IMPEDANCE TUBE CHARACTERIZATION OF ELASTIC PROPERTIES OF EXPANDING FOAMS

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1. INTRODUCTION

Many authors worked on the propagation of acoustical and elastic waves in elastic open-cell porous materials. The energy carried by the waves is dissipated through structural damping loss, viscous loss (due to relative motion between the two phases), and thermal loss [1]. In the case of elastic closed-cell foams, there is no relative motion between the fluid and the solid phases. Consequently, the only energy dissipation mechanisms are the structural damping and thermal losses [2]. From the Biot's theory [3], only the elastic compression and shear waves now propagate in the closed-cell foams. In this case, few specific models were proposed to study the acoustic dissipation within this type of foams. The most common way of modelling these foams is to use a solid model with equivalent elastic properties. Even if the core of these foams is made of closed cells (i.e., no propagation of acoustical waves in the core), their surface may show open cells and irregularities (e.g., exploded cells). In this case, the surface may be seen as a thin resistive layer showing some surface sound absorption.

To account for the surface sound absorption of closed-cell foams, a model was worked out by one of the authors [4]. In this work, it was shown that closed-cell foams show resonant sound absorption (i.e., sound absorption at elastic resonances) with residual surface absorption (apart from resonances). To model this type of acoustic behaviour, the closed-cell foams are modelled as a two-layer material: a resistive layer covering a core made of an equivalent solid with bulk elastic properties. The bulk elastic properties account for the structural damping and thermal losses. The resistive surface layer is characterized by its static airflow resistivity. While the resistivity can be easily identified, the key element in the proper use of this so-called "surface absorption solid model" is the fine characterization of the bulk elastic properties.

The main objective of this work is to develop a method, based on sound absorption measurements, for the characterization of the bulk elastic properties of closed-cell foams –more especially those from heat expanding foam process [4]. This paper is organized as follows. In section 2, the theory behind the method is first reminded for the sliding edge condition for which the bulk's modulus and damping loss factor can be deduced. These results were worked out in previous works [5]. Then, the method is extended to the bonded edge condition which additionally allows the identification of the Poisson's ratio. In section 3, the method is experimentally tested for characterizing the bulk elastic properties of foam with the bonded edge condition. Then, sound absorption predictions using the identified bulk elastic properties are compared to impedance tube results. Finally, section 4 concludes this work.

2. THEORY

2.1 Sliding edge condition

The sliding edge condition is an ideal case for the characterization of the bulk elastic properties. The method was previously developed by considering this boundary condition [5]. Two main results are recalled in this section.

a) The 1st natural frequency is linked to the bulk modulus by:

$$f_1 = \frac{\omega_1}{2\pi} = \frac{1}{4L}\sqrt{\frac{K_b}{\rho_1}} . \quad (1)$$

b) The sound absorption coefficient at the resonance is linked to the bulk damping loss factor. Assuming that the damping loss factor is low enough ($\eta < 1$), the surface impedance can be approximated by Eq.(2). The optimal and reduced damping loss factors are then introduced by Eqs.(3) and (4), and the absorption coefficient at the resonance is linked to the bulk damping loss factor by Eq. (5).

$$Z_s(\omega_1) \cong \frac{1}{2}\rho_1\omega_1 L\eta \quad (2)$$

$$\eta_{op} = \frac{2Z_0}{\omega_1\rho_1 L} \quad (3)$$

$$\eta_r = \frac{\eta}{\eta_{op}} \quad (4)$$

$$\alpha(\omega_1) = 1 - \left|\frac{\eta_r - 1}{\eta_r + 1}\right|^2 \quad (5)$$

2.2 Bonded edge condition

Considering a bonded edge condition and a hard backing, the first compression resonance depends on the shape factor s and Poisson's ratio ν. This frequency is expressed in function of the first natural frequency of the sliding case:

$$f_1^b = c_b(\nu, s)\cdot f_1 . \qquad (6)$$

The factor c_b is called the bonded edge correction factor. This coefficient only depends on the shape factor and Poisson's ratio. When the Poisson's ratio is assumed to be known, the bulk modulus and Young's modulus can be deduced from the first natural frequency by using Eq. (6).

With this bonded edge condition, the sound absorption coefficient at the resonance still reaches a maximum for an optimal damping loss factor. The sound absorption coefficient can still be expressed by Eq. (5) but the optimal damping loss factor is no more defined by Eq. (3). This optimal factor is linked to that of the sliding case by:

$$\eta_{op}^b = \frac{\pi\cdot s}{c_b}\cdot m(c_b)\cdot\eta_{op} + b(c_b) . \qquad (7)$$

Thus, knowing the shape factor and Poisson's ratio, the bonded correction factor can be calculated and the method can be extended to the bonded edge condition. The bulk modulus and Young's modulus are deduced from the first natural frequency and the bulk damping loss factor is deduced from the sound absorption coefficient at the resonance peak.

3. EXPERIMENTAL RESULTS

The method is now experimentally tested on a sample with a bonded edge condition. Three samples of a different length are required for computing the Poisson's ratio [6]. Here, each foam samples were carefully and directly heat expanded in a hollow cylinder having a 29-mm inner diameter.

The sound absorption coefficient is now computed with the equivalent solid model and compared to impedance tube measurements in Fig. 1. The correlation with measurements is good, especially at the resonance peak. The surface absorption model [4] is used in order to correct the underestimation of the predicted absorption. The residual variation between these latter predictions and measurements may be attributed to the fact that the real elastic parameters of the expanded foam are not necessarily constant with the frequency.

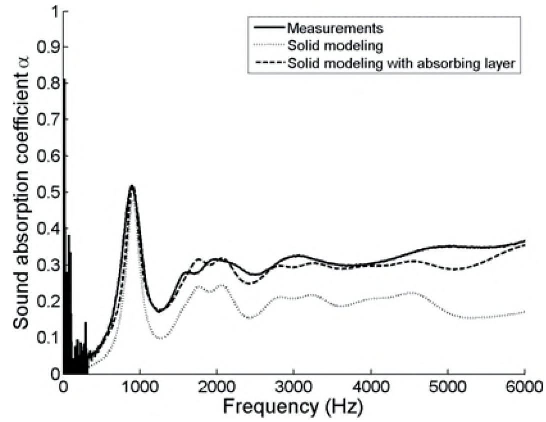

Figure 1: Normal sound absorption coefficient of the heat expanded foam.

4. CONCLUSION

In this work, a method was proposed to determine the bulk elastic properties of soft equivalent solids or closed-cell foams from simple impedance tube absorption tests. The method was tested experimentally with success in laboratory. It has revealed that the properties found with the proposed method can be used in the surface absorption solid model worked out in reference [4] to yield good correlations with measurements.

However, the accuracy of the method relies mostly on the proper control of the mounting conditions in the impedance tube. This is actually the most important limitation of the method, especially on small sample diameters for which the absorption measurement is very sensitive to boundary conditions. Further tests are required to validate the robustness of the proposed method.

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