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THE INFLUENCE OF PRESSURE DIFFUSION EFFECTS ON ABSORBING PROPERTIES OF POROUS MEDIA WITH DOUBLE POROSITY

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ABSTRACT
This paper is devoted to the study of plane waves propagation in double porosity media. Firstly, the definition of double porosity medium is recalled. Then the general description obtained in the case of strong permeability contrast, by way of an homogenisation method considering periodic separated scales media, is exposed. In this case of particular interest, a partial coupling between the networks of pores may occurred and the macroscopic description can be significantly modified by pressure diffusion effects. Models for macroscopic permeability and compressibility for infinite rigid frame materials are proposed and compared to experimental results in the case of perforated porous panels. We finally demonstrate the interest of such complex porous materials in order to build efficient wide range absorbing materials.

1 - INTRODUCTION

Porous materials are widely used as passive absorbers in order to control reflected waves in noisy environment. Most of them can be considered as single porosity media because two scales of representation are enough to describe the material: the macroscopic scale related to the wavelength (excitation), of characteristic size λ, and the microscopic scale related to the microstructure, of characteristic size l. From the macroscopic point of view, with the assumption that $\lambda \gg l$, and in case of motionless frame materials, the porous medium can be represented by an equivalent homogeneous medium, defined by a complex dynamic permeability ($\Pi(\omega)$), and a bulk modulus ($K(\omega)$). A double porosity material can be depicted as a porous medium with a micro-porous solid matrix. Two interconnected networks of very different characteristic sizes ($l_p >> l_m$), and then of different permeability, can be identified, and three scales can be defined to represent the material (Fig. 1).

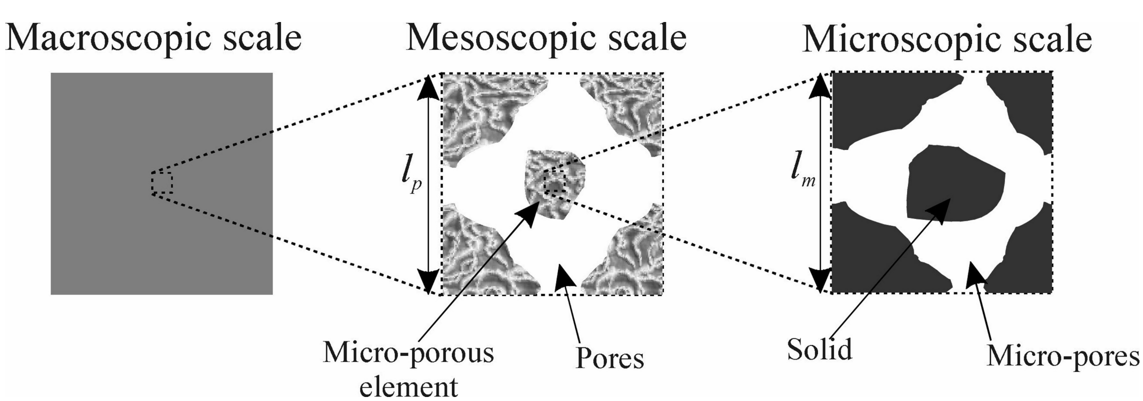


Figure 1: Double porosity medium.

Using the rigorous homogenisation method developed by Sanchez-Palencia [1], recent works [2,3,4] have shown that several macroscopic descriptions can be obtained depending on the contrast of permeability between the networks of pores and micropores. Boutin [2] showed theoretically that, in the case of strong permeability contrast, pressure in the micro-porous domain varies at the mesoscopic scale. This induces a partial coupling in terms of compressibility between pores and micropores. These theoretical results are briefly recalled and confronted to experimentation.

2 - THEORY

The porous media is assumed to be saturated by air, considered as a viscous fluid (η), with a static density ρ_0. Equations are written according to the $e^{j\omega t}$ temporal dependency. The subscripts m and p, db are respectively associated to micro-pores and pores and double porosity medium. In the case of a strong permeability contrast, only the main results obtained, thanks to the homogenisation technique, at the mesoscopic and macroscopic scales are presented. Two space variables, $\vec{y}$ and $\vec{x}$ are used to described phenomena respectively to these two scales. In first approximation, at the mesoscopic scale, physics is not perturbed by the presence of micro-pores, and the pressure in the pores is uniform: $p_p^0 = p_p^0(\vec{x})$ (varies according to the macroscopic scale). Because of ($l_p >> l_m$), below the viscous characteristic frequency ($\omega_{vm} = O\left(\eta / l_m^2 \rho_0\right)$) of the micro-porous medium, the wavelength (λ_m) in it is very small compared to the wavelength in the pores (λ_p). Assuming now that $|\lambda_m| = O(l_p)$, the problem obtained at the mesoscopic scale for the micro-porous domain is as follows [2]:
Waves in the microporous domain are of diffusive type and the boundary conditions are imposed by the macroscopic pressure field $p_p^0(\vec{x})$.

$$\begin{cases} j\omega \dfrac{p_m^0}{K_m^s} - \dfrac{\Pi_m^s(0)}{\eta} \Delta_y p_m^0 = 0 & \\ p_m^0 = p_p^0(\vec{x}) & \text{on the boundary} \end{cases}$$

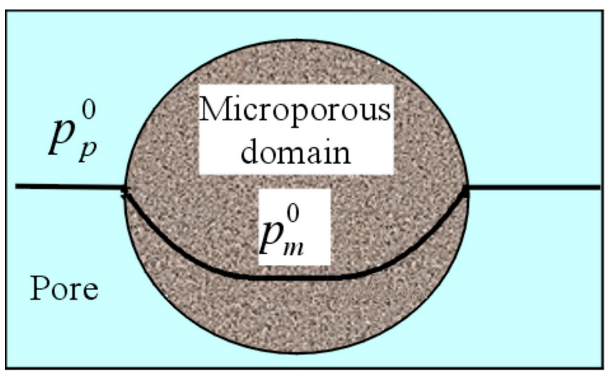


Figure 2: Pressure diffusion in a micro-porous grain (mesoscopic scale) bounded by macroscopic conditions.

This problem is analogue to the thermal diffusion problem in a single porosity, media, and p_m^0 is linearly related to $p_p^0(\vec{x})$ by a scalar function f depending on the mesoscopic geometry of the material: $p_m^0(\vec{x}, \vec{y}) = f(\vec{y})\, p_p^0(\vec{x})$. From the macroscopic point of view, this result leads to establish the expression of the bulk modulus of the homogenous material equivalent to the double porosity medium traducing the coupling between the networks of pores and micro-pores:

$$K_{db} = \left(1/K_p^s + (1-\phi_p)\, F\left(\omega P_0/\phi_m K_m^s\right)/K_m^s\right)^{-1}$$

with K_p^s and K_m^s, the bulk modulus of respectively the porous and the micro-porous media (single porosity), with porosity ϕ_p and ϕ_m. P_0 is the static pressure. F is obtained by integrating f over the micro-porous domain. A general phenomenological model, is proposed for the coupling function F:

$$F(\omega) = \left(1 - j\left(\omega/\omega_d\right) D(\omega)/D(0)\right) \qquad \text{with} \qquad \omega_d = (1-\phi_p)\, P_0 \Pi_m(0) / \left(\phi_m \eta D(0)\right)$$

where ω_d is the characteristic frequency for the pressure diffusion effects, $\Pi_m(0)$ the static permeability of the micro-porous material. D can be derived for example from the model proposed by Lafarge et al. for the "thermal permeability" [5]:

$$D(\omega) = D(0) / \left(j\omega/\omega_d + \left((1+j)\left(M_d/2\right)\left(\omega/\omega_d\right)\right)^{\frac{1}{2}}\right)$$

$D(0)$ and M_d are geometrical parameters depending on the mesoscopic geometry of the micro-porous domain.

3 - EXPERIMENTAL RESULTS

A simple double porosity material can be built by perforating micro-porous panels, the holes (pores) created being large compared to the micro-pores size (Fig. 3). Propagation of plane waves is studied in the $\vec{x}_1$ direction. Rock wool panels of high density and flow resistivity ($\sigma = 135000 N m^{-4} s$), form the micro-porous material.

Measurements have been performed using Kundt tubes, in rigid backing conditions from 50 to 2000 Hz.

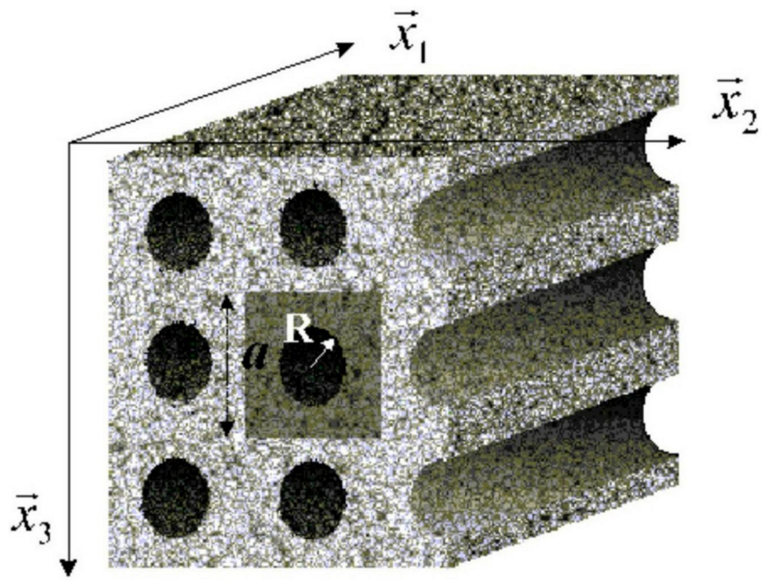


Figure 3: Double porosity material made of perforated micro-porous material; a= 8.5 10^{-2}m, R= 1.73 10^{-2}m, $\phi_p = \pi R^2/a^2 = 0.13$.

In this frequency range, the waves in the micro-porous material are essentially diffusive waves ($\omega_{vm} \approx$8000 Hz), the dynamic flow being viscous.

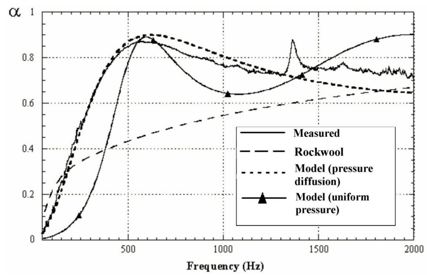
Regarding, the permeability of the homogeneous medium equivalent to the double porosity medium, the homogenisation technique leads to establish that it is given by the permeability of the porous system, the flux brought by the micro-pores being negligible. However, Olny [4] has experimentally shown that it should be taken into account because of the small value of ϕ_p. Thus $\Pi_{db}^{x_1}$ can be exactly calculated from the dynamic permeability of rock wool in the $\vec{x}_1$ direction ($\Pi_m^{x_1}$), and assuming that the flow in the pores is purely inertial in the considered frequency domain:

$$\Pi_{db}^{x_1}(\omega) = (1 - \phi_p)\, \Pi_m^{x_1}(\omega)/\eta + \phi_p / j\omega\rho_0$$

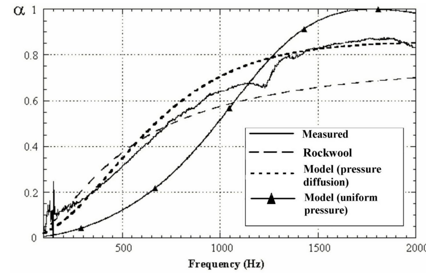
Propagation of plane waves in the double porosity media is then entirely characterised from the knowledge of Π_{db}^{x1} and K_{db}. The absorption coefficients of two perforated panels of different thickness have been measured and compared to the proposed model including pressure diffusion effects. These measurements have also been compared to the model supposing a uniform pressure ($F(\omega) = 1$) in the all material and which corresponds to the case of low permeability contrast.

Results (Fig. 4) show that pressure diffusion effects must be taken into account in order to describe the absorption coefficient of such a material. For this simple mesoscopic geometry, $D(0)$, ω_d and M_d, can be calculated. For instance the frequency ω_d has been estimated around 245 Hz. However, the tested perforated panels are of small thickness (”mesoscopic”) so that the parameters have been readjusted in order to take the surface effects into account [4]. For the panel (a) ω_d is estimated to 550 Hz whereas it is 1600 Hz for the panel (b).

These results also show that creating a second pores network can increase the absorption coefficient of a given simple porosity media (rockwool on Fig. 4), in a large frequency band and especially in the low frequency domain.



(a): 5.75 cm thick panel on rigid backing.



(b): 2.25 cm thick panel on rigid backing.

Figure 4: Absorption coefficients.

4 - CONCLUSION

Firstly it is to be noticed that the behaviour of double porosity media can be very different from single porosity media. It appears that the effect of pressure diffusion increases significantly the attenuation in the material. Moreover, this study demonstrates how double porosity can be simply used to build new high performances absorbers.

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