# Is my material an efficient acoustical material?

**Olivier Doutres*[1], Franck Sgard†[2], Frédéric Laville[1], Jérémie Voix[1], Olivier Bouthot[1], Hugues Nélisse[2], Pierre Marcotte[2], and Jérôme Boutin[2]**

[1]Department of Mechanical Engineering, École de technologie supérieure, Montréal, Québec H3C 1K3, Canada.
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Montréal, Québec H3A 3C2, Canada.

## Abstract

Researchers of ÉTS and IRSST decided to synergize again their efforts in order to expand the ICAR laboratory to include a facility dedicated to acoustical materials. Acoustic properties of porous materials such as the normal incidence sound absorption coefficient and the normal incidence sound transmission loss together with several physical intrinsic parameters required as input in the most commonly used associated models (i.e., porosity, airflow resistivity, Young's modulus...) can now be measured in ICAR. This new facility aims at (1) improving the knowledge about the physical phenomena associated with the dissipation of the acoustic energy in porous materials of various microgeometries, (2) developing new materials with dedicated or uncommon acoustical properties (e.g., metamaterial, metacomposite,...) for industrial applications such as hearing protection, building, aeronautic or aerospace and (3) providing the input parameters required in acoustical prediction software dealing with acoustical materials.

**Keywords:** sound absorption, acoustic materials, foam, porosity, airflow resistivity

## Résumé

Les chercheurs de l'ÉTS et de l'IRSST ont decidé d'unir à nouveau leur efforts afin d'agrandir le laboratoire ICAR pour y ajouter des équipements dédiés à la caractérisation et au développement de nouveaux matériaux acoustiques. Les propriétés acoustiques telles que le coefficient d'absorption et la perte par transmission de matériaux poreux éxcités acoustiquement en incidence normale ainsi que les propriétés physiques intrinsèques (i.e., porosité, résistivité au passage à l'air...) utilisées dans les principaux modèles associés peuvent maintenant être mesurées. Ces équipements ont pour but: (1) l'amélioration des connaissances quant aux phénomènes physiques associés à la dissipation de l'énergie acoustique au sein de matériaux ayant diverses micro-géométries, (2) la conception de nouveaux matériaux aux propriétés acoustiques adaptées ou inusitées (e.g., métamatériaux, métacomposite...) pour différentes applications industrielles telles que la protection auditive, le bâtiment, l'aéronautique ou l'aérospatiale et enfin (3) fournir les données d'entrée requises dans les logiciels de simulation acoustique dédiés aux matériaux acoustiques.

**Mots clefs:** absorption acoustique, matériaux acoustiques, mousse, porosité, résistance spécifique au passage à l'air

## 1 Introduction

The science of acoustical materials faces a number of challenges identified by various industrial sectors and research laboratories dealing either with transportation or occupational health and safety issues. These acoustical materials should be (1) lighter to reduce payload and fuel consumption, (2) environmentally sustainable, (3) more efficient and particularly at low frequencies and (4) more comfortable in the case of hearing protection in order to increase the wearing time and decrease hearing impairments. In order to meet these challenges, researchers of École de technologie supérieure (ÉTS) and Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) expanded the Infrastructure commune en acoustique pour la recherche ÉTS-IRSST (ICAR) laboratory [1] and include a facility dedicated to the analysis and characterization of acoustical materials. Acoustic properties of materials such as the diffuse field sound absorption coefficient and the diffuse field sound transmission loss can already be measured using the coupled chambers of ICAR laboratory. However, these measurements are cumbersome and can be time consuming if multiple tests have to be done. Furthermore, large surface of materials are most of the time not available in a design phase of new products. The facility presented in this paper is thus complementary since it allows for measuring the absorption and insulation properties of small sample of material subjected to a normal incidence acoustic excitation. The various physical parameters (e.g., porosity, airflow resistivity, tortuosity...), referred to as the nonacoustic properties, as well as mechanical properties required in the models established to predict the acoustical properties of materials [2] can also both be measured. This paper aims at presenting the various test benches available in this new facility.

*olivier.doutres@etsmtl.ca
†franck.sgard@irsst.qc.ca

## 2 Test benches

### 2.1 Acoustic properties

**Sound absorption coefficient** ($\alpha$)

The sound absorption coefficient is related to the reflection coefficient ($r$) defined as the ratio of the pressures created by the outcoming and incoming waves at the surface of the layer: $\alpha = 1 - |r|^2$. The normal incidence sound absorption coefficient is measured according to standard ASTM E1050-10 using impedance tubes. Multiple tubes of various inner diameter are available to cover the frequency band [50 Hz - 9 kHz].

**Sound transmission loss (TL$_n$)**

The normal incidence sound transmission loss is ten times the common logarithm of the reciprocal of the sound transmission coefficient ($\tau$); the latter being the fraction of airborne sound power incident on a material that is transmitted through the material. It is determined from pressure measurements at three positions within the impedance tube according to the three microphone method [3] and standard ASTM E2611-09. According to this standard method, the following properties can also be assessed in the case of an homogeneous material: the characteristic impedance in material, the propagation wavenumber in material, the equivalent dynamic bulk modulus and equivalent dynamic density.

**Earplug insertion loss (IL)**

The normal incidence insertion loss of earplugs is measured by the use of a classical impedance tube [4]. The earplug is inserted in a rigid sample holder which is itself placed in a larger diameter impedance tube. The transfer matrix of the system is measured according to ASTM E2611-09 and the one of the earplug alone is then recalculated by eliminating the effect of the sample holder. Finally, the IL is estimated by coupling the earplug transfer matrix to a one-dimensional model of the occluded ear canal taking into account the tympanic membrane impedance.

### 2.2 Nonacoustic properties

**Open porosity ($\phi$ [-])**

The open porosity is the fraction of the total material volume that is occupied by the fluid in the interconnected porous network. The volume of fluid present in closed pores is thus excluded. This property is measured using an isothermal pressure/mass method.

**Airflow resistivity ($\sigma$ [N.s.m$^{-4}$])**

The airflow resistivity of acoustical materials is the airflow resistance ($R$) divided by the sample thickness. The later parameter is defined as the quotient of the air pressure difference across a sample divided by the volume velocity of airflow through this sample. It is measured in ICAR according to the ISO 9053 standard.

**Tortuosity ($\alpha_\infty$ [-])**

The tortuosity is another intrinsic parameter related to the complexity of the frame micro-geometry. It is often interpreted as a characteristic of the sinuous aspect of the fluid flow associated with the passage of a wave in a porous media. Tortuosity of low airflow resistivity materials can be determined from the measurement of ultrasound acoustic waves transmitted through a slab of porous material. In the case of highly resistive materials, it can be estimated from the measurement of ultrasound acoustic waves reflected by a slab of porous material at oblique incidence. This parameter can also be estimated using indirect or inverse characterization techniques [5]. These two techniques are based on impedance tube measurements and require sound absorption coefficient in the case of the inverse method and the equivalent dynamic bulk modulus and equivalent dynamic density of the tested material in the case of the indirect method.

**Viscous length ($\Lambda$) and thermal length ($\Lambda'$ [m])**

The viscous and thermal characteristic lengths are two parameters used to describe the viscous and thermal dissipation phenomena at medium and high frequencies. These two characteristic lengths are measured by inverse or indirect techniques as described previously in the case of the tortuosity parameter.

### 2.3 Mechanical properties

Following theoretical models based on the Biot theory [2], the solid phase of an isotropic viscoelastic porous material is characterized by three in vacuum elastic properties: Young's modulus, loss factor and Poisson's ratio. These parameters are estimated at low frequencies using a quasi-static method (QMA) based on the measurement of the mechanical impedance of a cylindrical sample placed between two rigid plates and subjected to a small amplitude sinusoidal compression. Two samples of the base material having different shape factors are used to get both complex Young's modulus and Poisson's ratio.

## References


[1] F. Laville, J. Voix, O. Doutres, C. Le Cocq, O. Bouthot, F. Sgard, H. Nélisse, P. Marcotte, and J. Boutin. Infrastructure commune en acoustique pour la recherche ÉTS-IRSST. *Canadian Acoustics*, 43(2), 2015.

[2] J. F. Allard and N. Atalla. *Propagation of sound in porous media: modelling sound absorbing materials*. (Wiley, Chichester, UK), 2nd edition, 2009.

[3] Y. Salissou, O. Doutres, and R. Panneton. Complement to standard method for measuring normal incidence sound transmission loss with three microphones. *J. Acoust. Soc. Am.*, 131:EL216, 2012.

[4] O. Doutres, F. Sgard, and G. Viallet. Measurement of earplugs insertion loss using a classical impedance tube. In *Internoise (San Francisco)*, 2015.

[5] O. Doutres, Y. Salissou, N. Atalla, and R. Panneton. Evaluation of the acoustic and non-acoustic properties of sound absorbing materials using a three-microphone impedance tube. *Applied Acoustics*, 71:506, 2010.