The acoustic characterization of porous media and its standards

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ABSTRACT

While there is a growing number of methods for the acoustic or elastic characterizations of porous materials, there is only a few test procedures which are standardized.

The benefits of using standards are to harmonize procedures and to reduce measurement uncertainties between laboratories. They should, moreover, give guidelines for accurate characterizations of materials and should clearly present the limits of the methods. They should also keep the door open for the development of innovative techniques which apply to current materials or new materials not covered by the already existing standards.

The context of this communication is the current revision of ISO 9053 standard (measurement of the static air flow resistivity) and the future revision of ISO 10534-2 (impedance tube measurements, 2 microphone technique). Therefore the objective is to collect comments and suggestions for these revisions and to share common views about the future standards.

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1. INTRODUCTION

The current revision of ISO 9053 [1] is the opportunity to take stock of characterization standards in the field of acoustical porous materials. This text thus gathers a non-exhaustive list of references to ISO standards dedicated or which can be applied to acoustical porous materials.

The goal of this communication is not to support standardization for any parameter but to update existing standards and to provide information on emerging methods toward a better description of acoustical porous materials. Indeed, parameter values are still too often lacking in models or simulations even for materials which, for example, are not orthotropic or do not exhibit non-linear elasticity.

A first section gives an overview of common procedures and standards for the acoustic and elastic characterizations of acoustical porous materials. A second section focuses on suggested amendments for the future revised ISO 9053.

2. OVERVIEW OF COMMON CHARACTERIZATION PROCEDURES AND STANDARDS FOR ACOUSTICAL POROUS MATERIALS

Methods and standards for the characterization of acoustical porous media can be divided in two parts. On the one hand, the characterization of the acoustical parameters related to the visco-inertial and thermal dissipation effects resulting from the fluid-skeleton interface inside the material microstructures. On the other hand, the characterization of the elastic parameters related to the skeleton.

It is worth noting here that at the scale of a pore (or at the scale of the Representative Elementary Volume, REV) for a material, the structure do not undergoes deformations but only displacements. This point is a consequence of the scale separation between the pore and the wavelengths required to model porous media as macroscopic equivalent homogeneous materials [2]. As a consequence, both characterization, acoustic and elastic, can be handled separately as the motion of the skeleton of the material will not modify the shape of the pores where visco-inertial and thermal dissipation effects occur. Visco-inertial and thermal dissipations

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will neither modify the shape of the skeleton. However visco-inertial and thermal effects on the one hand and elastic effects of the material skeleton on the other hand can obviously interact with each other.

2.1 Acoustic characterization

The acoustic description of porous media involves 1 to 8 parameters depending on the material microstructures (see fig. 1 which cannot summarized all existing models. Readers are invited to visit APMR [3] for more information about the existing models).

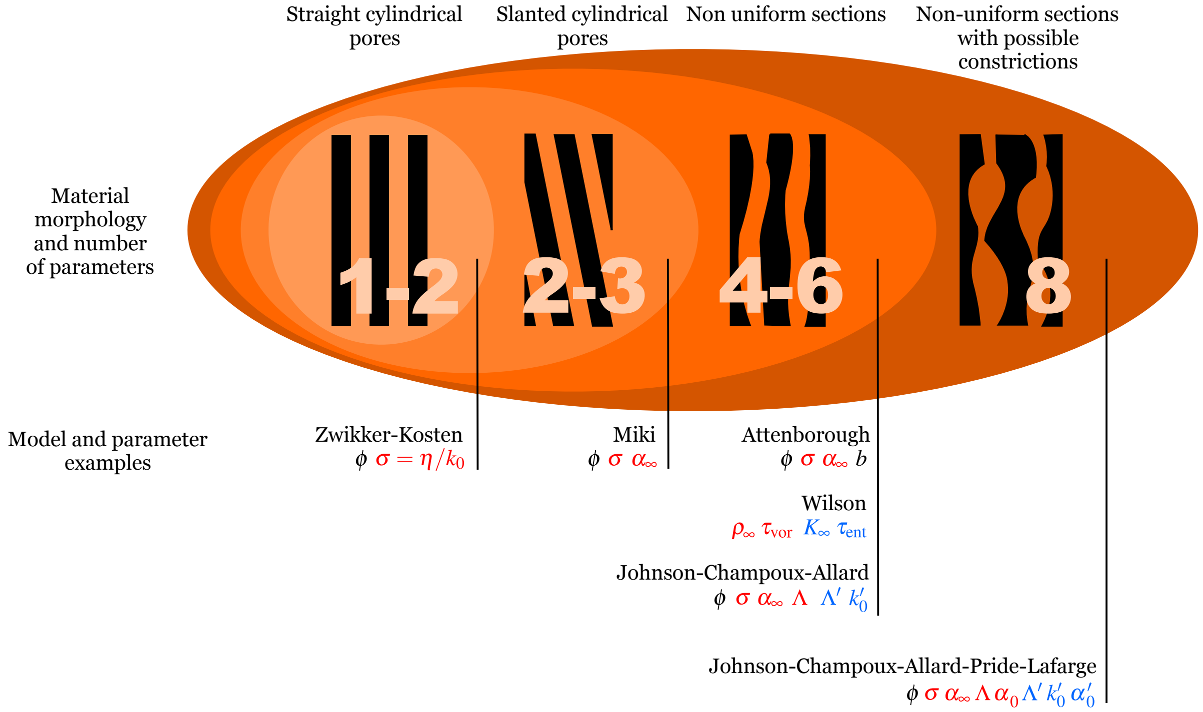

Figure 1: Growing complexity of visco-thermal models used to describe the sound propagation in porous media depending on their pore microstructure. In red: visco-inertial parameters, in blue: thermal parameters.

The static airflow resistivity, σ, is the most significant parameter for usual acoustical porous materials with high open porosities ϕ. σ is related to the static viscous permeability k_0 of the material with $\sigma = \eta/k_0$ where η is the dynamic viscosity of air ($\sim$ 1.82 N.s.m^{-2} for usual ambient temperature and pressure conditions). σ can be directly measured and its dedicated standard for its assessment is ISO 9053 [1].

The parameter open porosity, ϕ, can also be directly measured. The most common method for such a measurement is the one introduced by L. Beranek[4] and further refined by Champoux, Stinson & Daigle [5]. Although there are based on the same principle than ISO 4590 [6] (air pycnometer, i.e. application of the Boyle-Mariotte law), these methods use different procedures. The method used in [5] is indeed more convenient than the inflexible ISO 4590 and more accurate for very high porosity materials used in acoustics (ϕ is usually greater than 0.70 except for perforated facings).

No standard exists for other acoustical parameters, namely the high frequency limit of the dynamic tortuosity: α_∞, the viscous characteristic length: Λ, the thermal characteristic length: Λ', the static thermal permeability k'_0 and the low frequency limits for the viscous and the thermal tortuosities: α_0 and α'_0. No method even exists to estimate these last two parameters except than model fitting to measurements.

Methods based on the measurements of the reflection and transmission coefficients at audible frequencies in an impedance tube [7, 8] or at ultrasound frequencies with dedicated transducers [9] have been developed to estimate, respectively, α_∞, Λ, Λ', k'_0 or ϕ, α_∞, Λ, Λ'.

A proposition will be submitted during the revision of ISO 10534-2 [10] to add some information about the method at audible frequencies in an impedance tube. Indeed, this method only requires a small modification of the tube compared to usual impedance tube. It would also be an opportunity to clarify and warn about measurements of transmission coefficient in tubes, for plane waves at normal incidence.

2.2 Elastic characterization

When a porous material is mechanically excited or when its skeleton can be set in motion by an acoustic wave, elastic parameters of the material are required to describe its acoustic behavior.

Acoustical porous materials can exhibit different behaviors such as visco-elasticity, orthotropy or non-linear elasticity. Therefore, there is not a single methods to characterized their elastic parameters [11].

A various list of standards also exist, mainly under the 6721 series as it can be observed in table 1.

Table 1: Non-exhaustive list of the standards which can be applied to estimate parameters or properties of acoustical porous materials. E denotes a complex Young's modulus, G a shear modulus, D a bending stiffness and ν a Poisson's ratio (materials are assumed isotropic for compression tests).

Standard	Test	Parameter or property
ISO 604 [12]	Static compression	Estimation of E
ISO 6721-2 [13]	Quasi-static torsion (free vibrations)	Estimation of G
ISO 6721-3 [14]	Bending vibration	Estimation of D
ISO 6721-4 [15]	Quasi-static tension	Estimation of E
ISO 6721-5 [16]	Quasi-static bending	Estimation of D
ISO 6721-6 [17]	Quasi-static shear	Estimation of G
ISO 6721-7 [18]	Quasi-static torsion	Estimation of G
ISO 9052-1 [19]	Compressional vibrations	Measurement of dynamic stiffness
ISO 18437-5 [20]	Quasi-static compression	Estimations of E and ν

3. SUGGESTED AMENDMENTS FOR REVISED ISO 9053

The following subsections describe suggestions for amendments concerning 4 points in the current version of ISO 9053. Underline texts refer to text in the current version of the ISO 9053 while *italic texts* refer to suggested amendments.

3.1 Clarification on title and relation to other standards

The adjective *static* should be added to clarify the title of the standard: Determination of *static* airflow resistance (as a reminder, the resistance corresponds to the product of the resistivity and the thickness of the tested sample). Indeed, if one can introduces a dynamic airflow resistance it is a function of frequency including effects of other parameters (such as the high frequency limit of the tortuosity α_∞ or the viscous characteristic length Λ).

Some authors prefer to use the static viscous permeability, k_0 rather than the static airflow resistivity σ (as a reminder: $\sigma = \eta/k_0$ where η denotes the dynamic viscosity of air). As a consequence, the definition of the static viscous permeability should also be added to the introductive part of the standard.

Moreover, a note should be added to explain the difference and to avoid any misunderstanding between ISO 9053 and ISO 9237 [21]. Indeed, ISO 9237 requires pressure drops (100 or 200 Pa for a sample cross-section of 20 cm^2) and thus velocities much larger than ISO 9053 for which an airflow velocity of 0.5 mm.s^{-1} is required. As a reminder, v = 0.5 mm.s^{-1} corresponds to the air particle velocity, in free air, at 80 dB (p = 0.2 Pa with a reference of 2×10^{-5} Pa): $v = Z_0 p$ with $Z_0 = \rho_0 c_0$, ρ_0 being the mass density for the air at rest ($\sim$ 1.2 kg.m^{-3}) and c_0 being the celerity of sound waves in air ($\sim$ 340 m.s^{-1}). Usually, the airflow velocity used in ISO 9237 is ten to a hundred times higher than in ISO 9053. For such high velocity, a linear flow through porous material is not ensure and this can results in estimations of static resistivities much higher in ISO 9237 than the ones used in acoustics and in ISO 9053.

3.2 Sizes of samples

The current version of ISO 9053 defines requirements for the sample sizes. If it is circular in cross-section, the internal diameter shall be greater than 95 mm. For the rectangular parallelepiped shape, the preferred cross-section is a square. In any case, all sides shall measure at least 90 mm.

However, the larger the diameter (or edge), the higher leakages can exist at the perimeter of the sample inside its holder. A common idea is to reduce the effect of leakages by using a high surface to perimeter ratio (i.e. large diameter or edge). However, reducing the effect of possible leakages is not sufficient, for accurate measurements, there should be no leakage. It is thus suggested that: *The diameter or smallest edge should be equivalent to:*

- *for foams, fibrous or granular materials: at least 10 cells (i.e. pores, fibres or grains),*
- *at least 95 mm in diameter or 90 mm for each edge in the case of materials with large pores, fibres or grains for which 10 pores, fibres or grains cannot be used.*

3.3 Superimposed samples

The current version of ISO 9053 suggests that If the test specimens available are not sufficiently thick to produce a suitable pressure drop, test specimens – but not more than five – chosen in the same way, may be superimposed.

Obviously, using superimposed specimens can change the microstructure of the material (and lead to an increase of the static air flow resistivity if holes or pores are not exactly superimposed).

The following addition to the current sentence is proposed: *only if it does not modified the material microscopic structure. For a foam or a granular material, superimposing specimens usually do not modify their microscopic structures. For fibrous materials, woven or non-woven textiles, the fibre orientations should be the same between all superimposed specimens. For perforated plates, holes should all be superimposed.*

Note that a method has been developed to estimate the static air flow resistivity of textiles and perforated plates from impedance tube measurements. This point is discussed in the next point.

3.4 The case of thin materials such as perforated facings

ISO 9053 cannot be used to accurately measure the static airflow resistance of thin porous materials for which the pressure drop is lower than the recommended set-up accuracy of 0.1 Pa (i.e. materials for which the resistance is lower than 200 N.s.m^{-3}). It is suggested to add a note about an alternative method described in [23] which relies on the measurements of the surface impedances of thin porous materials backed by an air-gap in an impedance tube.

In addition, the method developed in [23] account for the flow distortion in the vicinity of the holes or perforations which can have a significant effect on the static airflow resistivity values of thin porous materials.

3.5 A calibration sample

As suggested in a paper authored by Garai & Pompoli in 2003 following an inter laboratory test on static airflow resistivity measurements [22], a calibration procedure might be added to ISO 9053 (a calibration procedure concerning the pressure level in method B of ISO 9053 - alternating airflow method - already exists, the proposed calibration would be complementary). The use of a calibration sample before a series of measurements could provide a consistency check of these measurement results. This calibration sample could be a solid sample with straight cylindrical perforations to be able to compute its theoretical static resistivity.

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