Methods for measuring the porosities of porous materials incorporating dead-end pores

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Abstract

Theoretical and experimental results of the acoustic properties of porous materials containing dead-end pores have been proposed recently[1]. These results are presented in another paper at this conference. It appears that these materials cannot be described well by the classical Johnson-Champoux-Allard (JCA) model as Biot's assumption on the viscous flow in all open pores is not fulfilled for dead-ends. Indeed, there are situations where the fluid inside the cavities (dead ends) is almost at rest so that a volume fraction of the porosity (the dead-end porosity) is "acoustically inert" and does not contribute to the attenuation by viscous friction of a passing wave. In addition, it is believed that depending on the frequency, the fluid properties and the dimensions of the cavities, standing wave fields can settle in within the dead-end pores, resulting in resonances in acoustic indicator curves. A first confirmation of these predictions was provided by experimental results obtained on materials with cavities created artificially and on porous metals that are likely to contain dead-end porosity. This model can account for quarter wavelength type (open-closed cylindrical pores) or even Helmholtz type (ink bottles) cavities, and can confirm results obtained previously in bottom up approaches[2]. The first experimental results on the absorption coefficient and on the transmission loss for these materials are very encouraging.

In order to further validate the model, new material characterization techniques are being investigated in the present study. The model involves two new physical parameters, namely the *dead-end porosity* ϕ_{DE} and the *average length of the dead-end pores* L_{DE}. Classical non-acoustic methods (e.g. methods based on Boyle's law[3], on missing mass[4] or on comparison of air volumes[5]) can be used to determine the total open porosity. However, the total open porosity results from the sum of the kinematic porosity (also referred to as the Biot porosity ϕ_B in Ref. 1) and dead-end porosity. In order to distinguish the contributions of these two last porosities in the acoustic behavior, another method has to be applied that will either provide a measure of ϕ_B and of ϕ_{DE}.

In this study, two methods are proposed for the determination of the Biot porosity ϕ_B. These methods are based on acoustic transmission in a porous layer of material containing dead ends. It is found that only methods based on sound transmission are able to provide a measure of the Biot porosity and therefore of the dead-end porosity. Methods based on reflection coefficients yield the surface porosity[7,8] and cannot be applied as the assumption of homogeneous and statistically isotropic material may not be fulfilled for dead-end porous materials.

The first method is based on the asymptotic behaviors at high frequency and at low frequency of the phase velocity or of the attenuation and on Biot's characteristic frequency f_c separating the two regimes. This frequency (corrected to account for the tortuosity α_∞) given by: $f_c = \sigma \dfrac{\phi_B}{2\pi\,\alpha_\infty \rho_f}$ where σ is the flow resistivity and ρ_f is the fluid density. A log-log plot of the phase velocity as a function of frequency (see Fig. 1) shows the low and high frequency asymptotic behaviors separated by Biot's characteristic frequency.

A measurement of this frequency can provide the Biot porosity. The determination of the characteristic frequency can provide a measurement of the Biot porosity.

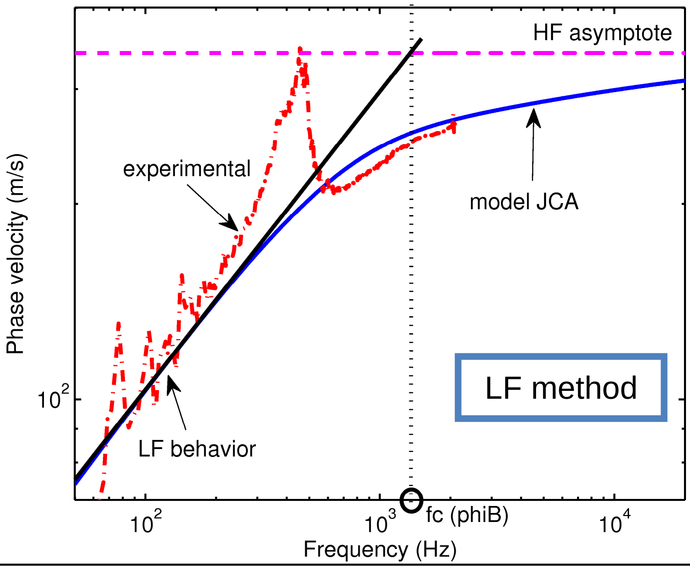

Fig1- Phase velocity JCA model and experimental for a melamine foam (log log representation). The Biot porosity is obtained via fc from the intercept of the linear high frequency asymptote with the linear low frequency behavior.

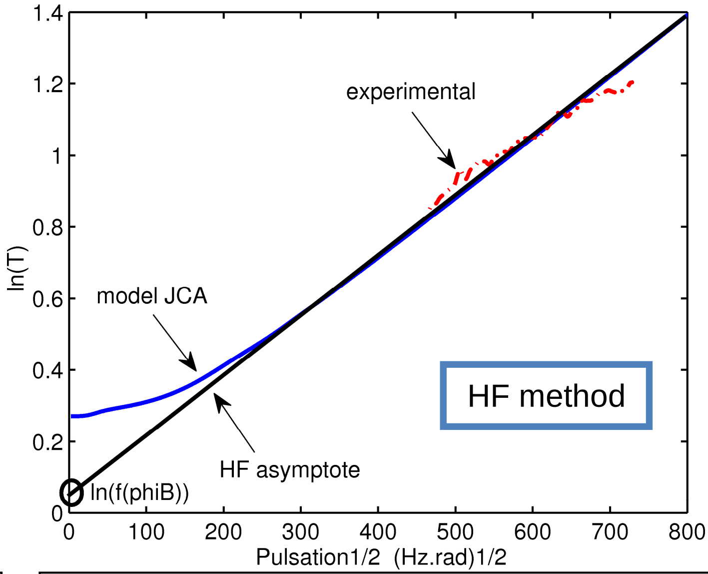

Fig2 – logarithm of transmission coefficient versus square root of pulsation for a melamine foam (validation). The Biot porosity is obtained from the intercept of the linear high frequency behavior with the vertical axis.

The second method is based on the asymptotic behavior at high frequency of logarithm of the transmission coefficient[6]: $\lim_{\omega\to\infty}\left|\ln\left|T(\omega)\right|\right| = \ln(\varepsilon) + \sqrt{\omega}\left(\sqrt{\frac{\eta\alpha_\infty}{2\gamma P_0}}\frac{L}{L_{eq}}\right)$, where $\varepsilon = \frac{\left(1+\phi_B/\sqrt{\alpha_\infty}\right)^2}{4\phi_B/\sqrt{\alpha_\infty}}$ and $L_{eq} = \left(\frac{1}{\Lambda}+\frac{\gamma-1}{B\Lambda'}\right)^{-1}$.

Where Λ, Λ' are viscous and thermal lengths. This parameter, when plotted as a function of the square root of frequency exhibits a linear behavior at high frequency (see Figure 2). The intercept of the straight line with the vertical axis provides the parameter ε and therefore leads to the Biot porosity. Measurements using this method were performed on melamine foams, artificial materials with well controlled parameters (Biot and dead end porosity) and on metallic foams likely to incorporate dead-end porosity.

In this study, two experimental techniques based on sound transmission in porous materials with dead-end porosity are proposed. Other experimental characterization methods are currently being investigated in order to evaluate the average length of the dead ends.

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