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REPRODUCIBILITY EXPERIMENTS ON MEASURING ACOUSTICAL AND RELATED NON-ACOUSTICAL PARAMETERS OF POROUS MEDIA (ROUND-ROBIN TESTS)

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Abstract
A series of reproducibility experiments on the characterisation of acoustical parameters of selected samples of porous media is carried out on a range of porous samples in several independent laboratories in Europe and North America. The studied acoustical characteristics are the characteristic acoustic impedance and complex propagation constant. The data on the normal incidence, plane wave sound absorption coefficient is presented in this paper. The assessment of the related geometrical parameters required for model, namely the steady-state flow resistivity, porosity, tortuosity, viscous and thermal characteristic lengths and thermal permeability, will be discussed in the oral presentation. Detailed procedures related to sample preparation, installation are discussed together with data on the material property variation observed between individual material samples and laboratories.

INTRODUCTION

There is considerable interest in determination of the acoustical, related geometrical and elastic properties of porous materials. This interest mainly relates to vibro-acoustic applications of porous media. These applications require a knowledge of the fundamental parameters which characterise the acoustical behaviour of porous media. These parameters are commonly assessed from the standard acoustic measurements technique detailed in [1]. This technique relies on a standing wave apparatus with appropriate acoustical sensors and signal processing hardware. It is mainly used to measure the sound absorption coefficient of porous materials from which data on the non-acoustical (geometrical) parameters of the porous materials are inverted. As a result, the characterisation process relies heavily on the accuracy of experimental data on the acoustic absorption coefficient. The accuracy of this technique is affected by the quality and homogeneity of the material samples, their conditions during the experiment, environmental and operational conditions, quality of the setup and the signal processing method. These conditions and measurement apparatus can vary from lab to lab and their effect on the measured values of the absorption coefficient is largely unknown.

There have been a number of studies into the accuracy of the standing wave tube method [2-4]. These works are mainly concerned with the effect of the mounting conditions on the measured values of the sound absorption coefficient. The authors are not aware of any studies which provide experimental data on the performance of the method between individual laboratories which use different diameter of standing wave tubes, excitation stimuli and signal processing methods.

The objectives of this work are: (i) to determine the dispersion of acoustic absorption data obtained for different samples of the same sheet of material in different laboratories; (ii) to determine the dispersion of acoustic absorption data for the same material obtained between different laboratories. This paper presents a part of a larger project which aims at harmonising the material characterisation process. The paper is focused entirely on normal incidence, plane wave absorption coefficient data.

This paper is organised as follows. Firstly, the methodology is detailed. Secondly, the results from individual laboratories are presented and comparisons between these results are made. Finally, the conclusions on the dispersion between the results are made.

METHODOLOGY

In total seven acoustic research centres were involved in this work. These are: University of Perugia (Italy), Katholieke Universiteit Leuven (Belgium), ENTPE (Lyon, France), Gesellschaft für Akustikforschung (Dresden, Germany), University of Bradford (UK), University of Ferrara (Italy) and Sherbrooke University (Canada). In total, seven commercial products were studied. Due to formatting requirements, this paper reports only the results for three particular materials which are: reticulated foam, fibreglass and reconstituted porous rubber. Table 1 provides a summary of some physical and geometrical characteristics of these materials.

Material	Description	Porosity	Density, kg/m^3	Thickness, m
#A	reconstituted porous rubber	0.80	242.0	0.0245
#B	reticulated foam	0.98	8.8	0.0197
#C	fibreglass	0.97	21.0	0.0290

Table 1. A summary of the characteristics of the investigated porous materials.

Each partner has been provided with a 400mm x 400mm sheet of the above materials. Samples of these materials have been cut individually by the partners using a circular cutting tool or water jet cutting machine to fit the diameter of the standing wave tube. The diameter of the standing wave tube, the measurement method, the sample preparation procedure and the mounting method for the sample used by the partners are detailed in Table 2. Note that Song & Bolton's method [3] is based on a transmission loss measurement which allows for the operator to determine the characteristic impedance (z_b) and propagation constant (k_b) within the material. In this case, the sound absorption coefficient of the material backed by a rigid wall is recalculated using the following expressions $\alpha = 1 - \left| \frac{z_s - \rho_0 c}{z_s + \rho_0 c} \right|^2$, where $z_s = z_b \coth(-ik_b h)$ is the surface impedance, ρ_0 is the density of air and c is the sound speed in air. Either of the following methods of support were adopted: (i) the diameter of the cut samples was 1-2mm larger than the diameter of the tube in order to ensure their tight fit (TF); (ii) the diameter of the cut samples was close or slightly smaller than the diameter of the tube and the samples were wrapped in a tape to prevent any leakage around the edge (TC); (iii) the diameter of the sample was exactly equal to that of the tube (PF); (iv) the diameter of the sample was exactly equal to that of the tube and the sample was glue bonded to the rigid backing (GB).

Partner	Tube diameter, m/ Tube manufacturer	Measurement method	Material preparation method	Method of support
#1	44mm/HM/V	ISO 10534-2	water jet/circular tool	TF/TC
#2	46mm/HM/H	ISO 10534-2	rotating blade	TF/TC
#3	38mm/HM/H	ISO 10534-2	rotating blade	GB
#4	29mm/HM/H	ISO 10534-2	rotating blade	TF
#5	29mm/BK4206/H	ISO 10534-2	rotating blade	TF/TC
#6	100mm/HM/H	Song-Bolton	rotating blade	TF/TC
#7	45mm/HM/H	ISO 10534	water jet	PF

Table 2. Equipment and material preparation procedures (HM – home-made tube; H – horizontally-installed tube; V – vertically-installed tube).

RESULTS

Figures 1 to 3 present the average measured normal incidence sound absorption coefficient together with its standard deviation obtained by each partner for materials labelled #A, #B, #C. Up to six samples of each material were studied, except for laboratory #3 which investigated only one samples per material. For this laboratory the results are only shown in Figures 4(a)-(c). Because the measurements were carried out in standing wave tubes of different diameters (see Table 2), the absorption coefficient spectra were limited by different cut-off frequencies (see Figures 1-3).

Figures 4 to 6 compile the measured normal incidence sound absorption coefficients obtained by all partners for all tested samples of materials #A- #C, respectively. Sample #A represents the case of a low permeability porous medium. It has been shown [4] that measurements on this kind of media are very sensitive to the edge conditions. There seems to be stronger variability in the quality of the investigated material samples which were cut from various parts of the original material sheets. This effect is particularly pronounced in the case of the smaller diameter tube. It can be a function of the manufacturing process in which porous rubber granulates are mixed with the binder and then reconstituted under a static pressure into a large material bun. It can also be attributed to the number of samples studied in an individual laboratory. There are obvious differences between the mean values of the acoustic absorption coefficient measured in individual acoustics centres. We note that there seems to be good similarities between the results from the following laboratories: #1 and #4; #2 and #5. The results from laboratories #7 and #6 fall in between the results from the other laboratories. There is a relatively small dispersion in the results presented by laboratories #2 and #7.

Sample #B represents the case of a high permeability, relatively homogeneous foam. The results show that the dispersion of the acoustic absorption spectra for this material is considerably less than that in the case of material #A. Here the largest values of the standard deviation occur near the structural resonance in the material frame which frequency depends on the mounting conditions attained during the measurement. It is clear from the results obtained in laboratory #2 that the selected mounting conditions using the appropriate sample constraints enabled to move the structural resonance frequency out of the measurement spectral range. The structural resonance frequency observed in the results from laboratory #5 is consistent for all the investigated samples. This means that similar mounting conditions were attained during these experiments. Measured data from laboratories #1 and #4 suggests that the investigated samples were inconsistently mounted which resulted in two distinct peaks in the standard deviation which occurred between 1500 Hz and 3500 Hz.

Sample #C represents the case of transversely isotropic fibrous material. The air permeability of this material is similar to that measured in material #B, but its density is approximately 2.5 times greater. The latter characteristic seems to drive the resonance frequency towards the lower spectral end so that none of the presented results exhibits the distinctive resonant behaviour. The dispersion in the presented data is noticeably less than that observed in the case of materials #A and #B. It appears that the measured acoustic absorption coefficient for this material is less sensitive to the mounting conditions. There seems to be much less variation between the results for different materials samples studied within a particular acoustic laboratory.

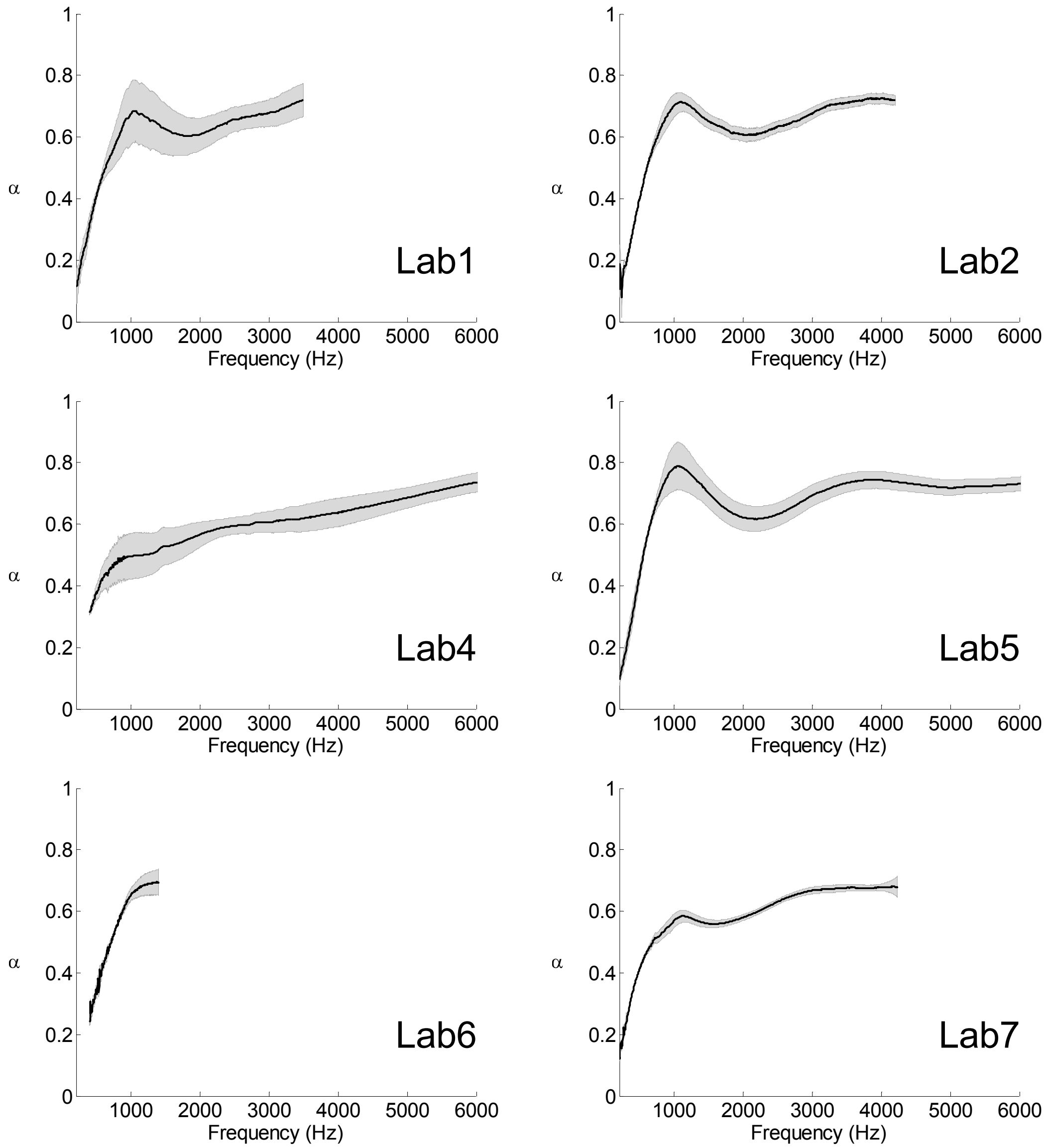


Figure 1. Average absorption coefficient and standard deviation spectra for material #A.

Figure 4(a) illustrates the dispersion observed in the results for the absorption coefficient of material #A measured in all the seven acoustic centres. The maximum dispersion (up to a maximum of 0.5 around 1 kHz) is in the data observed around the first interference maximum in the absorption spectrum. It can be attributed to the variation in the permeability of the investigated samples as well as the mounting conditions. The latter is likely to affect the thickness of the circumferential air gap and the compression rate of the investigated sample. In the case of material #B (Figure 4(b)) the dispersion in the results is relatively small (ca. 0.12 at 1000 Hz and 0.06 at 4000 Hz), but increases noticeably near the structural resonance frequency which value can change depending upon the mounting conditions from 1600 Hz to 3500 Hz (around 0.2 for the maximum variation).

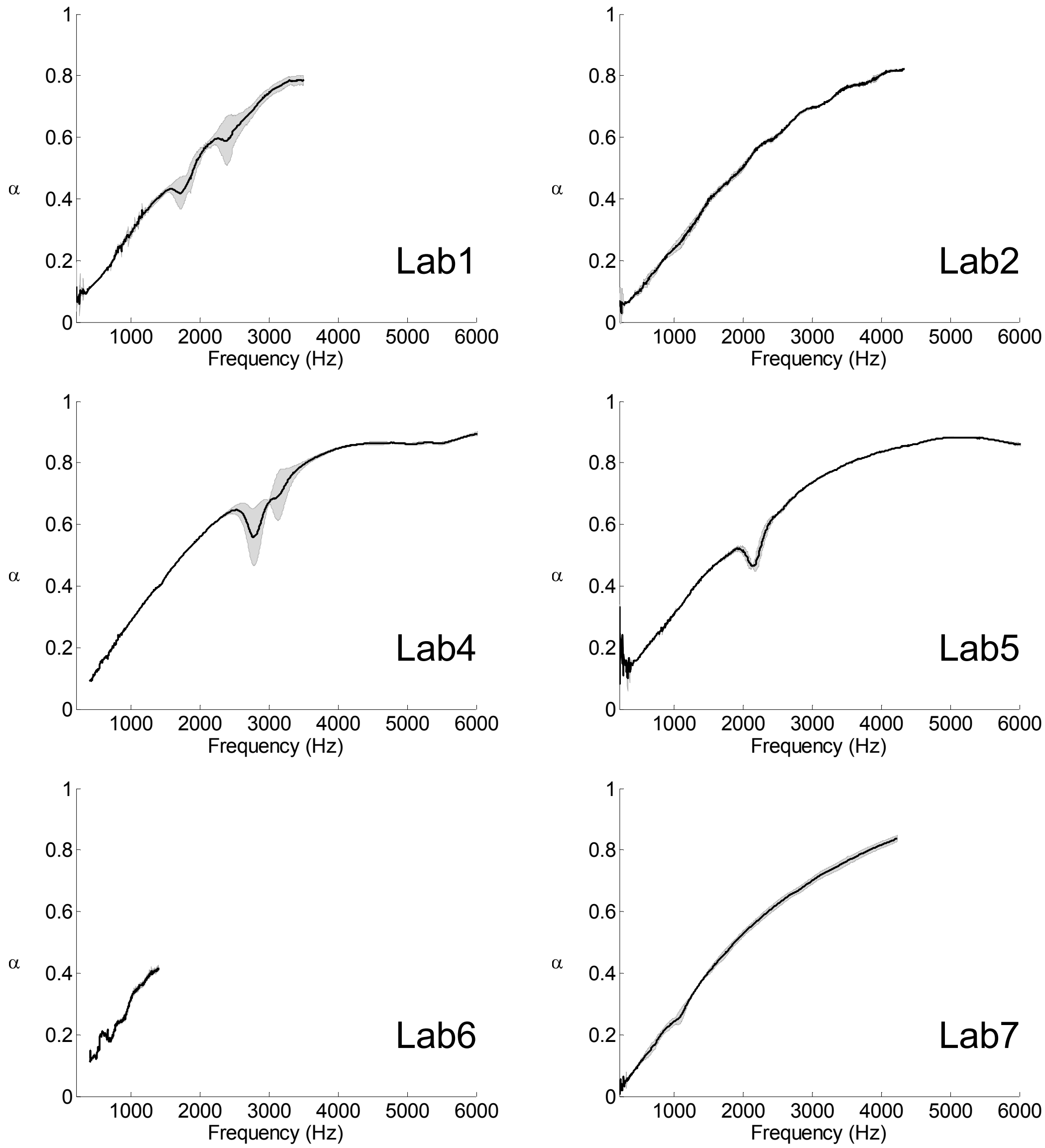


Figure 2. Average absorption coefficient and standard deviation spectra for material #B.

In the case of material #C, which is a fibrous product, Figure 4(c) shows the dispersion (up to 0.3 at 1500Hz) between the results obtained in each laboratory. There are several factors which can explain this phenomenon: (i) the quality of the material samples submitted to individual partners may not be consistent; (ii) the condition of the samples prepared for the acoustic absorption measurement can differ because of the transportation and cutting process; (iii) the thickness and composition of the sample in the standing wave tube can be affected when the sample is inserted.

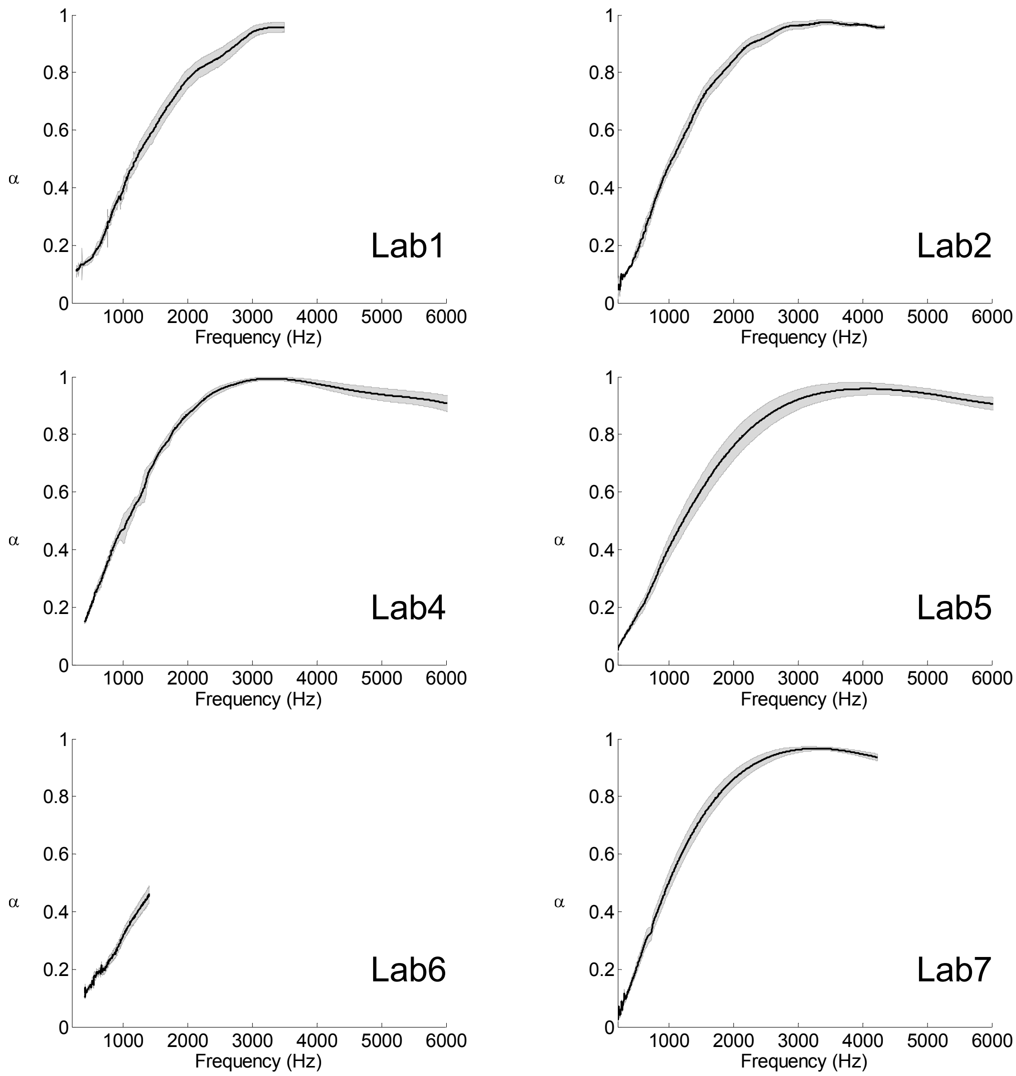
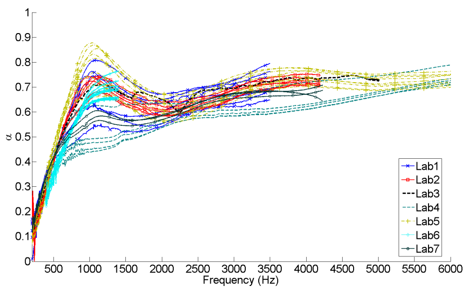
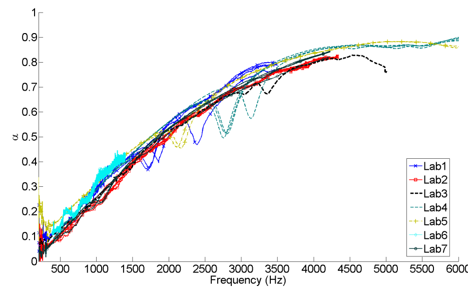


Figure 3. Average absorption coefficient and standard deviation spectra for material #C.

CONCLUSIONS

Inter-laboratory standing wave tube measurements have been performed on samples of three commercial porous products with different micro-structure. Two different methods have been used, namely the ISO 10534-2 [1] and Song-Bolton [3]. Considerable variations in the measured spectra for the acoustic absorption coefficient have been observed both in the results between individual samples and individual laboratories. The least variations in the absorption coefficient spectra were observed in the case of high permeability porous foam (material #B). The maximum variations were observed in the case of low permeability, reconstituted porous rubber (material #A). These variations can be attributed to: (i) inhomogeneity of the provided material samples; (ii) methods of sample preparation; (iii) mounting and structural conditions during the test; (iv) diameter of the standing wave tube; (v) signal processing method. It is proposed that a more systematic analysis of the obtained results should be carried out to investigate the dependence of the dispersion in the measured data on the geometrical and elastic properties of the porous structure and on the method of sample mounting. More samples are necessary to provide a better statistical population to explain better the observed dispersion. This work is already underway.





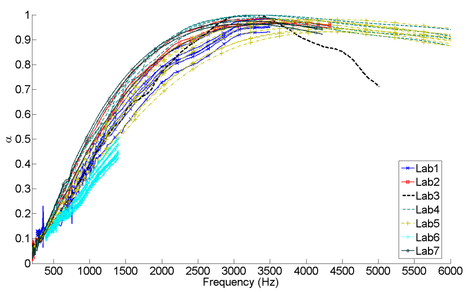


Figure 4. Summary of the results from the seven laboratories for all the tested samples of three porous materials #A, #B and #C.

ACKNOLEDGEMENTS

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