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AN EXPERIMENTAL APPROACH TO THE EFFECTIVE ELASTIC BULK MODULUS OF POROUS FIBROUS MATERIALS AT INTERMEDIATE FLOW REGIMES

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ABSTRACT
In this work is accomplished a study of the complex elastic bulk modulus. This parameter has a complex imaginary part much less than his real part and because of this in phenomenological approximations is tended to employ the modulus. When the materials are rigid the problem is tended to simplify supposing than this equivalent fluid have an isothermal behaviour in low frequency and adiabatic in high frequency. So that this parameter is reduced to a constant function related with the static pressure of the air. But in practical situations the frequencies are intermediate and a review of these simplifications must be made. Because of this in this work the thermodynamic behaviour of the equivalent fluid has been checked experimentally, at intermediate frequencies and flow regimes. With this the elastic bulk modulus is adapted for the analysis of real rigid samples in any frequency.

1 - INTRODUCTION
For the acoustic modelling of the semirigid and rigid porous fibrous materials is customary to employ physical and empirical approach. In the first procedure [1], [2], [3], the bulk modulus and the complex density of the equivalent fluid are calculated, and from an empirical point of view [4], [5], [6], the parameters are the complex characteristic impedance and the complex constant of propagation. Following the first procedure and the previous references, it is possible to determine the complex elastic bulk modulus of the equivalent fluid theoretical and experimentally, and with these expressions the variation of the bulk modulus in frequency can be observed. Indeed, the commonly accepted hypothesis of selecting an elastic module of the air similar to the pressure of the air p_0, for isotherm propagation conditions, and to equal it to $(\gamma\, p_0)$ under adiabatic conditions, does not have physical meaning for samples of fibrous material of intermediate density as it will be seen next. These statements can be revised starting from the number of acoustic Reynolds applied to the commercial samples. In a previous work [7], this value was evaluated for commercial samples whose density was in the range from the 30 to 170 kg/m^3 and a frequency range from 500 to 3500 Hz. By this study it was proven that the samples of more density were only in a regime of Poisseuille, for the suitable range of frequencies, and therefore with an isotherm behaviour. The rest of commercial samples overcomes the regime of Poiseuille and they are in an intermediate regime between this and that of Helmholtz. So that the employment of the previous constants to define the elastic modulus does not make any sense in samples of intermediate density considered non-rigid samples. In the previously bibliography mentioned there are numerous examples of calculation of the complex elastic modulus, [3], [8], and this work incorporates an experimental procedure to determine it for intermediate density samples and intermediate flow regimes.

2 - THEORY AN EXPERIMENTATION
Following J.F. Allard [3] one has a theoretical expression for the elastic modulus (page 85) based on microscopic properties of the porous fibrous samples. This formula can be tested by an experimental

procedure that is based in the measurement of the dynamic flow impedance of the samples and the formulation of Morse [1] as follows.
The dynamic flow impedance is defined for very thin sample [9]:

$$\breve{Z}_f = \frac{\Delta\breve{p}}{\breve{v}} = \phi + j\omega\rho_p \tag{1}$$

where ϕ is the flow resistance, ω is the circular frequency, and ρ_p is the density of air in the pores. The results of this measurement and using the formulation of Morse [1] is possible to express the complex constant of propagation:

$$\breve{\gamma} = \pm j\sqrt{\frac{\omega h\left(\rho_p\omega - j\phi\right)}{\breve{K}_p}} \tag{2}$$

where $\breve{K}_p$ is the complex elastic modulus of the air in the pores and h is the porosity.
Then

$$\breve{K}_p = \pm\frac{\left(j\phi - \rho_p\omega\right)\omega h}{\breve{\gamma}^2} \tag{3}$$

and the complex elastic bulk modulus is

$$\breve{K} = \breve{K}_p/h \tag{4}$$

In this expression for the calculation of $\breve{\gamma}$ the formulation of Delany and Bazley [4] could be used.
The theoretical and experimental formulation used can be substituted by means of the characteristic impedance of the sample and the formulation of other authors [6], [8]. But in all the cases in the studied range of frequencies, the difference between the module and the real part of the expression of the complex elastic bulk modulus is scarce. With it the imaginary part is very small and also the phase. It becomes correct in these cases to consider it like a real magnitude that varies in function of the frequency.

3 - EXPERIMENTAL SET-UP

The experimental set-up employed allows to measure the dynamic flow impedance for very thin samples, and it has been explained in a previous work [7].

4 - RESULTS AND CONCLUSIONS

In the figures 1 and 2 can be seen how many changes the real and imaginary parts of the complex elastic modulus in a typical sample in a intermediate flow regime. Although the real part is much bigger that the imaginary one, the real part is never constant in frequency, and it varies between the static value and the adiabatic value.
By these results can be obtained a worthless phase and a real part equivalent to the modulus of $\breve{K}$. Finally with the previous results for samples in intermediate flow regimes the following conclusions can be deduced:

- When the complex modulus of compressibility is analysed, the real part or the modulus is enough, since the imaginary part and the phase are very small.
- The elastic bulk modulus is a function of the frequency in intermediate flow regimes, it is never constant, but it varies between p_0 and γp_0, depending on the tested samples.

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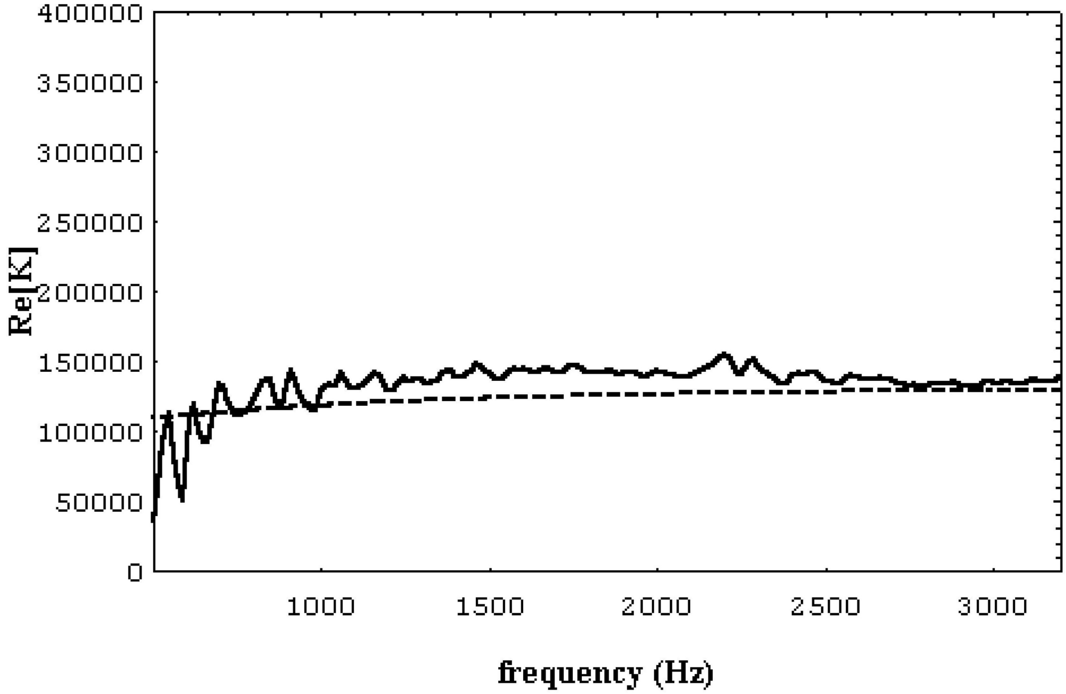

Figure 1: Theoretical [3] and experimental real part [4] of the elastic bulk modulus for a sample of 70 kg/m^3.

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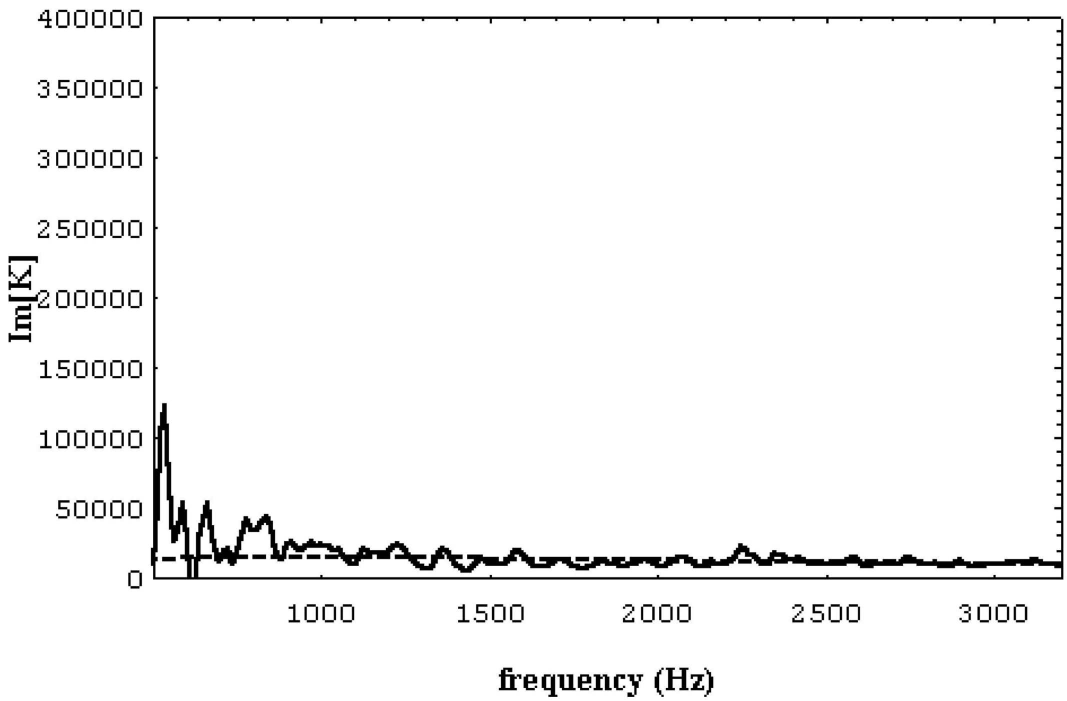

Figure 2: Theoretical [3] and experimental imaginary part [4] of the elastic bulk modulus for the same sample.