Finite Element Study of Perfect Sound Absorbing Porous Material with Periodic Conical Hole Profile

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1 Introduction

The acoustic performance of porous materials used in several engineering applications for noise reduction is limited at low frequencies. Their sound absorption can be improved at low frequencies by increasing the thickness, however if the thickness is equal to the acoustic penetration depth, the sound absorption reaches its asymptotic limit so that any additional thickness will show no improvement for the absorption coefficient. Laly et al. [1] proposed a design of porous absorbing material with periodic decreasing hole profiles using the finite element method (FEM). They showed excellent sound absorption performance with large frequency band where the limitation of the critical depth was overcome. To increase the sound absorption of the porous materials beyond the asymptotic absorption limit, classical wedge-shape [2] can be used, the concept of double porosity or holes with decreasing profile [3] (see Figure 1) can be used.

In this paper, a porous material design with a periodically distributed conical hole is presented and its acoustic performance is investigated numerically. Multi-layered system made of porous material with embedded periodic conical holes that is combined with other conventional porous materials is studied. It is demonstrated that the sound absorption coefficient of the proposed designs is significantly improved over a large frequency band.

2 Design and investigations of porous material with embedded conical hole

Figure 1(a) shows a porous material (1) containing a set of holes with decreasing profiles (2). Figure 1(b) presents a section of the unit cell (3) with a conical hole, which is approximated by a series of cylindrical holes of decreasing diameter as shown in Fig. 1(c). The thickness of the porous material is denoted by L and H is the length of the conical hole. The radii of the conical hole are denoted by Ra and Rb¬. Figures 2(a) and (b) show the numerical geometry and mesh of the periodic unit cell (PUC) used for the calculations of the acoustic parameters. The pressure acoustics module of Comsol Multiphysics is used to model all the domains in Fig. 2. The porous material is characterized using the Johnson-Champoux-Allard model. A normal incidence plane wave with pressure amplitude of 1 Pa is applied on the inlet plane with plane wave radiation condition. The two microphones transfer function method is used to calculate the reflection and sound absorption coefficients from the surface average acoustic pressures P1 and P2 at planes 1 and 2 positions. The reflection and sound absorption coefficients are given by

$$R = e^{2jk(L_m+s)}(H_{12} - e^{jks})/(e^{jks} - H_{12}), \qquad \alpha = 1 - |R|^2 \qquad (1)$$

with k the wavenumber and H12 the transfer function, s=30mm and Lm=120 mm.Résultats

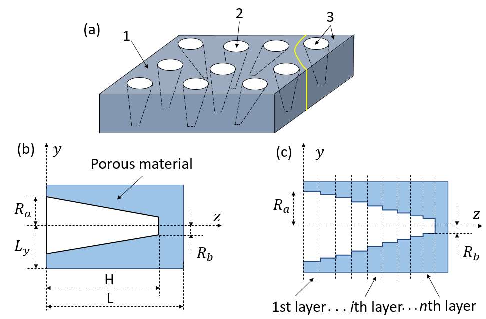

Figure 1: Porous material: (a) with decreasing hole profile (b) conical hole and (c) a series of cylindrical holes.

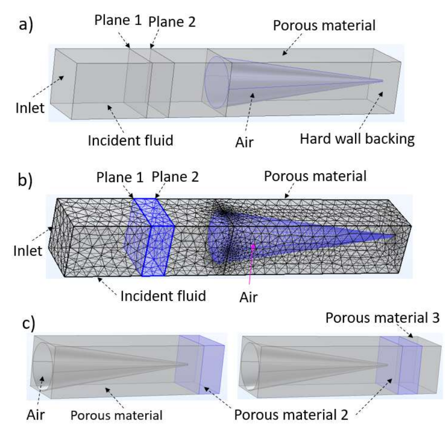

Figure 2: Numerical model: (a) porous layer with conical hole (b) mesh, and (c) multi-layer system.

Figure 3 shows the sound absorption coefficient of the porous material A of Table 1 for different thickness values L, L_y=30 mm, R_a=28 mm and R_b=1 mm. For L=0.254 m (10 inches), H is 0.25 mm and for L=0.381 m (15 inches), H is 0.379 m.

Figure 3 shows that the sound absorption coefficient of the porous material without conical holes does not increase when its thickness L is greater than the critical depth ($\approx 50\ mm$). With the conical hole, a significant improvement of the sound absorption is obtained.

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Table 1: Porous material properties.

Materials	φ	σ (N s m^{-4})	α_∞	Λ (µm)	Λ' (µm)
A	0.99	123 170	1	22.25	44.49
B	0.99	17 717	1	58.40	116.8
C	0.99	26 000	1.02	150	300
D	0.99	13 904	1	65.88	131.8

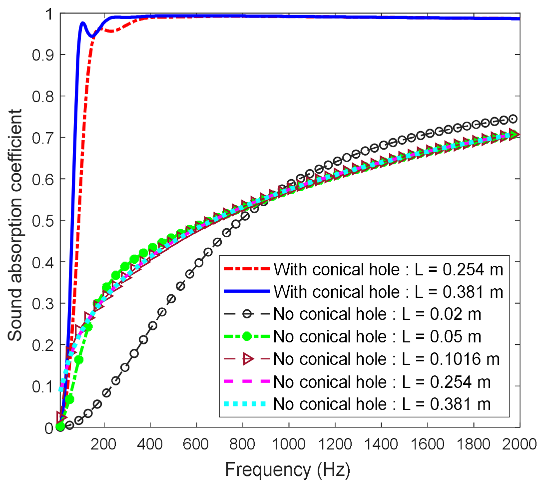

Figure 3: Comparison of the sound absorption coefficient.

The analytical sound absorption coefficient of the porous material with a series of cylindrical holes using the double porosity model is compared with FEM result in Fig. 4. The i^{th} layer is modeled by its transfer matrix T_i [4] and the global matrix T is obtained by multiplying all the matrices of the different layers $T = T_1T_2...T_i...T_n$ [1]. The comparison in Fig. 4 is presented using the porous material D from Table 1 for n=12 and n=20 material layers with a thickness of 152.4 mm (6 inches), L_y = 15 mm, R_a = 13 mm, R_b = 1 mm; and H=150 mm. The analytical results of the sound absorption coefficient agree well with FEM result. The sound absorption presents a large frequency band.

Figure 5 shows the absorption coefficient of porous material A from Table 1 with periodic conical hole combined with one and two other porous layers (see Fig. 2(c)). Porous materials 2 and 3 in Fig. 2(c) have respectively the same properties as B and C in Table 1 with a thickness of 20 mm, L=0.254 m, H=0.25 m, L_y=*30 mm,* R_a= *28 mm* and R_b=*1 mm*.

The sound absorption coefficient of the multiple layer system containing periodic conical hole in Fig. 5 is significantly improved compared to the multiple layer system without periodic conical hole.

3 Conclusion

A design of porous material with a periodically distributed conical holes was presented and its acoustic performance was studied using the finite element method. It was demonstrated that the sound absorption coefficient of the material design is significantly improved over a large frequency band. An excellent sound absorption performance was obtained at low frequency where conventional porous material presents poor sound absorption. The porous material with periodic conical hole was combined with other conventional porous materials to create multi-layered systems with sound absorption strongly improved compared to classic multi-layered system.

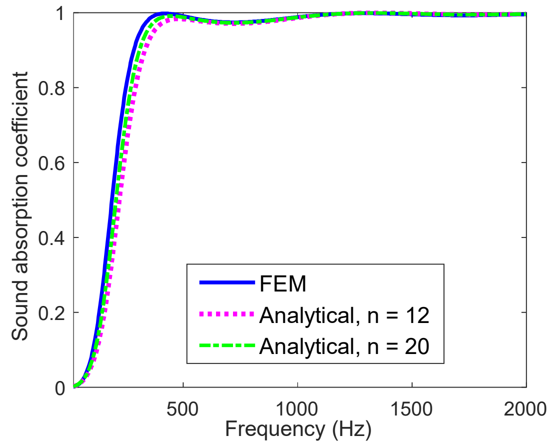

Figure 4: Comparison of FEM with analytical results.

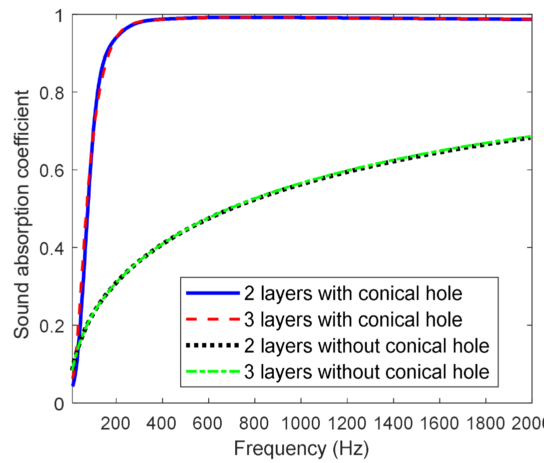

Figure 5: Sound absorption coefficient of multiple layers.

Acknowledgments

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