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ACOUSTICAL CHARACTERIZATION OF FIBROUS MATERIALS BY USING MEASURED FLOW RESISTIVITY DATA

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ABSTRACT
The flow resistivity is an easily measurable physical quantity of fibrous materials which characterizes their sound absorption and sound propagation properties. According to present knowledge two methods are available: the standardized (static) airflow resistance method and the acoustical flow resistance method developed by Ingard and Dear. The scope of this work was to acquire practical knowledge of the measurement methods and to apply the measured flow resistivities to the calculation of the most typical acoustical quantities. Instruments for measuring the airflow resistance and the acoustical flow resistance were constructed. The flow resistivities of five different mineral wool blankets were determined. The density of the materials was in the range of 20...150 kg/m^3. The acoustical impedance and the acoustical absorption coefficient of these materials were calculated according to Delany and Bazley (normal incidence) and Mechel (diffuse incidence). Verification of the calculations was done by comparing results to those obtained in the original articles. The results were in agreement with original results. The normal incidence absorption coefficient and the acoustical impedance were measured by using the impedance tube method. The diffuse incidence (Sabine) absorption coefficient was determined by using the reverberation room method. Measured and calculated values of the absorption coefficients and the acoustic impedances were compared. It was found that the flow resistivity can be used with sufficient accuracy to predict the acoustical absorption coefficient. In the future, these measurement methods will be applied to the calculation of the sound insulation of double panels.

1 - INTRODUCTION

Propagation of sound in an isotropic fibrous material is determined by two complex quantities, the characteristic impedance W_0 and the propagation coefficient γ. Delany and Bazley found in their work in 1969 [1] that the characteristic impedance and the propagation coefficient normalize in terms of the dimensionless parameter $\rho_0 f/\sigma$, where ρ_0[kg/m^3] is the density of the fluid (in this case air), f [Hz] is the frequency and σ [MKS rayls/m] is the flow resistivity of the material. The empirical relations given by Delany and Bazley for fibrous sound absorbing materials are:

$$W_0 = \rho_0 c \left[1 + 0.0571 \left(\frac{\rho_0 f}{\sigma}\right)^{-0.754} - j \cdot 0.0870 \left(\frac{\rho_0 f}{\sigma}\right)^{-0.732}\right] \quad (1)$$

$$\gamma = \left(\frac{\omega}{c}\right) \left[1 + 0.0978 \left(\frac{\rho_0 f}{\sigma}\right)^{-0.700} - j \cdot 0.189 \left(\frac{\rho_0 f}{\sigma}\right)^{-0.595}\right] \quad (2)$$

where c[m/s] is the speed of sound and ω [1/s] is the angular frequency of sound. The regression parameters in Eqs (1) and (2) were found by measuring a large amount of fibrous material samples using impedance tubes.

These empirical equations are considered to be accurate in the range $0.01 \leq \frac{\rho_0 f}{\sigma} \leq 1.0$. Bies and Hansen have developed formulas for use outside this range [2]. The accuracy of the empirical equations (1) and

(2) is considered to be good enough to achieve a more precise characterization of the acoustical properties than would be possible by measuring individual material samples using stationary-wave techniques.
F. Mechel has further developed and refined these formulas. On the basis of an extensive measurement series Mechel has found that the dependence of W_0 and γ on flow resistivity is of the form: [3]

$$W_0 = \rho_0 c \left[1 + b' \left(\frac{\rho_0 f}{\sigma} \right)^{-\beta'} - jb'' \left(\frac{\rho_0 f}{\sigma} \right)^{-\beta''} \right] \tag{3}$$

$$\gamma = \left(\frac{\omega}{c} \right) \left[1 + a' \left(\frac{\rho_0 f}{\sigma} \right)^{-\alpha'} - ja'' \left(\frac{\rho_0 f}{\sigma} \right)^{-\alpha''} \right] \tag{4}$$

where the regression parameters have different values below and above $\rho_0 f/\sigma$=0.025. The values for a, b, α and β, when the material is glass wool, are given in Table 1.

$\rho_0 f/\sigma$	a'	α'	a''	α''	b'	β'	b''	β''
≤0.025	0.396	0.458	0.135	0.646	0.0668	0.707	0.196	0.549
>0.025	0.179	0.674	0.102	0.705	0.0235	0.887	0.0875	0.770

Table 1: Regression parameters for predicting propagation constant and characteristic impedance of fibrous sound-absorbing materials.

The values obtained by Eqs (1)... (4) can be applied to determine the wall impedance and the absorption coefficient. Data can also be applied to predict the sound insulation of lightweight walls. In this work, the flow resistivity information was used to predict the absorption coefficient.

2 - MEASUREMENT METHODS

The flow resistivity of five different mineral wools in the density range 20 kg/m^3... 150 kg/m^3 was measured. Two measurement methods were used: the standardized static airflow resistance method [4] and the acoustical flow resistance method as suggested by Ingard and Dear [5].
The airflow resistivity σ [MKS rayls/m] of a material is defined as

$$\sigma = \frac{SP}{lU} \tag{5}$$

where S = area of the specimen [m^2], P = pressure difference across the specimen [Pa], l = thickness of the specimen [m] and U = volume velocity of airflow through the specimen [m^3/s].
A measurement apparatus was constructed to measure the airflow resistivity. A plastic circular sewer tube of diameter 104 mm was used as the body. A sample holder was constructed from a similar tube. Airflow in the tube was generated by an air pump. The pressure difference across the sample was measured by a micromanometer, while a rotameter was used to observe the volume air flow velocity. The volume velocity through the sample was controlled using an adjustable valve.
An alternative method to determine the flow resistivity of a fibrous material is the acoustical flow resistivity method suggested by Ingard and Dear [5]. In this method the flow resistivity of a material is determined by measuring the sound pressure loss across a specimen. The specimen is mounted in a tube for which the impedance can be calculated. The preferred frequency for measurements is below 100 Hz to keep the reactive part of the flow impedance small. The acoustical flow resistivity of a material is defined by

$$\sigma_{acoust} = \frac{\rho_0 c}{l} 10^{(L_{p1} - L_{p2})/20} \tag{6}$$

where L_{p1} = sound pressure level in front of the specimen and L_{p2} = sound pressure level at the rigid termination behind the specimen. Other quantities have been defined above.
A measurement tube was constructed following the structure suggested by Ingard and Dear. The body for the instrument was a plastic circular sewer tube. A steel plate (thickness 12 mm) was installed to make the termination of the tube acoustically rigid. A 100 mm loudspeaker mounted in a 6 litre cabinet was used as the sound source in the other termination of the tube. The sound pressure levels were observed by condenser microphones (B&K 4165). The spectra were analyzed with a real-time analyzer (B&K 2133).
The acoustical impedance, the normal incidence absorption coefficient and the diffuse incidence absorption coefficient were measured using standardized practices, ASTM C 384-90a (normal incidence

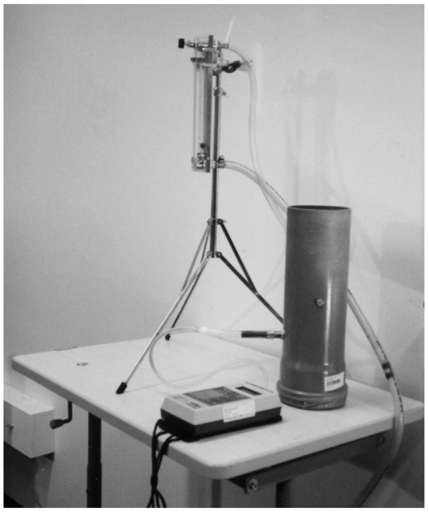

Figure 1(a): The constructed airflow resistance measurement tube.

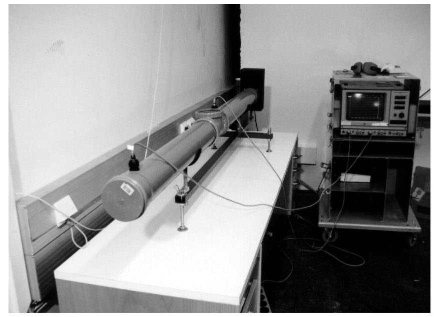

Figure 1(b): The acoustical flow resistance measurement tube (right).

absorption coefficient and impedance) and ASTM C 423-90a (diffuse incidence absorption coefficient), respectively.

3 - CALCULATION METHODS

The acoustical impedance, the normal incidence absorption coefficient and the diffuse incidence absorption coefficient were calculated using measured flow resistivity data. Calculation applications were programmed using the Microsoft Visual Basic 6.0 −development environment. Verification of the calculation methods was done by comparing the results to those obtained in the original articles. Verification was successful. The deviations between calculated and published results were less than 5 %.

The acoustical impedance Z of a rigidly backed sound absorbing plate can be calculated from $Z = W_o \coth \gamma l$. After the acoustical impedance of the material has been determined using measured flow resistivity data, the normal incidence absorption coefficient α_n can be calculated from

$$\alpha_n = 1 - \left| \frac{Z - \rho_0 c_0}{Z + \rho_0 c_0} \right|^2 \quad (7)$$

The diffuse incidence (statistical) absorption coefficient α_d can be calculated with the so-called Paris-formula by numerical integration [3].

$$\alpha_d = 2 \int_0^{\pi/2} \alpha(\theta) \cos\theta \sin\theta d\theta \quad (8)$$

where the material is supposed to be bulk-reacting.

4 - RESULTS

The calculated and measured normal incidence and diffuse incidence absorption coefficients of two different glass wools are presented in Fig. 2. The normal incidence absorption coefficient is calculated according to Delany and Bazley and the diffuse incidence absorption coefficient according to Mechel. The indicated flow resistivity values were determined by the airflow resistivity method.

5 - DISCUSSION

The measured values of airflow resistivity and acoustical flow resistivity are comparable, the deviations being 10 %...15 %. The measured airflow resistivity values agree well with published values [2], the deviations being 10 %...15 %. The acoustical flow resistivity method seems not to be widely used and reliable comparison values were not available.

The normal incidence absorption coefficient and the acoustical impedance can be predicted with sufficient accuracy (within 10 %...15 % from the measured value) from flow resistivity data. The calculated diffuse incidence (or statistical) absorption coefficient seems to be a different quantity than the measured

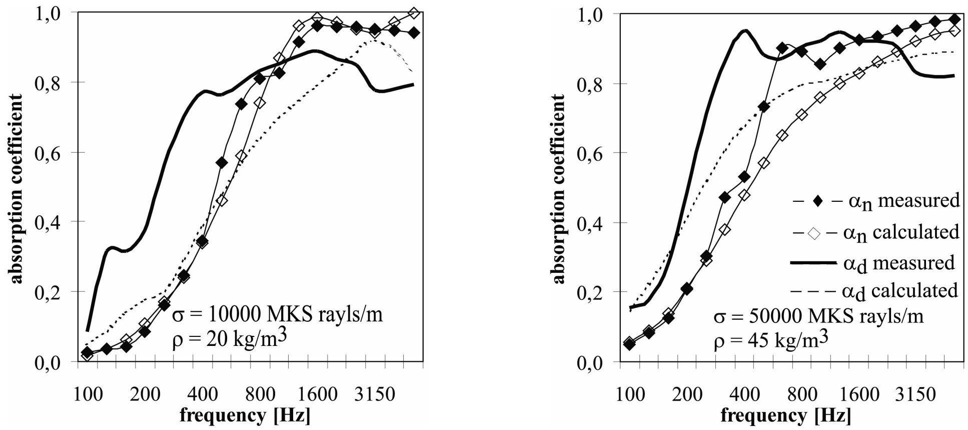

Figure 2: The absorption coefficients of two different glass wools.

(Sabine) absorption coefficient. The deviations between measured and calculated values were of the magnitude 40 %...50 % on a large frequency scale.

REFERENCES

1. **M. Delany, E. Bazley**, *NPL Aero Report Ac 37*, National Physical Laboratory, 1969

2. **D. Bies, C. Hansen**, Flow Resistance Information for Acoustical Design, *Applied Acoustics*, Vol. 3(1980), pp. 105-116, 1980

3. **F. Mechel, I. Ver**, *Sound Absorbing Materials and Sound Absorbers*, L. Beranek, I. Ver, pp. 203-241, 1992

4. **American Society for Testing and Materials**, *ASTM C522-87*, 1997

5. **K. Ingard, T. Dear**, Measurement of Acoustical Flow Resistance, *Journal of Sound and Vibration*, Vol. 103(4), pp. 567-572, 1985