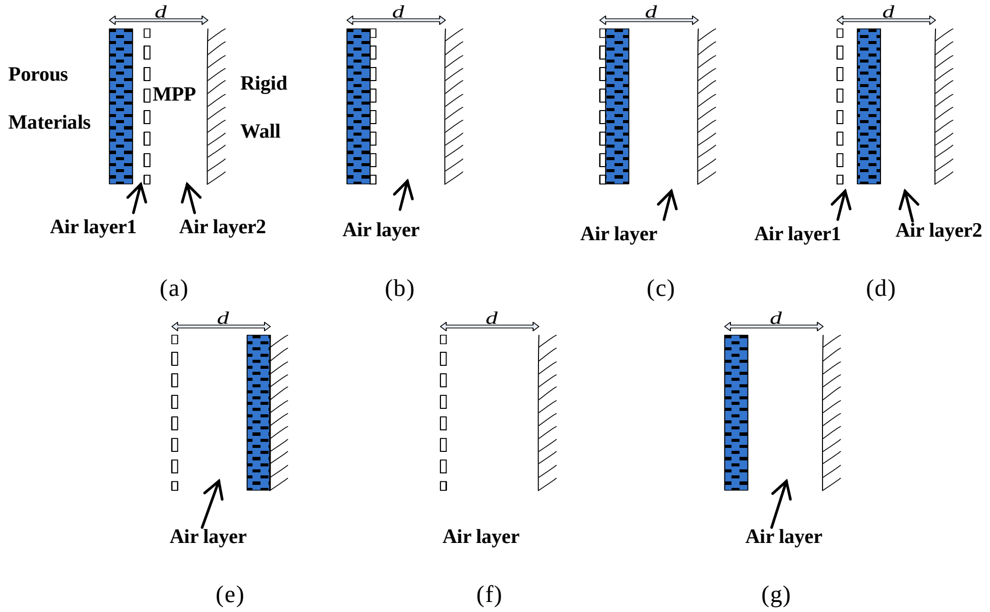



Figure 1 – seven types of compound sound absorber

The parameters of the MPP are given as follows:

Table 2 – Physical parameters of MPP

| Sample | Hole diameter, *mm* | Depth of holes, *mm* | Perforation, % |
|---|---|---|---|
| MPP | 0.7 | 1 | 1.1 |

The parameters of the glass wool are given as follows:

Table 3 – Physical parameters of Glass wool

| Sample | Flow resistivity, $Ns/m^4$ | Density, $Kg/m^3$ | Porosity, % |
|---|---|---|---|
| Glass wool | 10524 | 35 | 100 |

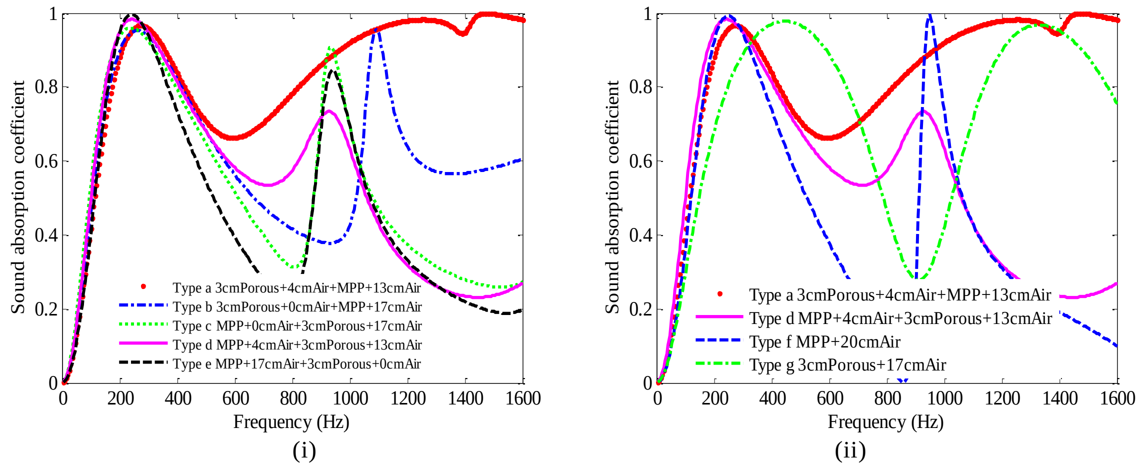



Figure 2 – Sound absorption coefficients of compound sound absorber. (i): type a,b,c,d and e; (ii): type a, d, f, and g.

Figure 2(i) shows that the sound absorbing performance of the compound absorber with the porous layer in front of the MPP (type a and b) is much better than those of the porous layer behind the MPP (type c, d and e). Through the comparison of the sound absorption coefficient curves of the type a and type b, we can find that the air layer between the porous materials and the MPP improves the sound absorbing performance above resonant frequency range of the MPP.

Comparing the curves of the type a, d and type f, g in Figure 2(ii), the porous material of the compound structure greatly improves the sound absorption bandwidth against no matter the MPP stays alone or porous material stays alone. In addition, the porous layer in front of the MPP can produce wider sound absorption bandwidth in high frequency range than putting it in the back of the MPP. That is due to the porous layer in front of the MPP can act as an impedance matching layer in high frequency.

### 3.2 Influence of the Porous Material's Thickness

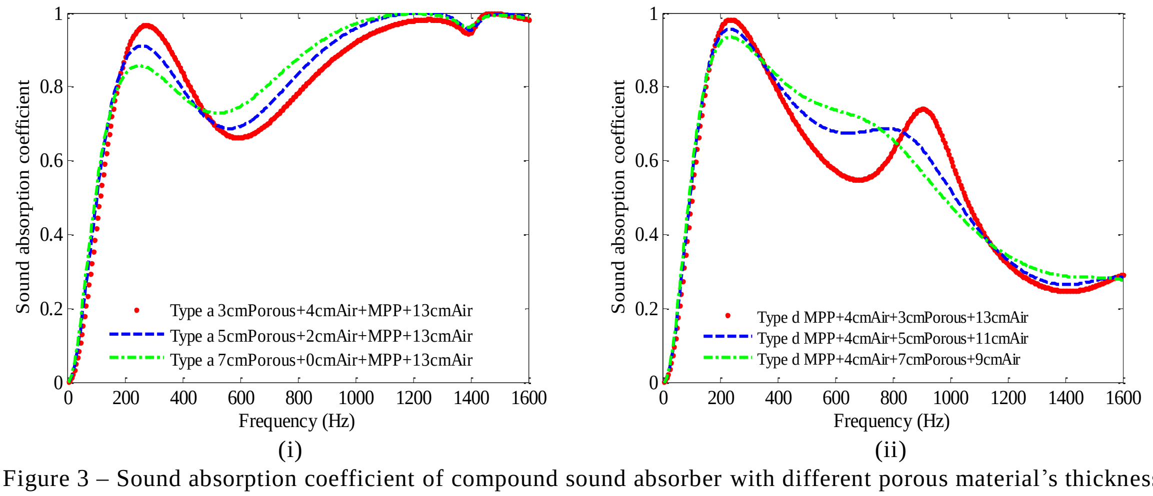
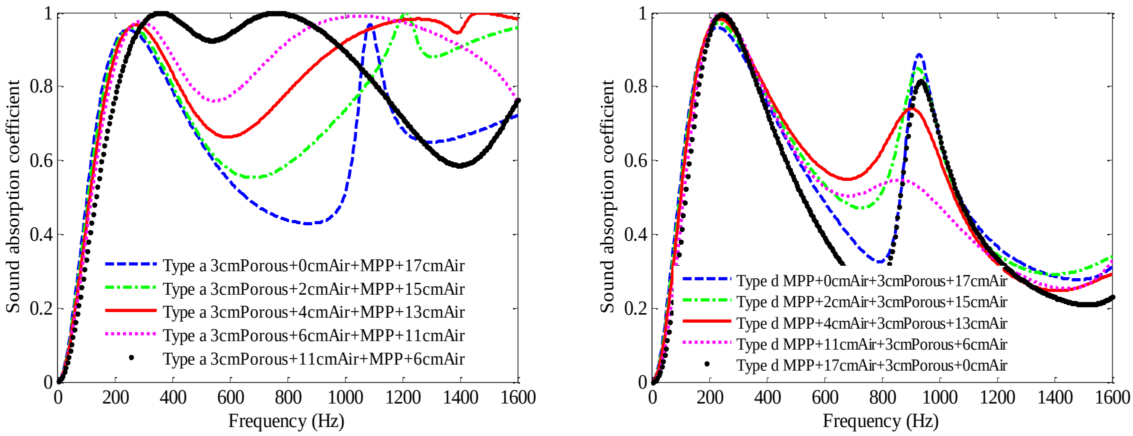



Figure 3 – Sound absorption coefficient of compound sound absorber with different porous material's thickness. (i): type a; (ii): type d.

Figure 3 shows the variation of the sound absorption coefficient of the compound sound absorber type a and d as the thickness of the porous layer increases. In Figure 3(i), it can be observed that the sound absorption coefficients for the frequency range 600Hz-1600Hz increase with thickening the porous layer in front of the MPP. At the same time the first peak of the MPP decreases a little. Furthermore, the 3cm porous layer with 4cm air has a better sound absorption at the low frequency than 7cm porous layer with 0cm air, while the sound absorption of middle frequency from 500Hz to 1600 Hz falls down. As shown in Figure 3(ii), thickening the porous layer behind the MPP will increase the absorption around the anti-resonance frequency range.

### 3.3 Influence of the Airspace between the porous material and MPP



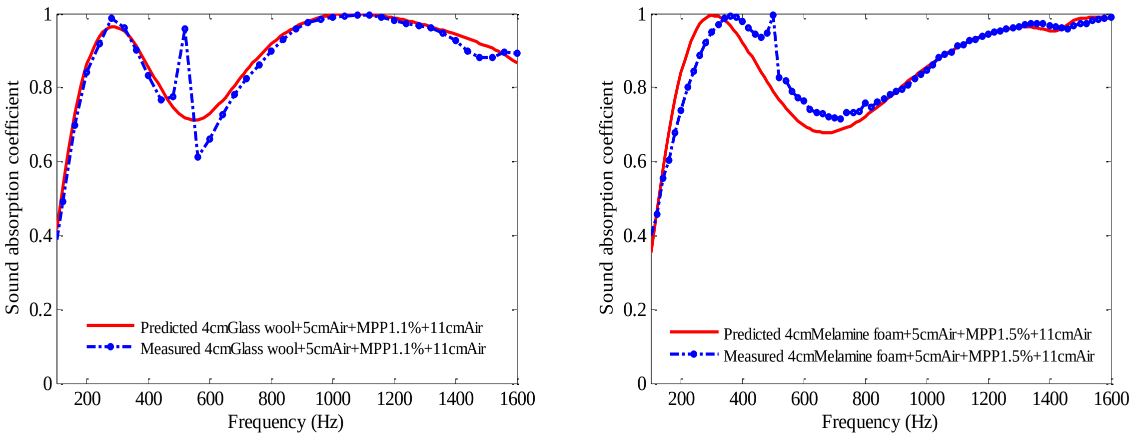

(i) (ii)

Figure 4 – Sound absorption coefficient of compound sound absorber varies with different airpace between porous material and MPP. (i): type a; (ii): type d.

From the Figure 4(i), it can be observed that adding the thickness of the airspace between the porous materials and MPP will increase the sound absorption of the anti-resonance frequency of the compound structure. Figure 4(ii) shows that the sound absorbing performance around the valleys are improved by increasing the thickness of the airspace between the MPP and the porous materials.

## 4. COMPARISON WITH MEASURED RESULT IN IMPEDANCE TUBE

Two kinds of porous materials with MPP were measured. The type a sample models were used to verify the predicted results.




(i) (ii)

Figure 5 – Comparison with measured result of compound sound absorber with different porous materials; (i):glass wool; (ii): melamine foam.

The parameters of MPP and glass wool for Figure 5(i) are listed in Table 1 and Table 2 respectively. The thickness of the glass wool, the air layer1 and the air layer2 is 4cm, 5cm, and 11cm respectively. The perforation of MPP for Figure 5(ii) is 1.5%, the radius of the holes in the panel is 0.7mm. The air flow resistivity of the melamine foam is 6754 $Ns/m^4$ . The thickness of the panel, the melamine foam, the air layer1, the air layer2 is 0.7mm, 1mm, 3cm, 4cm, and 13cm respectively. The predicted results get a good agreement with the experiment results. That indirectly verifies the numerical analysis in Part 3.

## 5. CONCLUSIONS

The influence of the porous material's position on the sound absorption of the MPP is investigated in this paper. The results show that adding the porous layer can broaden the sound absorption bandwidth of the MPP. The low frequency sound absorption mainly depends on the MPP, while the mid and high frequency sound absorption mainly attribute to the porous materials. It is interesting to note the sound absorption is much better when the porous materials are put in front of the MPP, rather than behind it. These results are helpful for designing the sound absorbers.

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