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The measurement of the shear modulus for polymer porous layer with two microphones

Vincent Garetton², Denis Lafarge¹, Sohbi Sahraoui^{*1}

¹*Laboratoire d'Acoustique de l'Université du Maine, UMR 6613
Avenue Olivier Messiaen, 72 085 Le Mans cedex, France*

²*Present address : Research & Development - Eurocopter Group
ETGA - External Acoustics Aeroport International Marseille Provence
13725 Marignane Cedex France*

Abstract

An experimental method is described for measuring the shear modulus of thin porous layer. An acoustical excitation with a loudspeaker and a simulation performed with the Biot theory allow measurement without any mechanical excitation.

Keywords : polymer foam; shear modulus; biot-johnson-allard theory; acoustic absorption

1 - Introduction

The Biot theory of fluid-saturated porous media provides a description of the waves propagating in soils (water saturated rocks)[1]. Several authors have extended this theory to sound-absorbing materials, such as glass wool and plastic foams, for noise control applications in engineering activities such as aeronautics and the automotive industries. At low frequencies or when the skeleton is fixed to a vibrating structure, the elastic properties are needed and their measurements are generally performed with mechanical excitations [2- 4]. These methods are limited to small sample with low frequency range.

In this paper, the measurements are performed through an acoustical excitation and two microphones ; this method [5] was initially used for the measurement of acoustic impedance. We describe the experimental setup and we used a numerical simulation of the Biot-Johnson-Allard theory [7] for calculating the shear modulus at various frequencies. These results are compared to the literature.

2 - Acoustical measurements

The experiment [5] is an adaptation of a method primarily worked out for measuring normal impedance in normal incidence. The layered media is an impervious plate fixed on thin acoustic foam backed on rigid ground. As shown in Fig. 1, two positions M_1 and M_2 are taken by a moved microphone (Sennheiser KE-4) on the axis of the panel. A loudspeaker S is set at a distance of about 4 m from the panel and generates a linear chirp signal (200-1000 Hz). In this configuration, the transfer function $H(\omega)$ between the measured pressure p_1 and p_2 at

* Corresponding author, *Email address*: sohbi.sahraoui@univ-lemans.fr

points M_1 and M_2 is related to the reflection coefficient R as [6]:

$$R(\omega) = \frac{e^{jkd_1} - e^{jkd_2} H(\omega)}{e^{-jkd_2} H(\omega) - e^{-jkd_1}} \quad (1)$$

where d_1 and d_2 are the distances between the impervious plate and the microphone positions; ω and k represent the radian frequency and the wave number in air. The M_1 position is very close to the plate surface without any contact with the microphone; the distance between the positions M_1 and M_2 are about 4 to 5 cm.

The simplified equation of motion of the spring-mass model is given by:

$$m \frac{d^2 u}{dt^2} = -Ku + pS \quad (2)$$

where m and u are the mass and the displacement of the plate, K is the stiffness of the porous layer and p is the pressure exerted on the plate. The area S of the panel is about 3 m^2 and the thickness L of the PU foam (Recticel) layer is 2 cm. The experiments were performed with two plates in PMMA (thickness 2 and 5 mm) and one plate in aluminium.

The stiffness $K = P/L$ where P the longitudinal compression modulus is related to the shear modulus N and to the Poisson ratio ν as [6]:

$$P(\omega) = \frac{4N(\omega)}{3} + \frac{2(1+\nu)}{3(1-2\nu)} N(\omega) + K_f \quad (3)$$

where K_f is the incompressibility of the air saturating the porous frame which is neglected.

The model given by Eq. (2) gives an illustration of the experiment and doesn't take into account of the complete effects described in the Biot-Johnson-Allard theory such as the coupling effects between the saturated air and the skeleton. For this reason the experimental determination of the absorption coefficient $A(\omega) = 1 - |R(\omega)|^2$ (where $R(\omega)$ is given by Eq. (1)) is compared with the simulated absorption by using MAINE3A; the general method [7] of modelling acoustic fields in stratified media (which include elastic solid, fluid and porous layers) is developed in this program.

3 – Results and conclusion

In Fig. 2 a typical curve of the measured absorption coefficient A is presented. We observe a resonant peak at 300 Hz. In the same figure, a computed A by means of the MAINE3A program and fitted to experimental A by using the foam parameters (Table 1). The longitudinal compression modulus P given by Eq. (3) is extrapolated in this fitting. The values of shear modulus N are obtained at different frequencies (218, 308 and 412 Hz).

The real and imaginary part of N are presented in Fig. 3 and are compared to quasistatic results [3] and time-temperature equivalence measurement [8]. The present method gives a good agreement with the time-temperature equivalence results which are obtained with quasi

static torsion tests and where the coupling frame-air effects are not present. This is a new example of the adequacy of the Biot theory for the description of the acoustic properties of sound-absorbing materials. The direct characterisation of porous layer is performed at a frequency depending on the plate mass and the layer thickness.

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Captions for illustrations

Table : Parameters of the foam

Figure 1 : Experimental setup

Figure 2 : Absorption coefficient versus frequency

Figure 3 : Comparison between present results (*), quasistatic measurements (o) and frequency-temperature equivalence characterisation (- - -)

Reticel foam (S20 Bulpren family)	
flow resistivity $\sigma(\text{Nm}^{-4}\text{s})$	57000
porosity ϕ	0.97
viscous dimension $\Lambda (\mu\text{m})$	40
thermal dimension $\Lambda' (\mu\text{m})$	130
tortuosity α_∞	1.1
density $\rho_s (\text{kg}/\text{m}^3)$	31
Poisson ratio	0.3
thickness L (cm)	2

Table

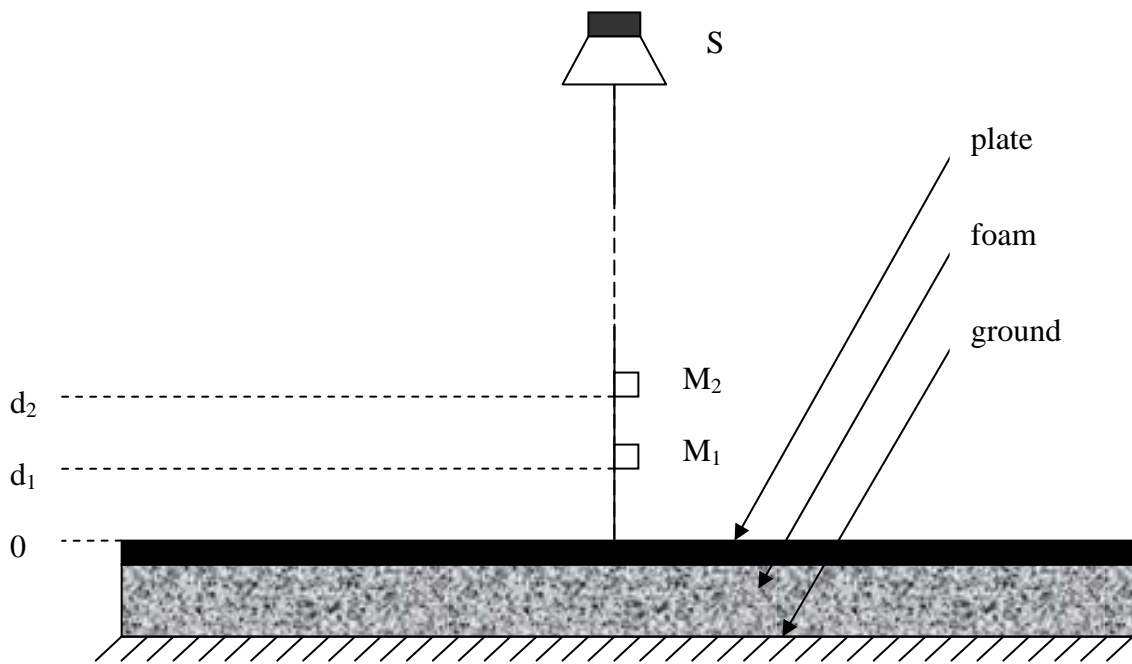


Figure 1:

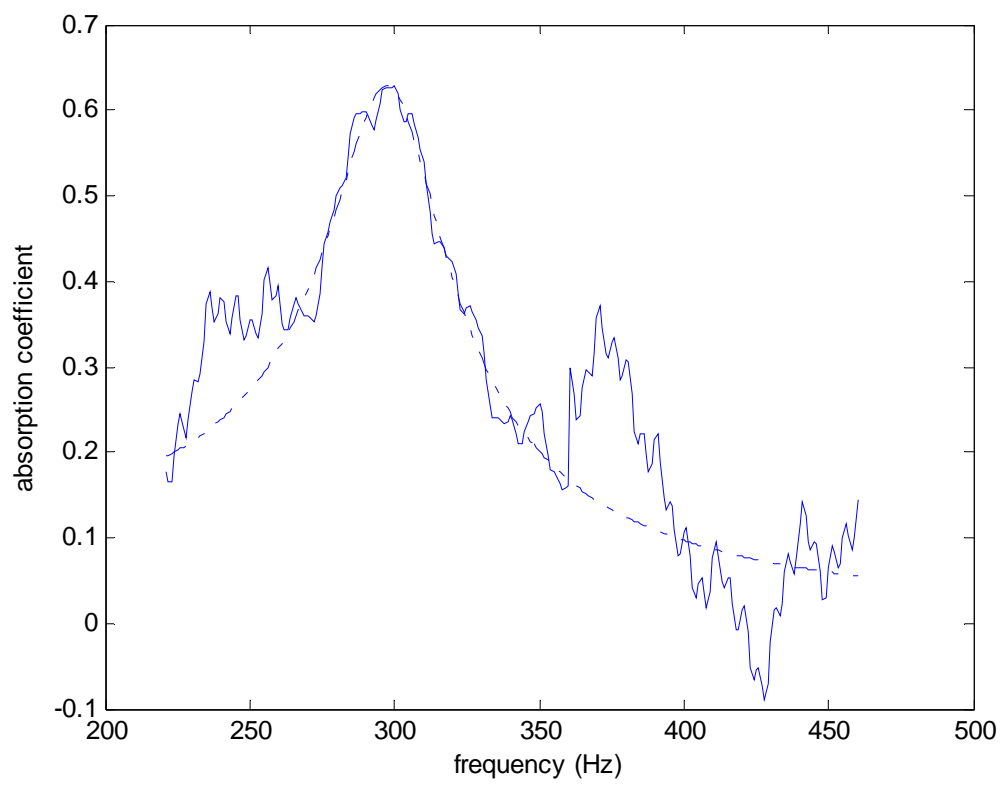


Figure 2

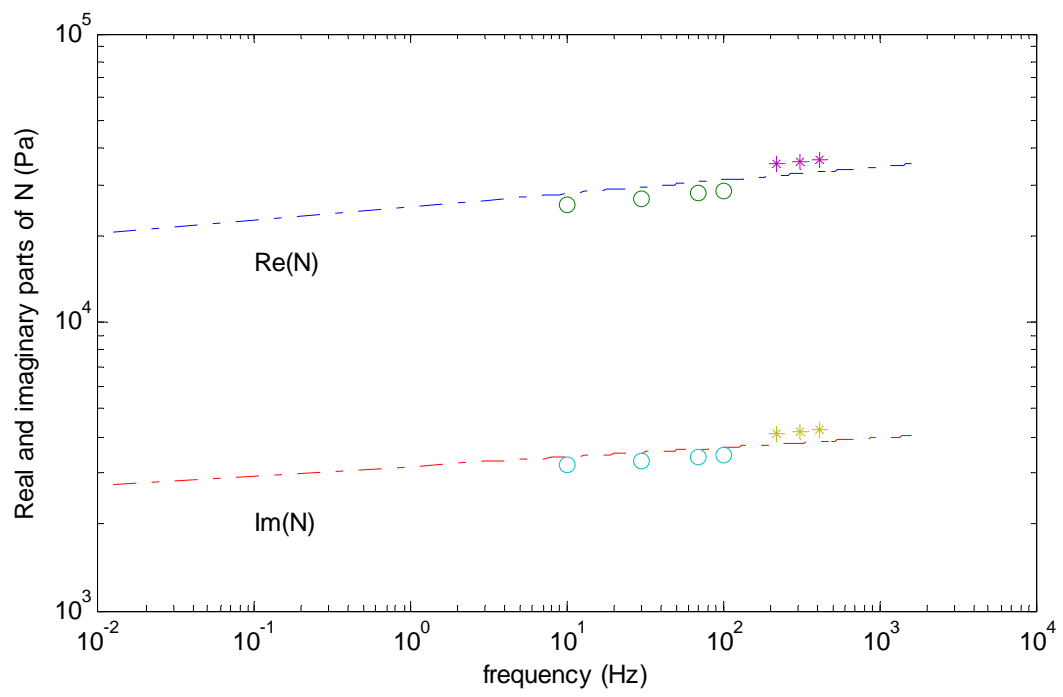


Figure 3 :