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Effect of a porous absorbing layer on absorption characteristics of a double-leaf MPP space sound absorber

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A micro-perforated panel (MPP) is usually placed in front of a rigid-back wall with an air-back cavity and forms a Helmholtz resonator with its holes and air-back cavity. However, the authors have so far proposed several kinds of MPP space sound absorber, which can absorb the sound energy without a rigid-back wall. A double-leaf MPP space absorber (DLMPP) is one of them, which is arranged with two MPPs in parallel without rigid-back wall. A DLMPP shows a peak absorption at the resonance frequency and additional absorption in a low frequency range. Therefore, a DLMPP can be used as a broadband space sound absorber in a practical situation. In this study, as an approach to improve its sound absorption performance, we propose a DLMPP with Porous which has a porous layer between two leaves of MPP, and its absorption characteristics are theoretically analyzed and discussed through the numerical examples. As a result, the absorption coefficient becomes 0.1...0.2 higher in all frequency ranges. The range of the resonance peak becomes broader. Thus, a porous layer can be said to improve the performance of a DLMPP.

1. Introduction

A micro-perforated panel (MPP) is a kind of perforation panel made of a thin panel (less than 1mm thick) and has small perforations (less than 1mm in diameter) with perforation ratio less than 1%. Due to its small perforations, an MPP has an optimum acoustic-impedance for sound absorber and it can offer better sound absorbing performance than ordinary perforation panels. An MPP can be made from various materials such as acrylic or metal, and furthermore, it has a high durability and recyclability and does not spread out any fibrous dusts. In this manner, MPP solves the problems with traditional sound absorbing materials. Thus, it is attractive as one of the most promising alternatives among so-called “next-generation sound absorbing materials”.

An MPP was first proposed by Maa¹⁾ in 1970s: he had developed its theory and validated its effectiveness^{2,3)}. Later, many researchers presented the studies on its applications to various purposes⁴⁻⁶⁾. An MPP is usually used with a rigid-back wall and an air-back cavity in order to form Helmholtz resonators, and shows a high absorption coefficient at the resonance frequency. However, these structures are limited to use in front of a rigid-back wall.

Therefore the authors have proposed several kinds of space sound absorbers using MPP: they do not require backing structures, such as “double-leaf MPP space sound absorber (DLMPP: see Fig. 1.)”⁷⁻⁹⁾. These panel-like structures can be used for a sound absorbing panel or partition. A typical absorption coefficient of a DLMPP has a resonance-peak lower than that of the conventional MPP absorber with a rigid-back wall, and shows nearly flat frequency characteristics. Sound absorption in a low frequency range appears due to its acoustic flow resistance.

The peak characteristics of its absorption coefficient change by the parameter of the MPP (the diameter, thickness and perforation ratio) in the same way as a single MPP absorber. On the other hand, sound absorption in a low frequency range

is affected by the entire acoustic resistance and the mass (surface density) of the MPP. The lighter its mass becomes, the lower its absorption coefficient tends to be at low frequencies, which shows the typical characteristics of a permeable structure. Thus, although the peak of its absorption coefficient is a little lower than that of a conventional single MPP absorber, it can be effectively used as a broadband absorber.

On the other hand, in a previous MPP study, sound absorption characteristics of an MPP backed by a porous absorbing layer are discussed: it can widen its absorption frequency range¹⁰⁾. By the way, since an MPP is originally proposed as alternative material in order to solve the problems of a porous absorbing material, the combined use of an MPP and a porous material seems to be a contradiction. However, many porous absorbing materials excellent in durability and recyclability have recently developed, using porous materials can be taken into consideration.



Fig. 1 The test specimen of a DLMPP used in the experiment⁹⁾. The MPPs used in this specimen are made of transparent polycarbonate.

Therefore, as improvement of DLMPP's sound absorption performance, insertion of a porous absorbing material into its cavity can be an advantage in its sound absorption characteristics, and need to be discussed.

2. Theoretical considerations

2.1 Analytical model

The model of a double-leaf MPP space sound absorber inserted porous absorbing material layer between two leaves of MPPs (a DLMPP with Porous) is shown in Fig.2. The parameters, t_i , d_i , p_i , ρ_i and R are the MPP's thickness[mm], diameter[mm], perforation ratio[%], density[kg/m³] and porous absorbing material's flow resistivity[Pa s/m²], respectively. It is the structure that porous absorbing material is inserted into the cavity of an infinite DLMPP in a xy -plane. Note that the cavity is fulfilled with the porous absorbent. Then we consider a plane wave of a unit pressure amplitude incident with the angle θ

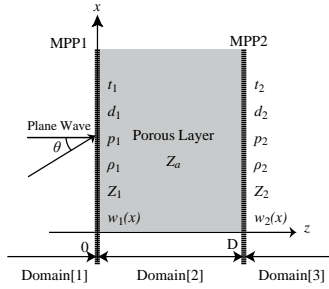


Fig. 2 The analytical model of a DLMPP with porous material in the cavity.

2.2 The impedance of an MPP and porous absorbing material

The impedances of the MPPs, $Z_{1,2}$, are expressed by the Maa's theory²⁾:

$$Z_j = (r_j - i\omega m_j) \rho_0 c_0, \quad (1)$$

$$r_j = \frac{32\eta t_j}{p_j \rho_0 c_0 d_j^2} \left(\sqrt{\frac{K_j^2}{32} + 1} + \frac{\sqrt{2}}{8} K \frac{d_j}{t_j} \right), \quad (2)$$

$$\omega m_j = \frac{\omega t_j}{p_j c} \left(1 + \frac{1}{\sqrt{9 + \frac{K_j^2}{2}}} + 0.85 \frac{d_j}{t_j} \right), \text{ where} \quad (3)$$

$$K_j = d_j \sqrt{\frac{\omega \rho_0}{4\eta_0}}, \quad (j=1,2)$$

In addition, the characteristic impedance, Z_a , and propagation coefficient, γ , of the porous absorbing material is expressed by following formulae based on Miki's formulae¹¹⁾:

$$Z_a = \left\{ 1 + 0.07 \left(\frac{f}{R} \right)^{-0.632} + i0.107 \left(\frac{f}{R} \right)^{-0.632} \right\} \rho_0 c_0, \quad (4)$$

$$\gamma = k_0 \left\{ 0.160 \left(\frac{f}{R} \right)^{-0.618} \right\} - ik_0 \left\{ 1 + 0.109 \left(\frac{f}{R} \right)^{-0.618} \right\} \quad (5)$$

Now, each of the impedance is not normalized. Also, ρ_0 is the air density (1.2[kg/m³]), c_0 is the speed of sound in air (340[m/s]), ω is the angular frequency, η_0 is the coefficient of viscosity (1.789×10⁻⁵[Pa s]), k_0 is the wave number, and f is the frequency. As is explained in the following section, the sound induced vibration of the MPPs by incident sound is discussed by the equation of motion of the panels.

2.3 Analysis based on the wave acoustic theory

The DLMPP with Porous, shown in Fig. 1, is analyzed analytically by the wave theory.

Using the integral formula of Helmholtz-Kirchhoff and the boundary condition the respective surfaces of MPPs, surface

sound pressure on the illuminated side of MPP1, $p_1(x, 0)$, in Domain[1] is expressed as follows:

$$p_1(x, 0) = 2p_i(x, 0) + \frac{i}{2} \int_{-\infty}^{\infty} [\rho_0 \omega^2 w_1(x_0) + iA_{m1} k_0 \Delta P_1(x_0)] H_0^{(1)}(k_0 |x - x_0|) dx_0 \quad (6)$$

Considering in the same way, the surface sound pressure on the transmission side of MPP2, $p_3(x, D)$, in Domain[3] is expressed as follows:

$$p_3(x, D) = -\frac{i}{2} \int_{-\infty}^{\infty} [\rho_0 \omega^2 w_2(x_0) - iA_{m2} k_0 \Delta P_2(x_0)] H_0^{(1)}(k_0 |x - x_0|) dx_0 \quad (7)$$

Now, p_i is sound pressure of incident wave and $H_0^{(1)}(x)$ is the Hankel function of the first kind of order zero. Also, $A_{m1,2} = \rho_0 c_0 / Z_{1,2}$, and ΔP_1 is the pressure difference of MPP1, and ΔP_2 is that of MPP2.

From general solutions of a wave acoustic theory of plane wave as follows and the boundary conditions, the surface sound pressure on the back side of MPP1, $p_2(x, 0)$, and the front side of MPP2, $p_2(x, D)$, in Domain[2] are expressed as follows:

$$p_2(x, 0) = \frac{iZ_a \omega \{ (e^\varphi + e^{-\varphi}) w_1(x) - 2w_2(x) \} - Z_a \left\{ (e^\varphi + e^{-\varphi}) \frac{\Delta P_1(x)}{Z_1} - 2 \frac{\Delta P_2(x)}{Z_2} \right\}}{\cos \theta (e^\varphi - e^{-\varphi})} \quad (8)$$

$$p_2(x, D) = \frac{iZ_a \omega \{ 2w_1(x) - (e^\varphi + e^{-\varphi}) w_2(x) \} - Z_a \left\{ 2 \frac{\Delta P_1(x)}{Z_1} - (e^\varphi + e^{-\varphi}) \frac{\Delta P_2(x)}{Z_2} \right\}}{\cos \theta (e^\varphi - e^{-\varphi})} \quad (9)$$

where, $\varphi = -\gamma D \cos \theta$.

The vibration displacement of MPP1 and MPP2, $w_{1,2}(x)$, with the vibration unit response of MPP1,2, $u_{1,2}$, are expressed as follows:

$$w_1(x) = \int_{-\infty}^{\infty} [p_1(\xi, 0) - p_2(\xi, 0)] u_1(x - \xi) d\xi \quad (10)$$

$$w_2(x) = \int_{-\infty}^{\infty} [p_2(\xi, D) - p_3(\xi, D)] u_2(x - \xi) d\xi \quad (11)$$

All the equations above are Fourier-transformed to solve in wavenumber space as follows: here, the Fourier-transform is defined as: $F(k) = 1/2\pi \int_{-\infty}^{\infty} f(x) e^{-ikx} dx$, and $f(x) = \int_{-\infty}^{\infty} F(k) e^{ikx} dx$, with k as a wavenumber parameter.

Eqs. (10) and (11) are Fourier-transformed to the equations of vibration of MPP1 and MPP2 in wavenumber space:

$$W_1(k) = 2\pi [P_1(k; 0) - P_2(k; 0)] U_1(k) \quad (12)$$

$$W_2(k) = 2\pi [P_2(k; D) - P_3(k; D)] U_2(k) \quad (13)$$

The Fourier-transformed unit responses to the vibration of MPP1,2 are defined as follows:

$$U_j(k) = \frac{1}{2\pi (D_j k^4 - \rho_j t_j \omega^2)} \quad j=1,2. \quad (14)$$

$$D_j = \frac{E_j t_j^3 (1 - i\eta_j)}{12(1 - \nu_j^2)}$$

where, E is the Young's modulus ($=205 \times 10^9$ Pa), η is the loss factor ($=0.0001$) and ν is Poisson's ratio ($=0.3$), in this study.

To solve these equations, the surface sound pressure is Fourier-transmitted as follows:

$$P_1(k; 0) = 2\delta(k - k_0 \sin \theta) + \frac{i\rho_0 \omega^2 W_1(k) - k_0 A_{m1} \Delta P_1(k)}{\sqrt{k_0^2 - k^2}} \quad (15)$$

$$P_2(k;0) = \frac{iZ_a \omega \{ (e^\varphi + e^{-\varphi}) W_1(k) - 2W_2(x) \} - Z_a \left\{ (e^\varphi + e^{-\varphi}) \frac{\Delta P_1(k)}{Z_1} - 2 \frac{\Delta P_2(k)}{Z_2} \right\}}{\cos \theta (e^\varphi - e^{-\varphi})} \quad (16)$$

$$P_2(k;D) = \frac{iZ_a \omega \{ 2W_1(k) - (e^\varphi + e^{-\varphi}) W_2(k) \} - Z_a \left\{ 2 \frac{\Delta P_1(k)}{Z_1} - (e^\varphi + e^{-\varphi}) \frac{\Delta P_2(k)}{Z_2} \right\}}{\cos \theta (e^\varphi - e^{-\varphi})} \quad (17)$$

$$P_3(k;D) = \frac{-i\rho_0 \omega^2 W_2(k) + k_0 A_{m2} \Delta P_2(k)}{\sqrt{k_0^2 - k^2}} \quad (18)$$

Eqs. (15) and (16) are substituted into Eq. (12), and Eqs. (17) and (18) are substituted in Eq. (13). Then, $W_1(k)$ and $W_2(k)$ are inverse transformed, and the vibration displacements of MPP1 and MPP2 are expressed as follows:

$$w_1(x) = \Gamma_1(k_0 \sin \theta) e^{ik_0 x \sin \theta} \quad (19)$$

$$w_2(x) = \Gamma_2(k_0 \sin \theta) e^{ik_0 x \sin \theta} \quad (20)$$

where,

$$\Gamma_1(k) = \frac{-\Phi_1 A_3 + \Phi_1 \Phi_2 A_3 B_2 - \Phi_1 \Phi_2 A_2 B_3}{-1 + \Phi_1 A_1 + \Phi_1 \Phi_2 A_2 B_1 + \Phi_2 B_2 - \Phi_1 \Phi_2 A_1 B_2},$$

$$\Gamma_2(k) = \frac{-\Phi_1 \Phi_2 A_3 B_1 - \Phi_2 B_3 + \Phi_1 \Phi_2 A_1 B_3}{-1 + \Phi_1 A_1 + \Phi_1 \Phi_2 A_2 B_1 + \Phi_2 B_2 - \Phi_1 \Phi_2 A_1 B_2},$$

$$\Phi_1 = 2\pi U_1(k) \Theta_1,$$

$$\Phi_2 = 2\pi U_2(k) \Theta_2,$$

$$\Theta_1 = \frac{1}{C_1(F_1 F_2 - 4E_1 E_2)},$$

$$\Theta_2 = \frac{1}{-C_1(F_1 F_2 - 4E_1 E_2)},$$

$$A_1 = -C_2 F_2 G + C_1 F_2 H - 4E_2 G,$$

$$A_2 = 2C_2 E_2 G + 2F_2 G - 2C_1 E_2 H,$$

$$A_3 = 2C_1 F_2,$$

$$B_1 = -2F_1 G - 2C_2 E_1 G + 2C_1 E_1 H,$$

$$B_2 = C_2 F_1 G - C_1 F_1 H + 4E_1 G,$$

$$B_3 = 4C_1 E_1,$$

$$C_1 = (e^\varphi - e^{-\varphi}) \cos \theta,$$

$$C_2 = e^\varphi + e^{-\varphi},$$

$$E_1 = \frac{Z_a}{C_1 Z_2},$$

$$E_2 = \frac{Z_a}{C_2 Z_2},$$

$$F_1 = 1 + I_1 - C_2 E_1,$$

$$F_2 = 1 + I_2 - C_2 E_2,$$

$$G = iZ_a \omega,$$

$$H = \frac{i\rho_0 \omega^2}{\sqrt{k_0^2 - k^2}},$$

$$I_1 = \frac{k_0 A_{m1}}{\sqrt{k_0^2 - k^2}},$$

$$I_2 = \frac{k_0 A_{m2}}{\sqrt{k_0^2 - k^2}}.$$

The reflected sound pressure is expressed by using the integral formula of Helmholtz-Kirchhoff, then is substituted Eqs. (15) and (16), and expressed as follows:

$$p_r(x, z) = \left[1 + \frac{i\rho_0 \omega^2 \Gamma_1(k_0 \sin \theta) - k_0 A_{m1} \Theta_1 \{ A_1 \Gamma_1(k_0 \sin \theta) + A_2 \Gamma_2(k_0 \sin \theta) + A_3 \}}{k_0 \cos \theta} \right] \times e^{i[k_0 x \sin \theta - k_0 z \cos \theta]} \quad (21)$$

Considering in the same way, the transmitted sound pressure is substituted Eqs. (17) and (18), and expressed as follows:

$$p_t(x, z) = \left[-i\rho_0 \omega^2 \Gamma_2(k_0 \sin \theta) + k_0 A_{m2} \Theta_2 \{ B_1 \Gamma_1(k_0 \sin \theta) + B_2 \Gamma_2(k_0 \sin \theta) + B_3 \} \right] \times e^{i[k_0 x \sin \theta - k_0 z \cos \theta]} \quad (22)$$

Using, the reflected sound pressure and transmitted sound pressure, an oblique incidence absorption coefficient α_θ and an oblique incidence incident transmission coefficient τ_θ are expressed as follows:

$$\alpha_\theta = 1 - |p_r|^2 \quad (23)$$

$$\tau_\theta = |p_t|^2 \quad (24)$$

Averaging α_θ and τ_θ from 0° to 78° of the angle of incidence θ , the field-incidence-averaged absorption coefficient α and transmission coefficient τ are obtained by following formulae:

$$\alpha = \frac{\int_{0^\circ}^{78^\circ} \alpha_\theta \sin \theta \cos \theta d\theta}{\int_{0^\circ}^{78^\circ} \sin \theta \cos \theta d\theta} \quad (25)$$

$$\tau = \frac{\int_{0^\circ}^{78^\circ} \tau_\theta \sin \theta \cos \theta d\theta}{\int_{0^\circ}^{78^\circ} \sin \theta \cos \theta d\theta} \quad (26)$$

Since sound transmission occurs in the case of a sound space absorber, sound absorption characteristics should be evaluated by $\alpha - \tau$ which indicates the ratio of the energy actually dissipated in the system.

3. Numerical examples and discussion

3.1 General features of the sound absorption characteristics

In Fig. 3, the numerical result of a typical DLMPP with Porous is shown by a solid line, and that of a typical DLMPP with air cavity is shown by a dotted line. As the typical parameter of MPP and porous material, the following parameters are assumed: 0.2mm for the thickness, 0.2mm for

the diameter, 0.8% for the perforation ratio, 7500kg/m³ for the density of the MPP, and 10000Pa s/m² for the flow resistivity of the porous absorbent.

The absorption coefficient of the DLMPP with Porous increases as a whole by inserting porous absorbing material. In a low-middle frequency range (around 31.25Hz~500Hz), $\alpha-\tau$ increases with a rise in frequency. The curve of $\alpha-\tau$ of a DLMPP with Porous is flatter than that of a DLMPP, and a DLMPP with Porous has a broader peak of absorption coefficient. In addition, the resonance system is damped by absorbing material, with the result that the peaks at higher-order resonance around 4kHz and 8kHz, which are shown in the case of a DLMPP, disappear.

The effect of the change of each parameter is discussed in the following sections.

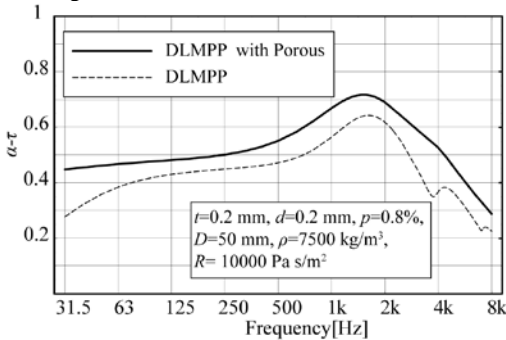


Fig.3 Comparison of the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP with Porous (thick line) and that with an air cavity (thin line): $t=0.2$ mm, $d=0.2$ mm, $p=0.8\%$, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m².

3.2 The effect of the thickness of the MPPs

In this section, the effect of MPPs' thickness, t , on the sound absorption characteristics is discussed. The sound absorption characteristics of a DLMPP with Porous and a DLMPP are respectively shown in Figs. 4 and 5 to be compared with each other as a reference.

In the case of a thick MPP, MPPs' resistances are too high, so that $\alpha-\tau$ is low, *e.g.*, 1.0mm in Fig. 5, therefore it is less affected by the inserted porous absorbing material because of its excessive resistance (see Fig. 4). On the other hand, in the case of a thin MPP, *e.g.*, 0.1mm in Fig. 5, MPPs' resistances are lower, so that $\alpha-\tau$ considerably increases in Fig. 4 because of the additional resistance by the porous layer. Thus, the sound absorbing characteristics are improved notably by the porous absorbing material in the thin MPP cases.

3.3 The effect of the diameter of the MPPs

In this section, the effect of MPPs' diameter, d , on the sound absorption characteristics is discussed. The sound absorption characteristics of a DLMPP with Porous and a DLMPP are respectively shown in Figs. 6 and 7 to be compared with each other as a reference.

In the case of the small diameter, *e.g.* 0.1 and 0.2mm in Fig. 7, MPPs' resistances are close to the optimal value, so that $\alpha-\tau$ is already high, and as seen in Fig. 6, it is somewhat improved, though not very much, by the porous materials, as the resistance is already high enough. On the other hand, in the case of the large diameter, *e.g.*, 0.5 and 1.0mm in Fig. 7, MPPs' resistances are lower, therefore, $\alpha-\tau$ is more significantly improved by the porous layer. Thus, the sound absorbing characteristics are improved by the porous absorbing material, when the hole diameter is somewhat larger than the optimal value.

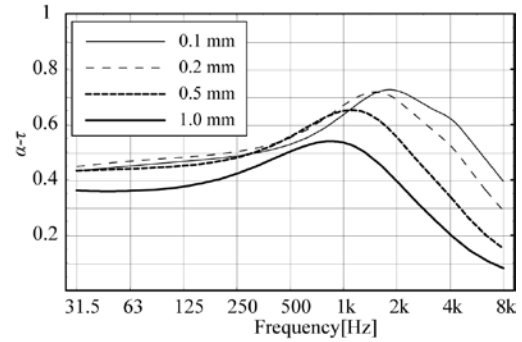


Fig.4 Effect of the thickness of panel on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP with Porous: $d=0.2$ mm, $p=0.8\%$, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

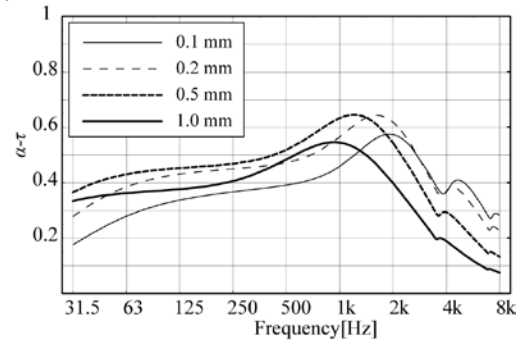


Fig.5 Effect of the thickness of panel on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP: $d=0.2$ mm, $p=0.8\%$, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

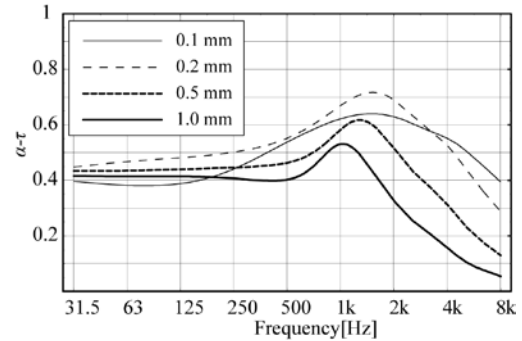


Fig.6 Effect of the hole diameter on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP with Porous: $t=0.2$ mm, $p=0.8\%$, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

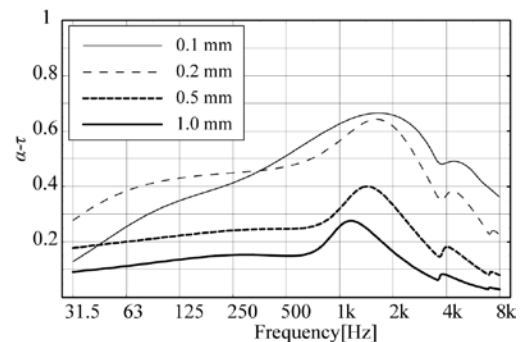


Fig.7 Effect of the hole diameter on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP: $t=0.2$ mm, $p=0.8\%$, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

3.4 The effect of the perforation ratio of the MPPs

In this section, the effect of MPPs' perforation ratio, p , on sound absorbing characteristics is discussed. The sound absorbing characteristics of a DLMPP with Porous and a DLMPP are respectively shown in Figs. 8 and 9 to be compared with each other as a reference.

As shown in Fig. 8, increasing the MPPs' perforation ratios, the peak of $\alpha-\tau$ becomes higher and broader, and the frequency of the peak becomes higher.

The typical sound absorption characteristics of porous material are low in low frequency bands and high in high frequency bands. Increased the MPPs' perforation ratio, this typical feature of the sound absorption characteristics of porous material appears. That means, the effect of the MPP becomes smaller and that of the porous absorbent becomes more dominant.

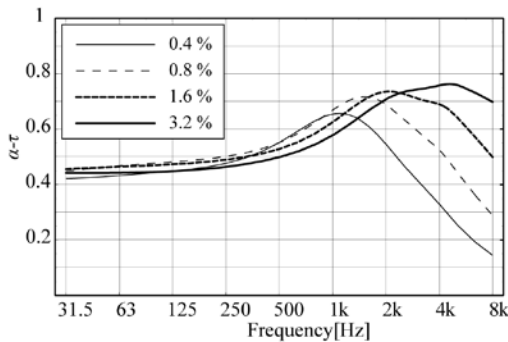


Fig.8 Effect of the perforation ratio on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP with Porous: $t=0.2$ mm, $d=0.2$ mm, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

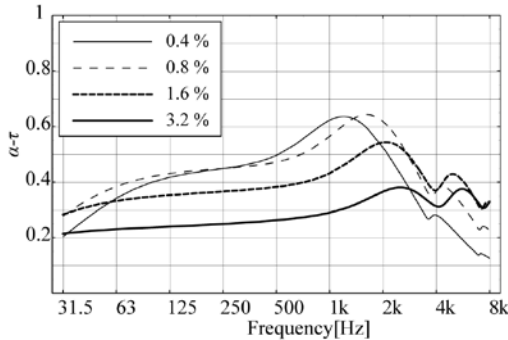


Fig.9 Effect of the perforation ratio on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP: $t=0.2$ mm, $d=0.2$ mm, $D=50$ mm, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

3.5 The effect of the depth of the porous cavity

In this section, the effect of the depth of the porous cavity, D , on the sound absorption characteristics is discussed. The sound absorption characteristics of a DLMPP with Porous are shown in Fig. 10. As a reference, these are compared with the effect of the depth of the air cavity of DLMPP. The sound absorption characteristics of a DLMPP are shown in Fig. 11.

It is observed, when Fig. 10 is compared with Fig. 11, that, as the effect of the depth of the cavity becomes larger, the frequency of the resonance peak becomes lower due to the shift of the resonance frequency and its $\alpha-\tau$ becomes higher and broader by increased resistance of the porous layer. Also it is inferred that the energy inserting the MPP on a transmission side decreases, which is caused by the decay of the propagating wave in the porous absorbing material. Accordingly, it is interpreted that the transmission coefficient τ decreases, and it makes $\alpha-\tau$ increase in all frequency range.

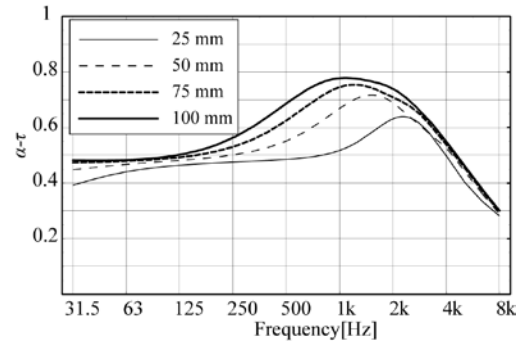


Fig.10 Effect of the porous layer depth on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP with porous: $t=0.2$ mm, $d=0.2$ mm, $p=0.8$ %, $\rho=7500$ kg/m³, $R=10000$ Pa s/m²

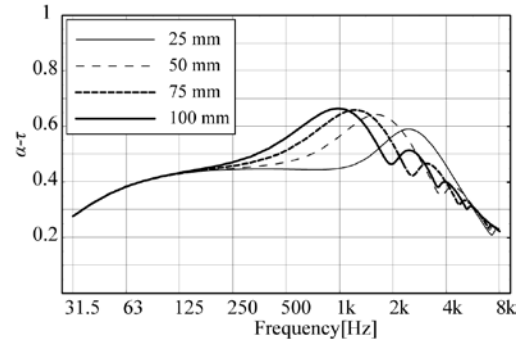


Fig.11 Effect of air cavity depth on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP: $t=0.2$ mm, $d=0.2$ mm, $p=0.8$ %, $\rho=7500$ kg/m³

3.6 The effect of the density of the MPPs

In this section, the effect of the density of the MPPs, ρ , on sound absorption characteristics is discussed. This means that the change in the MPPs material is considered. The sound absorption characteristics of a DLMPP with Porous and a DLMPP are respectively shown in Figs. 12 and 13 to be compared with each other as a reference.

The density of the MPPs does not affect significantly the characteristics of a DLMPP with porous. This can be interpreted that it is because the effect of the porous layer is very significant, so that the effect of the density is less significant than in the case of a DLMPP.

3.7 The effect of the flow resistivity of the porous absorbing material

In this section, the effect of the flow resistivity of the porous absorbing material, R , on the sound absorption characteristics is discussed. The results are shown in Fig. 14. In a certain range, below 40000 Pa s/m², as the flow resistivity of the porous absorbing material becomes higher, the peak of its energy absorption coefficient becomes higher and broader. Exceeded a certain range, however, $\alpha-\tau$ tends to decrease a little in low frequency range, so that it is considered that there is an optimal value: i.e., the flow resistivity should not be excessively increased.

In addition, the result for the excessively large flow resistivity is shown in Fig. 15. The value of $\alpha-\tau$ decreases in the case of the excessively large flow resistivity. That is because the permeability of entire absorbing structure is disappeared by the excessively large flow resistivity, so that sound absorption gradually disappears.

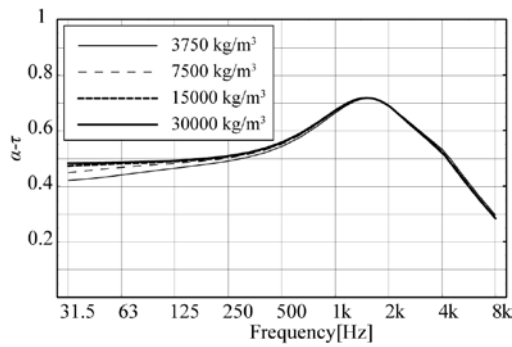


Fig.12 Effect of the density on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP with Porous: $t=0.2$ mm, $d=0.2$ mm, $p=0.8$ %, $D=50$ mm, $R=10000$ Pa s/m²

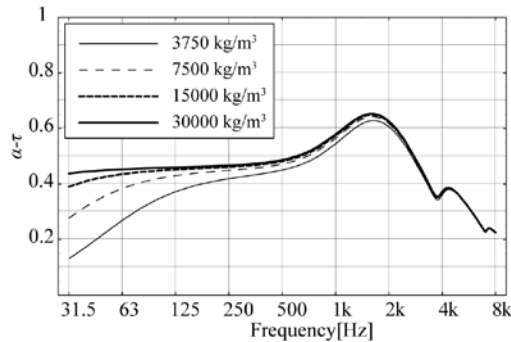


Fig.13 Effect of the density on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP: $t=0.2$ mm, $d=0.2$ mm, $p=0.8$ %, $D=50$ mm

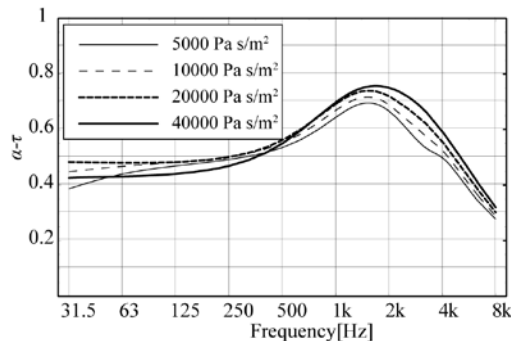


Fig.14 Effect of the flow resistance of the porous absorbent material on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP inserted by a porous absorbent layer. : $t=0.2$ mm, $d=0.2$ mm, $p=0.8$ %, $D=50$ mm, $\rho=7500$ kg/m³

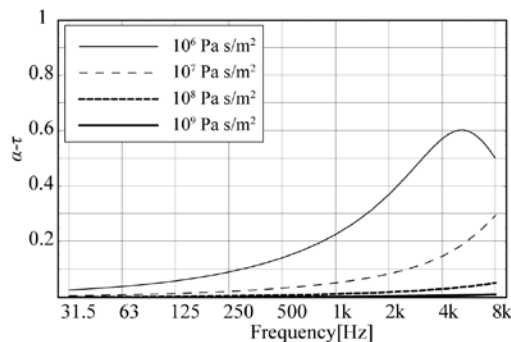


Fig.15 Effect of the excessively large flow resistance of the porous absorbent material on the field-incidence-averaged value of $\alpha-\tau$ of a DLMPP inserted by a porous absorbent layer. : $t=0.2$ mm, $d=0.2$ mm, $p=0.8$ %, $D=50$ mm, $\rho=7500$ kg/m³

4. Concluding remarks

As a trial to improve the absorption characteristics of a DLMPP, and DLMPP with Porous, whose cavity is filled with a porous absorbing material, is proposed, and its acoustic characteristics are analyzed theoretically. In the analysis, formulation by Helmholtz-Kirchhoff integral formula is discussed through the numerical examples. In addition, sound absorption mechanism and the effect of each parameter of DLMPP with Porous on sound absorbing characteristics are discussed through the parametric study.

Inserting porous absorbing material into typical DLMPP, its energy absorption coefficient $\alpha-\tau$ increases about 0.1...0.15 and is improved especially in a low frequency range. Also, the peak becomes broader. The higher order resonance does not occur due to the damping to resonance system by the porous material. From the discussion through the numerical examples, it is found that the effects of variable parameters are somewhat different between DLMPP and DLMPP with Porous. From above findings, it can be said that DLMPP inserted porous absorbing material can be used as an effective space absorber.

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