Modeling of a perforated solid with dead-end porosity by the transfer matrix method

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Abstract

Modeling a single layer of a homogeneous rigid-frame porous material using the transfer matrix method is well-known to acoustician. However, when the material shows a heterogeneous surface, or a composite surface combining different properties at the macroscopic scale (see Figure 1), the material cannot be modeled by an existing transfer matrix. In the past, to model such heterogeneous materials, the finite element method and an approximated analytical method have been used.[1] To the authors' knowledge, no transfer matrix modeling of such heterogeneous materials was made in the past. The objective of this paper is to develop and validate the transfer matrix modeling of one type of heterogeneous material. The material consists of a solid medium perforated by straight cylindrical pores fully open on both ends to the surrounding medium. Also, some semi-open pores are drilled on its surfaces in a symmetric or non-symmetric configuration (see Figure 2). The construction of the transfer matrix of this heterogeneous medium is made by summing in parallel the admittance matrix of two pores (i.e., the semi-open pore and the full pore) on a representative elementary volume (REV). The fully open pore may be seen as the dynamic porosity taken into account in the Biot's theory (hereby called the Biot porosity). The porosity associated to the semi-open pore forms the dead-end (DE) porosity. Once the transfer matrix of the perforated solid with the dead-end porosity is built, it can be multiplied to existing transfer matrices to simulate multilayer acoustic materials. To validate the proposed transfer matrix model, simulation results are compared to experimental results in terms of sound absorption and sound transmission loss. The symmetric and asymmetric constructions are validated. For the sound absorption case, two backing conditions are studied: rigid backing and air-cavity backing. Good correlations are obtained (see Figure 3).

Finally, the model is used to predict the sound absorption and sound transmission loss of a real aluminum foam sample containing dead-end pores.[2] For porous materials with dead-end pores, it is shown that the Johnson-Champoux-Allard (JCA) model fails to predict the acoustical behavior. In fact, since the material contains dead-end pores, the classical characterization methods do not provide the good properties to be used in the JCA model. In particular, the methods yield the global open porosity (i.e., sum of Biot porosity and DE porosity), and not only the Biot porosity. It is shown that correcting the JCA model by the Biot porosity improves the prediction at lower frequencies but not at higher frequencies. On the contrary, using adjusted macroscopic averages of the depth (L_{DE}) and radius (r_{DE}), the proposed model seems to predict correctly the acoustic behavior of the foam on the whole frequency range (see Figure 4). While the results are rather encouraging, further studies are necessary to characterize these two macroscopic parameters, and to better understand the extension of the proposed model to simulate real porous materials containing dead-end porosity.

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1. Atalla, Panneton and Allard. "Sound absorption by non homogeneous thin porous layers," Acustica · Acta acustica **83**, 891-896 (1997).
2. Dupont, Leclaire, Sicot, Gong, Panneton. "Acoustic properties of air-saturated porous materials containing dead-end porosity," Submitted to J. Appl. Phys. (2011).

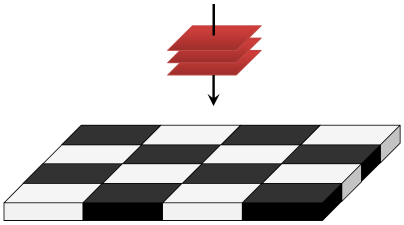

Figure 1 – A single layer material with macroscopic surface heterogeneities

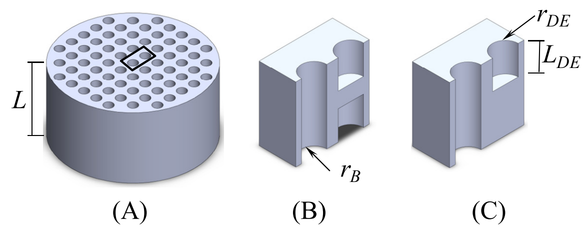

Figure 2 – A) Studied heterogeneous material. B) Symmetric configuration. C) Asymmetric configuration

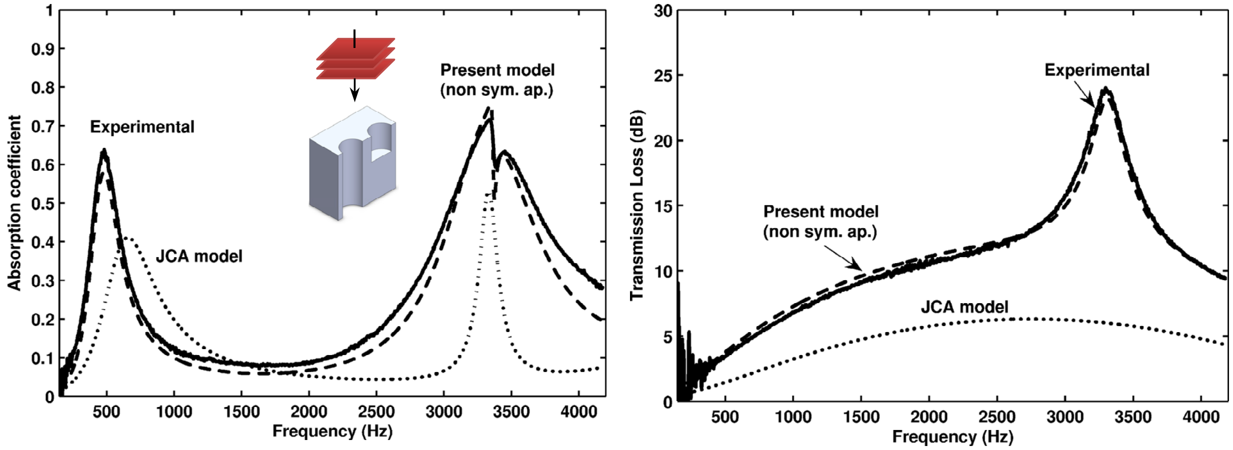

Figure 3 – Comparison between simulations and experiments on the perforated solid with dead-end pores.
A 50-mm air-cavity is backing the sample for absorption test.

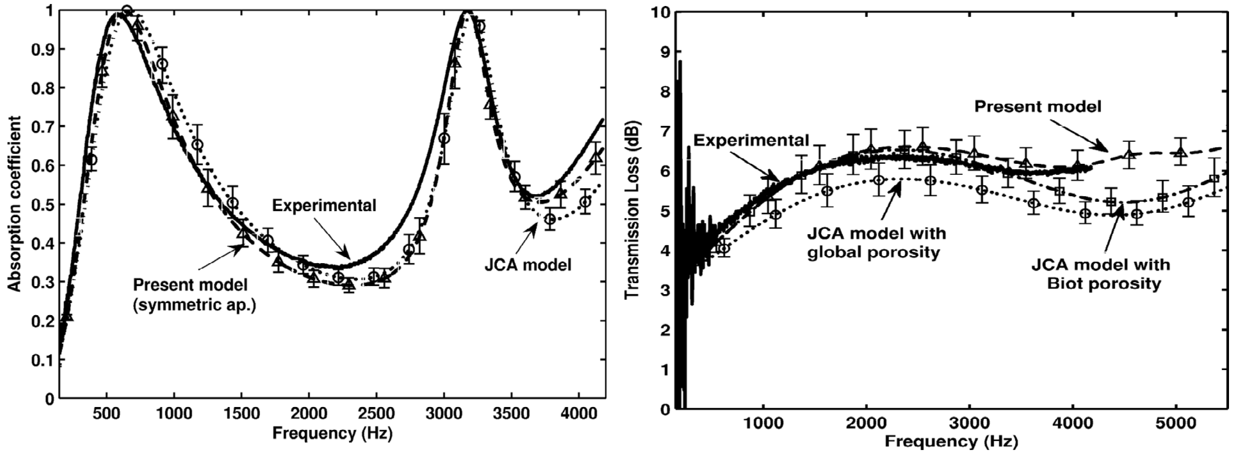

Figure 4 – Comparison between simulations and experiments on an aluminum foam containing dead-end pores.
A 50-mm air-cavity is backing the sample for absorption test.