A Method for the Mechanical Characterisation of Poroelastic Materials

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1. Introduction

Following theoretical models based on the Biot theory, the solid phase of an isotropic elastic porous material is defined by three vacuum elastic properties: Young's modulus, Poisson's ratio and loss factor. However, under vacuum conditions, closed cells trapped in the materials may burst and change the properties of the material. To prevent this problem and for the sake of simplicity, current techniques based on static or dynamic measurements with compression, shear or torsion tests are performed in air to characterize the elastics properties.

In the classical compression test sketches in figure 1, frequency, boundary conditions, initial strain, and the air saturating the material may affect the transfer function measurement ($F(L)/x_0$) uses to compute the elastic properties of an open-cell porous material. The objective of this paper is to analyse one of these effects, the boundaries conditions, and to derive by the way a measurement method for the three elastic parameters.

2. Influence of boundaries conditions

For the compression test sketches in figure 1, the shape factor of the porous test specimen is defined by the ratio of its cross-sectional area to the total area of the stress-free surfaces. For sample of large shape factor, the transfer function is strongly dependent on the shape factor if the ends of the sample are bonded. That is, under compression, the sample bulge out as shown in figure 2.

Because the shape factor is related to the geometry of the sample and to the Poisson's ratio, many works have been done with the goal of using it as a secondary effect methods, using two different geometry, to compute both the Poisson's ratio and the Young's modulus [1]. However, it generally led to the development of methods that requires at least one sample of negligible shape factor effect since the appropriate shape factor are not known exactly [2]. These samples are inconvenient since they are long, slim, and then subjected to buckling.

Our investigation with an axisymmetrical poroelastic FEM model showed us that the measured transfer function ($F(L)/x_0$) may be correlated to the shape factor of the test specimen for different Poisson's coefficients as shown in figure 3. In figure 3, H, $H\infty$ and R are the static () transfer function with boundary conditions effects (N/m), the static transfer function with a zero shape factor (N/m), and the specimen radius (m). These results were obtained using an in-house axisymmetrical poroelastic FEM code.

3. Measurement method

The method proposed here is to first offset the dynamic transfer function measurement ($H(\omega)$) to a static value with an analytical relation. This yields the static transfer function H. Using figure 3, a relation between the transfer function H, the Poisson's ν, and the L/R ratio can be drawn:

$$\frac{H_i L_i}{EA_i} = G_i\left(\frac{L_i}{R_i}, \nu\right) \quad (1)$$

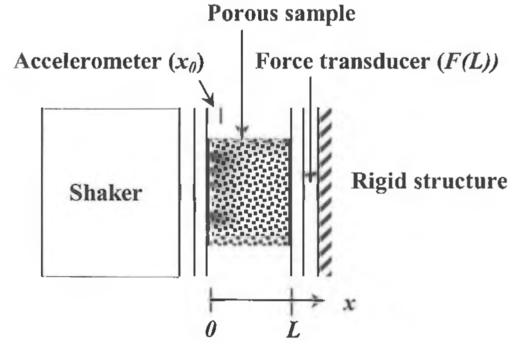

Fig. 1 - Sketch of the vibration transmissibility test

where i simply refers to a specific test specimen, G is a curve fit relation established from the FEM results (figure 3), and A is the surface area (m^2) of the sample. For two specimens of different L/R ratios taken from the same material, since both have the same Young's modulus, it is then possible to write the following relation:

$$\frac{H_1 L_1}{G_1\left(\frac{L_1}{R_1}, \nu\right) A_1} - \frac{H_2 L_2}{G_2\left(\frac{L_2}{R_2}, \nu\right) A_2} = 0 \quad (2)$$

Solving the latter equation for ν is a simple matter using any kind of minimisation algorithm. The solution for ν can then be used in relation (1) to compute the Young's modulus.

In applying this procedure, one then makes the assumption that boundary conditions and frequency have independent effects in the frequency range of measurements. This holds true if measurements are taken well above the first resonance. Another important assumption is that the saturating air does not influence the measurements. As stated by Mariez *et al* [4], this is true at relatively low frequencies. The same assumptions are also valid for the loss factor.

Because the Young's modulus was considered as a real algebraic value until this point, the damping factor is then simply the ratio of the imaginary part to the real part of any transfer function used for the computation.

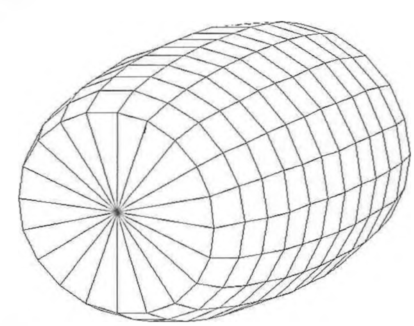

Fig. 2 - Representation of the bulge out effect of the specimen under compression test with bonded ends.

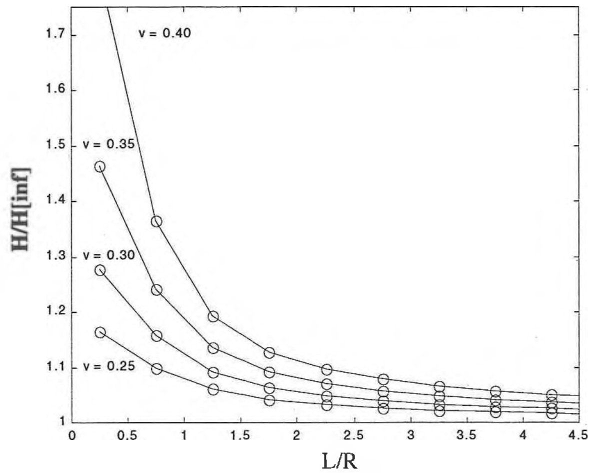

Fig. 3 - Correlation between the transfer function and the L/R ratio for a specimen under the compression test with bonded ends

4. Results

To partly verify the validity of the method, numerical simulations using the parameters given in Tables 1 and 2 are compared to standing wave tube measurements of the sound absorption coefficient for a 54.4-mm thick foam specimen. The numerical simulations are done with software MNS/Nova™ [5] which is based on the Biot and Johnson-Champoux-Allard models [3,6]. Both rigid-frame and elastic-frame models are used. For the elastic-frame model, sliding edge conditions are used.

Figure 4 presents the comparisons. It is noted that the numerical simulations are in good agreement with the measured sound absorption coefficients. The simulation using a rigid-frame approximation does not show the frame resonance of the foam backed on the rigid wall. In this case, the use of the elastic-frame model gives better predictions.

The discrepancies between the elastic-frame prediction and the measurement may be due to the additional friction loss between the specimen contour and the tube. Also, the numerical sliding edge boundary conditions are not a perfect representation of the experimental one. The experimental one is something between bonded edge and sliding edge.

Table 1 - Foam parameters measured with LCMA/GAUS facilities

ϕ	Porosity	0.960
σ	Flow resistivity (Ns/m^4)	49 541
α_∞	Geometrical tortuosity	3.82
Λ	Viscous characteristic lengths (10^{-6} m or μm)	65.4
Λ'	Thermal characteristic lengths (10^{-6} m or μm)	141.0
ρ_1	Bulk density (kg/m^3)	47.45

Table 2 - Elastic properties measured with the proposed method

E	Young's or elastic modulus (Pa or N/m^2)	337 300
ν	Poisson's ratio	0.15
η	Damping loss factor	0.135

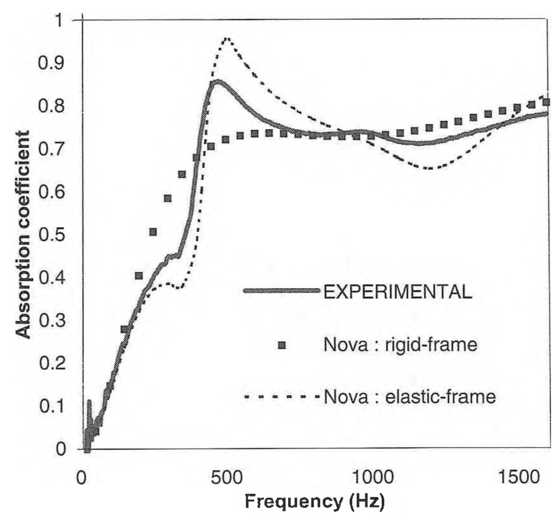

Fig. 4 - Experimental results used to explore the validity of the proposed method

5. Acknowledgments

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6. References

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