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ACOUSTIC ABSORPTION OF HETEROGENEOUS POROUS MATERIALS

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ABSTRACT
The paper deals with the numerical investigation of the acoustic absorption performance of materials made up from a combination of thin porous patches, with different acoustic properties. The heterogeneous material is bonded onto a hard-walled termination of a semi-infinite rectangular wave-guide. The numerical model is based on an equivalent fluid finite element description for the porous material patches and a modal description of the acoustic field in the wave-guide. Experimental results are presented that validate the model in the special case of a double porosity porous material i.e. macro-perforated porous material. The influence of the hole shape factor is then studied using the proposed model. It is shown that absorption may be increased in a large frequency band by using non-homogeneous patch-works.

1 - INTRODUCTION
The acoustic absorption of porous materials is poor at low frequencies. However, recently, Olny [1] showed theoretically and experimentally that the absorption coefficient of such materials could be significantly increased in a given frequency band by performing holes in the porous materials (these materials are called double porosity materials). However, his model is currently limited to air-filled macro-pores, laterally infinite materials with a regular distribution of circular holes and provides only the effective density and bulk modulus of the equivalent homogeneous material. To relax these limitations, Atalla et al [2] proposed a finite element based numerical formulation to model such configurations. The model consisted of a non-homogeneous porous material, made up from thin porous patches, bonded onto the hard termination of an infinite rectangular wave-guide. Each thin patch was assumed to behave as an equivalent fluid (the frame is motionless). The coupling between the porous material and the wave-guide was accounted for explicitly using the modal behavior of the wave-guide. A numerical parameters study was presented to illustrate the absorption mechanisms and performance for different three-dimensional double porosity materials. This paper is a continuation of Atalla's work [2]. It recalls briefly the theory and some experimental results. In addition, new results on the effects of the distribution of the holes on the normal incidence absorption coefficient are presented.

2 - THEORY
The geometry of the problem is depicted in Fig. 1. It consists of a three-dimensional patchwork inserted in a semi-infinite rectangular wave-guide. The system is excited by an incoming plane wave propagating in the wave-guide. Each 3-D patch is rectangular and made from a homogeneous porous material modeled as an equivalent fluid. The density and sound speed in the wave-guide are noted ρ_0 and c_0, respectively. In the following, a temporal dependency $e^{j\omega t}$ for all the fields is assumed.
The associated weak integral form is given by Atalla [2]:

$$\int_{\Omega_p}\left[\frac{\phi^2}{\omega^2\tilde{\rho}_{22}}\underline{\nabla}\mathrm{p}.\underline{\nabla}\delta\mathrm{p}-\frac{\phi^2}{\tilde{\mathrm{R}}}\mathrm{p}\delta\mathrm{p}\right]\mathrm{d}\Omega-\int_{\partial\Omega_p}\frac{\phi^2}{\omega^2\tilde{\rho}_{22}}\frac{\partial\mathrm{p}}{\partial\mathrm{n}}\delta\mathrm{p}\mathrm{d}\Gamma=0\quad\forall\delta p \tag{1}$$

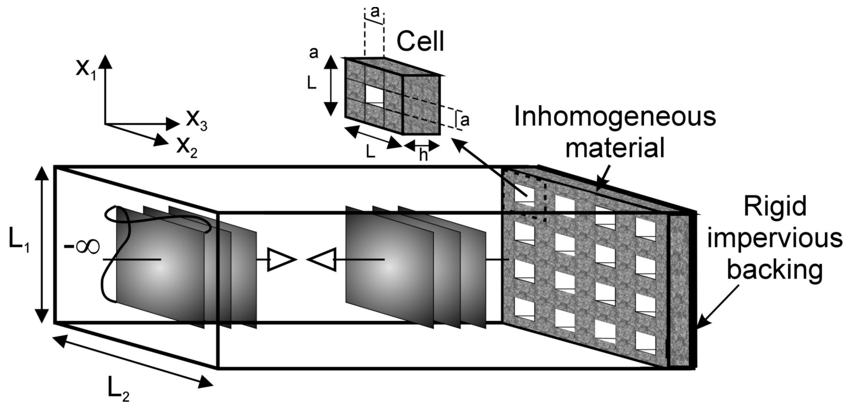

Figure 1: Configuration of the problem.

where δp is an arbitrary admissible variation of p, $\dfrac{\partial \mathrm{p}}{\partial \mathrm{n}}$ is the normal derivative of p with respect to the unit normal vector $\underline{\mathrm{n}}$ external to the bounding surface, $\partial\Omega_p$ enclosing the porous material volume Ω_p. ϕ stands for the porosity, $\tilde{\rho}_{22}$ is the modified Biot's density of the fluid phase accounting for viscous dissipation, $\tilde{\mathrm{R}}$ may be interpreted as the bulk modulus of the air occupying a fraction ϕ of the unit volume aggregate.
The wave guide is accounted for through the boundary coupling term of the integral formulation (1). Using the orthogonal modes of the rectangular wave-guide, this term can be rewritten as [2]:

$$\int_{\partial\Omega_\mathrm{p}} \frac{\phi^2}{\omega^2\tilde{\rho}_{22}} \frac{\partial \mathrm{p}}{\partial n} \delta \mathrm{p} d\Gamma = \frac{1}{\mathrm{j}\omega} \int_{\Omega_\mathrm{p}} \int_{\Omega_\mathrm{p}} \underline{\underline{\mathrm{A}}} \left(\underline{\mathrm{x}}, \underline{\mathrm{y}}\right) \mathrm{p}\left(\underline{\mathrm{y}}\right) \delta \mathrm{p}\left(\underline{\mathrm{x}}\right) \mathrm{d}\Gamma_\mathrm{y} \mathrm{d}\Gamma_\mathrm{x} - \frac{1}{\mathrm{j}\omega} \int_{\Omega_\mathrm{p}} \int_{\Omega_\mathrm{p}} \underline{\underline{\mathrm{A}}} \left(\underline{\mathrm{x}}, \underline{\mathrm{y}}\right) \mathrm{p_b}\left(\underline{\mathrm{y}}\right) \delta \mathrm{p}\left(\underline{\mathrm{x}}\right) \mathrm{d}\Gamma_\mathrm{y} \mathrm{d}\Gamma_\mathrm{x} \tag{2}$$

where $\underline{\mathrm{x}} = (x_1, x_2, x_3)$ and $\underline{\underline{\mathrm{A}}}$ is an admittance operator given by

$$\underline{\underline{\mathrm{A}}}\left(\underline{\mathrm{x}}, \underline{\mathrm{y}}\right) = \sum_{(\mathrm{m,n})} \frac{\mathrm{k_{mn}}}{\rho_0 \omega \mathrm{N_{mn}}} \varphi_\mathrm{mn}\left(\underline{\mathrm{x}}\right) \varphi_\mathrm{mn}\left(\underline{\mathrm{y}}\right) \tag{3}$$

with $\varphi_\mathrm{mn}\left(\underline{\mathrm{x}}\right) = \cos\left(\dfrac{\mathrm{mn}}{\mathrm{L_1}}\right) \cos\left(\dfrac{\mathrm{n}\pi}{\mathrm{L_2}}\right)$, $\mathrm{k^2_{mn}} = \mathrm{k}^2 - \left(\dfrac{\mathrm{m}\pi}{\mathrm{L_1}}\right)^2 - \left(\dfrac{\mathrm{n}\pi}{\mathrm{L_2}}\right)^2$ and $\mathrm{N_{mn}} = \displaystyle\int_{\partial\Omega_\mathrm{p}} \left|\varphi_\mathrm{mn}\left(\underline{\mathrm{x}}\right)\right|^2_{\mathrm{x_3}=0} \mathrm{d}\Gamma_\mathrm{x}$;
p_b is the blocked pressure loading at the porous material interface ($\mathrm{x_3} = 0$).
This form has the advantage of depicting the coupling with the wave guide in terms of radiation admittance and blocked-pressure loading. Note that at low frequencies (below the cut-off frequency of the wave-guide), higher modes lead to a purely imaginary admittance operator of an inertance type.
The total power dissipated in effects in the porous-rigid medium is the sum of the powers dissipated through viscous and thermal which can be written respectively as

$$\Pi^\mathrm{v}_\mathrm{diss} = \frac{1}{2}\Im\left[\int_{\Omega_\mathrm{p}} \frac{\phi^2}{\omega\tilde{\rho}_{22}} \underline{\nabla}\mathrm{p}.\underline{\nabla}\mathrm{p}^* \mathrm{d}\Omega\right] \tag{4}$$

$$\Pi^\mathrm{t}_\mathrm{diss} = \frac{1}{2}\Im\left[\omega \int_{\Omega_\mathrm{p}} \frac{\phi^2}{\tilde{R}} \mathrm{pp}^* \mathrm{d}\Omega\right] \tag{5}$$

The power absorption coefficient is defined as the ratio of $\Pi^\mathrm{v}_\mathrm{diss} + \Pi^\mathrm{t}_\mathrm{diss}$ to Π_inc, where Π_inc is the incident power which in the case of a plane wave excitation, of complex amplitude p_0, the incident power is given by $\Pi_\mathrm{inc} = S\left|p_0\right|^2 / \left(2\rho_0 c_0\right)$ where S is the cross-section of the wave guide.

3 - RESULTS

A special case of inhomogeneous materials is considered here: double-porosity materials. They consist in a porous medium with a periodic lattice made up of several periods of a generic square L×L cell, in which holes containing air (called macro-pores) have been performed. The porosity of the porous medium and the porosity associated to the holes will be denoted by micro-porosity ϕ_m and macro-porosity ϕ_p respectively.

The presented method has been validated experimentally and investigated in Atalla et al [2]. Figure 2 shows the good agreement between the model and the measurements which have been performed using a Kundt tube for a cell with dimension L = 0.085 m on a 5.75 cm thick rock wool. Also fig. 2 exhibits the important increase in the absorption coefficient of the double porosity material compared to the corresponding simple porosity one. Note that the importance of this effect depends on the flow resistivity contrast between the microporous material and the hole.

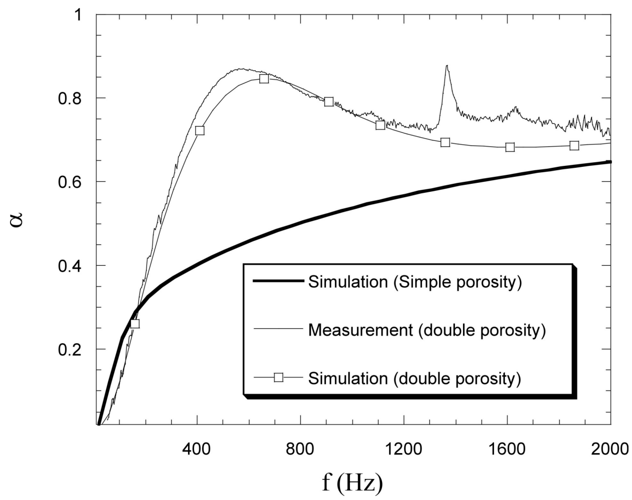

Figure 2: Comparison between simulation and measurements for a double porosity material.

The acoustic behavior of double porosity materials is governed by three important parameters (Olny): the size of the hole, the macro-porosity and a shape factor which depends on the hole shapes and on the macro-pores distribution. The influence of these parameters has been investigated in Atalla et al [2] in the case of holes with constant size within the thickness. This paper concentrates on one special configuration: the effects on the absorption coefficient, for a constant macroporosity and cell size, of holes with varying cross sections along the thickness of the materials. Figure 3 displays the cuts through the thickness of the double porosity material that are investigated: the white part corresponds to the hole shape whereas the gray part is related to the porous material. Note that case (h) and (i) are obtained by randomly distributing air patches along the thickness so as to obtain the desired macro-porosity. Case (i) is similar to case (b) but the distribution of holes is random. The size of the cell is 8.5 cm and the macroporosity is 0.14. Figure 4 shows the absorption coefficient obtained by the present model. One sees that the hole profile induces very strong changes in the performance of the double porosity material. A suitable design of the hole enables one to improve significantly the absorption coefficient in a given frequency band. A progressive decrease of the macroporosity as the wave goes deeper inside the material provides a significant increase of the absorption coefficient in a very wide frequency band. A small macroporosity at the surface of the porous material leads to a very selective peak at low frequencies but this solution is not interesting at higher frequencies. The random distributions give materials that are efficient on a wide frequency band. Note the very similar appearance of case (i) and (b).

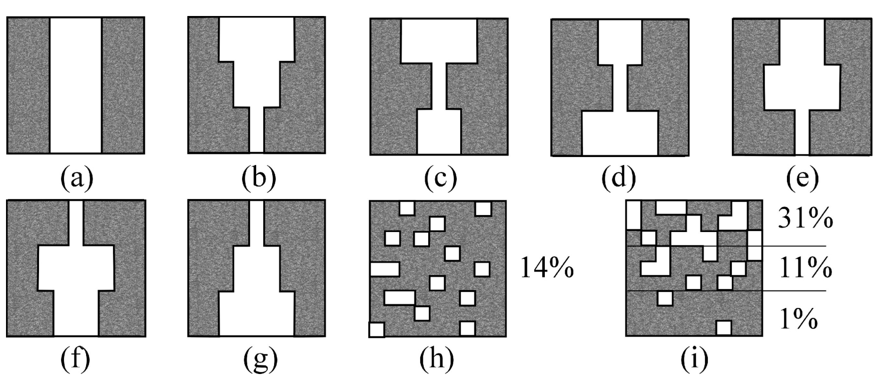

Figure 3: Hole profiles investigated.

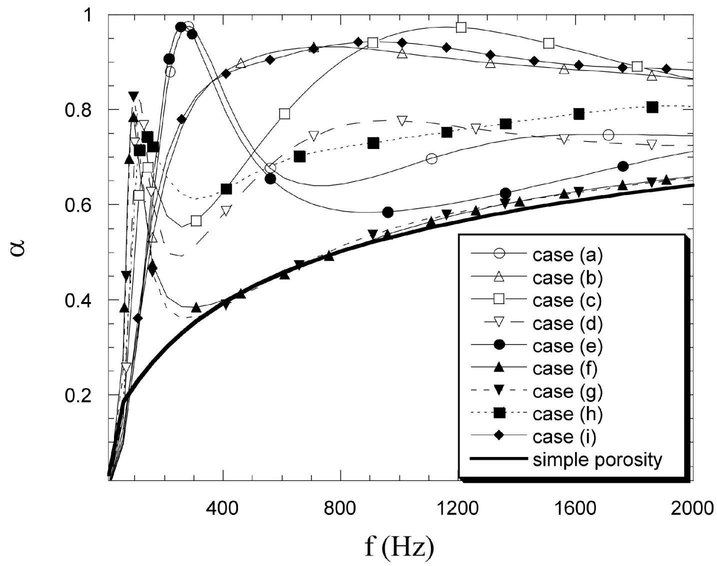

Figure 4: Comparison of the absorption coefficient for the different hole profiles investigated.

4 - CONCLUSION

The absorption coefficient of non homogeneous porous layers has been predicted from a 3D numerical model wherein each patch is modeled as an equivalent fluid. It has been shown that the normal incidence absorption coefficient of homogeneous materials could be significantly increased in a given frequency band by performing holes with appropriate profiles.

REFERENCES

1. **X. Olny**, *Absorption acoustique des milieux poreux à simple et double porosité. Modélisation et validation expérimentale*, PhD Thesis INSA de Lyon, pp. 281, 1999

2. **N. Atalla, F.C Sgard, X. Olny, and R. Panneton**, Acoustic absorption of macro-perforated porous materials, *submitted to Journal of Sound and Vibration*, 2000