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VIBRATIONS AND NOISE DAMPING OF POROUS MATERIALS

Martin Juřička*[1], Martin Vašina[1], and Lubomír Lapčík, Jr.[1]

[1]Institute of Physics & Material Engineering, Tomas Bata University in Zlín
Nad Stráněmi 4511, CZ-760 05 Zlín, Czech Republic
juricka@ft.utb.cz

Abstract

Study of the sound attenuation by means of Kundt´s tube measurements (in the frequency range of 16 to 6300 Hz) as well as the vibration damping (in the frequency range of 50 to 2500 Hz) are related with the structural material characteristics such as mechanical tensile modulus, free voids volume and porosity. Effect of the mutual sandwich combination of selected materials interconnected by suitable bonding agents or by simple mechanical contacts will be judged with respect to the transmission of the whole structural element. Obtained experimental results of both acoustic performance and vibration damping will be generalized by means of empirical equations and will be interconnected with selected material mechanical and geometrical characteristics.

INTRODUCTION

Mechanical vibrations and noise belong in many cases to negative effects of our life (for example in transportation[1], industry, aeronautics or domestic appliances)[2]. Therefore, it is necessary to reduce mechanical vibrations and noise to increase comfort and security in the application[3]. This is possible to be done by application of suitable materials with good damping and sound-absorbing properties[4]. Porous materials belong in general to materials capable for vibration damping and sound absorption applications. Studies of the polyurethane (PUR) acoustic performance in the ultrasonic fields were done in early 80s by group of Volkova et al. [5;6], where the strong effect of the crystalline content of the matrix on acoustic properties was found.

The purpose of this work is to investigate damping and sound-absorbing properties of selected polyurethane material and their mutual sandwich combinations. There were used single types of polyurethane materials of different thicknesses for the investigation.

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THEORY

The porosity ϕ of a porous material is defined as the ratio of the volume of the voids V_a in a porous material to the total volume V_m:

$$\phi = \frac{V_a}{V_m} \cdot 100; \qquad [\phi] = [\%], [V] = [m^3] \tag{1}$$

The Hooke´s law describes material behaviour in the area of elastic deformations at static loading. The stress-strain curve is linear in this case. The Young's modulus of elasticity E is the ratio of the stress σ to the strain ε:

$$E = \frac{\sigma}{\varepsilon}; \qquad [E] = [MPa], [\sigma] = [MPa], [\varepsilon] = [-] \tag{2}$$

For viscoelastic materials at dynamic loading, the modulus is represented by a complex quantity. The real component of this complex quantity (storage modulus or Young´s modulus of elasticity, $E^{´}$) relates to the elastic behaviour of materials and defines the material's stiffness. The imaginary component (loss modulus, $E^{´´}$) relates to the viscous behaviour of materials and defines their ability of energy dissipation. Using the Hooke´s law, the complex modulus of elasticity E^* is defined as:

$$E^* = E^{´} + i \cdot E^{´´}; \tag{3}$$

The loss factor η is defined as the ratio of the loss modulus to the Young's modulus of elasticity:

$$\eta = \frac{E^{´´}}{E^{´}}; \qquad [\eta] = [-] \tag{4}$$

Damping properties of materials at dynamic loading are expressed by the transfer function D:

$$D = 20 \cdot \log \frac{|a_0|}{|a_1|}; \qquad [D] = [dB], [a] = [m \cdot s^{-2}] \tag{5}$$

where: $|a_0|$ = excitation acceleration amplitude
$|a_1|$ = exit acceleration amplitude

The sound absorption coefficient α is given by the ratio of the absorbed acoustic output P_1 to the general incident acoustic output P_0:

$$\alpha = \frac{P_1}{P_0}; \qquad [\alpha] = [-], [P] = [W] \tag{6}$$

EXPERIMENTAL

Materials

For investigation of vibration damping and sound-absorbing properties four types of porous polyurethane materials were used. The parameters of the polyurethane materials (commercially available samples purchased from Gumotex (Czech Republic)) are given in Table 1. From the individual material types the combination of two layer sandwich structures (bonded/non-bonded) were prepared and tested. This allowed study the effect of the layer order and thickness of the materials constituents on the final sandwich composition mechanical and acoustical performance.

Table 1 – Basic material parameters of polyurethane materials

Material designation	Material Type	Density [kg·m^{-3}]	Thickness [mm]
P1	N2529	25	13
P2	N2529	25	21
P3	N2529	25	28
Z1	2550	25	10
Z2	2550	25	16
Z3	2550	25	29
M1	2500	25	12
M2	2500	25	19
M3	2500	25	29
C1	CRHM	36	12
C2	CRHM	36	19
C3	CRHM	36	30

Measurement Methods

Porosity measurements were performed by the method of air-exhaust from polyurethane samples that were submerged in water. The voids volume and porosity were proportional to the water mass in studied samples[7].

Tensile testing was performed on Instron type 1122 tensile test machine. Samples were in the form of the dog-bone of 150 mm length.

Complex modulus of elasticity and damping measurements were performed on two- channel signal analyzer Brüel & Kjær type 2034 in combination with vibrator exciter B&K 4810 in the frequency range of 50 to 2500 Hz.

Sound absorption coefficient measurements were performed on two-channel signal analyzer Brüel & Kjær type 2034 in combination with Impedance tube B&K 4206 in the frequency range of 16 to 6300 Hz.

All measurements were performed at the ambient temperature (22 °C).

RESULTS AND DISCUSSION

The aim of this study was to compare the basic mechanical and vibro-acoustical characteristics of the latter materials with respect to their porosity, rigidity and sample thickness. For that reason the set of commercially available samples were tested. The total volume of data thus generated exceeds the space available for the presentation in these proceedings. That is why only selected results are offered in this paper.

In Fig. 1 are shown results of the frequency dependence of the sound absorption coefficient of basic sandwich constituents. Here the clear difference of the performance is clearly visible, where with increasing the sample thickness, the sound absorption increases, what is in agreement with the theoretical predictions[8-10]. With increasing elasticity of the PUR macromolecular chains (or decreasing permanent deformation) the increasing sound absorption was found. The maximum sound absorption was varying from 2800 Hz up to 5000 Hz as a function of sample rigidity reaching the relatively low maximum of the sound absorption coefficient of 0.7.

In Fig. 2 are shown results of the sandwich combinations. Here the best acoustic performance was found for the combination of the two samples of the lowest permanent deformation, i.e. the ones with the highest elasticity. The improvement in the maximum sound absorption was found (around 0.98 at frequencies close to 6000 Hz) while the similar increase was obtained also in the frequency range of 2000 to 3000 Hz (α_{max} ranges from 0.75 to 0.85).

In Fig. 3 are shown results of the frequency dependence of the damping. The first resonance frequency was shifting to the higher frequencies with decreasing sample thickness and the increasing sample elasticity. The maximum damping was found for the most elastic samples (Sample M1), and was found to be around 60 dB in the frequency range of 1000 to 2500 Hz.

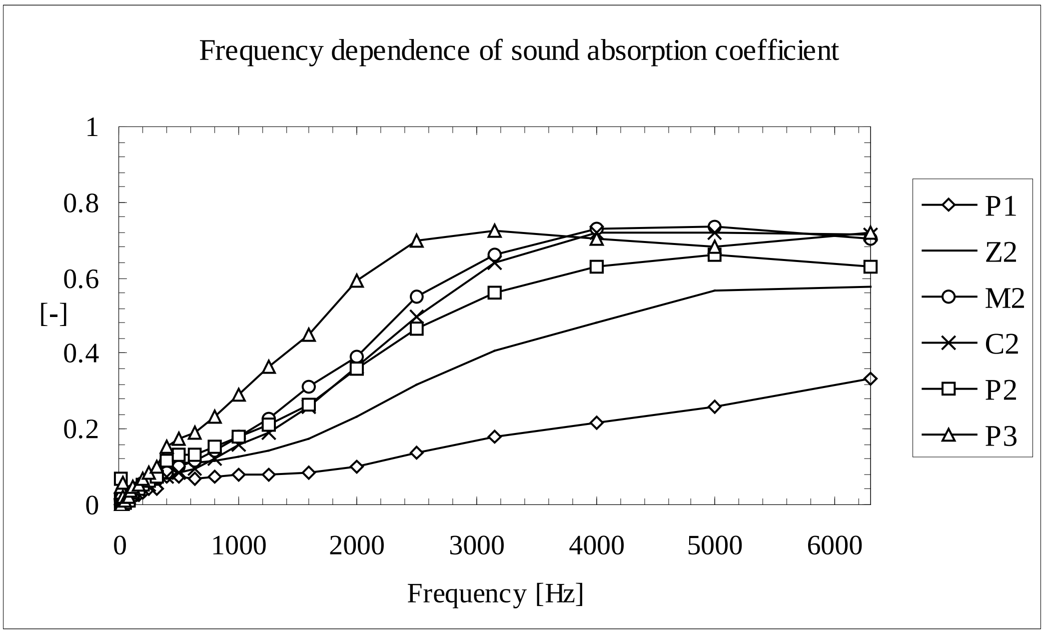

Figure 1. Frequency dependence of the sound absorption coefficient of basic materials used for the sandwich structure composition (for sample marking see Table 1).

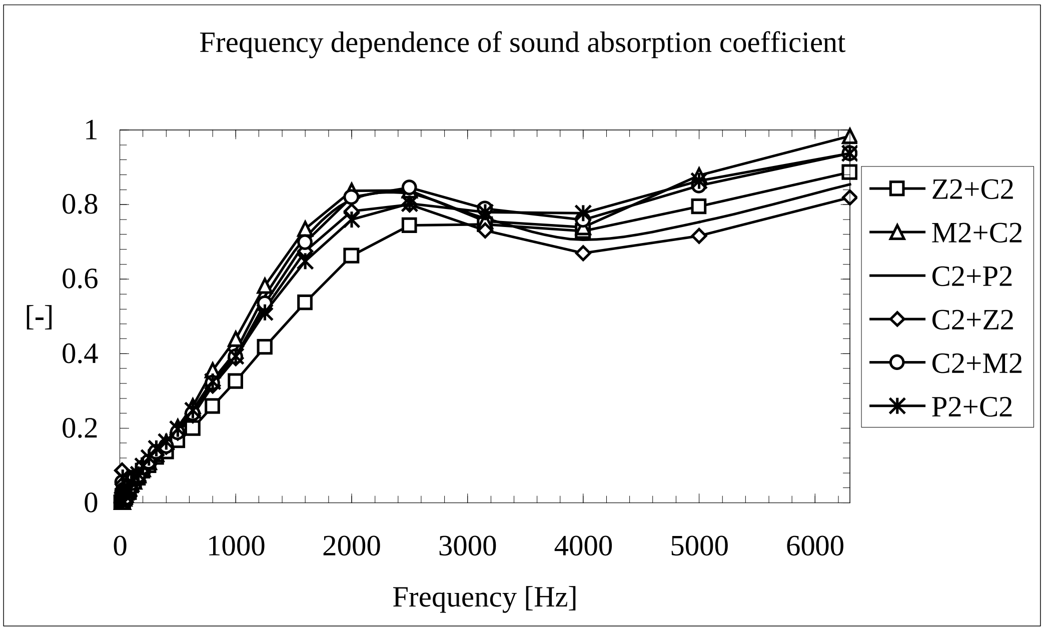

Figure 2. Frequency dependence of the sound absorption coefficient as obtained for tested sandwich structure articles (for sample marking see Table 1).

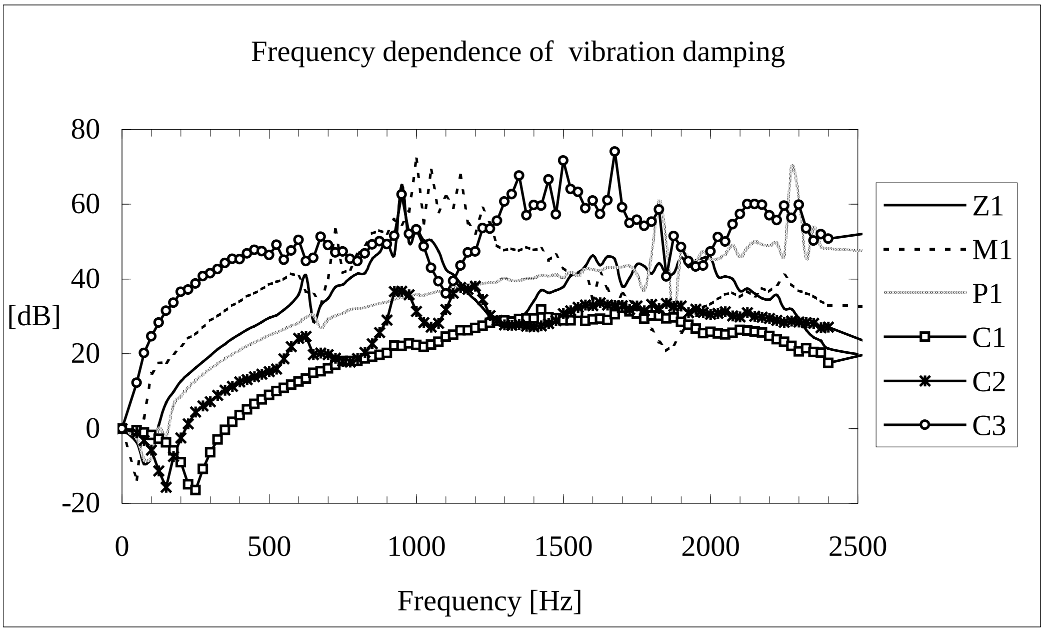

Figure 3. Frequency dependence of the damping of basic materials used for the sandwich structure composition (for sample marking see Table 1).

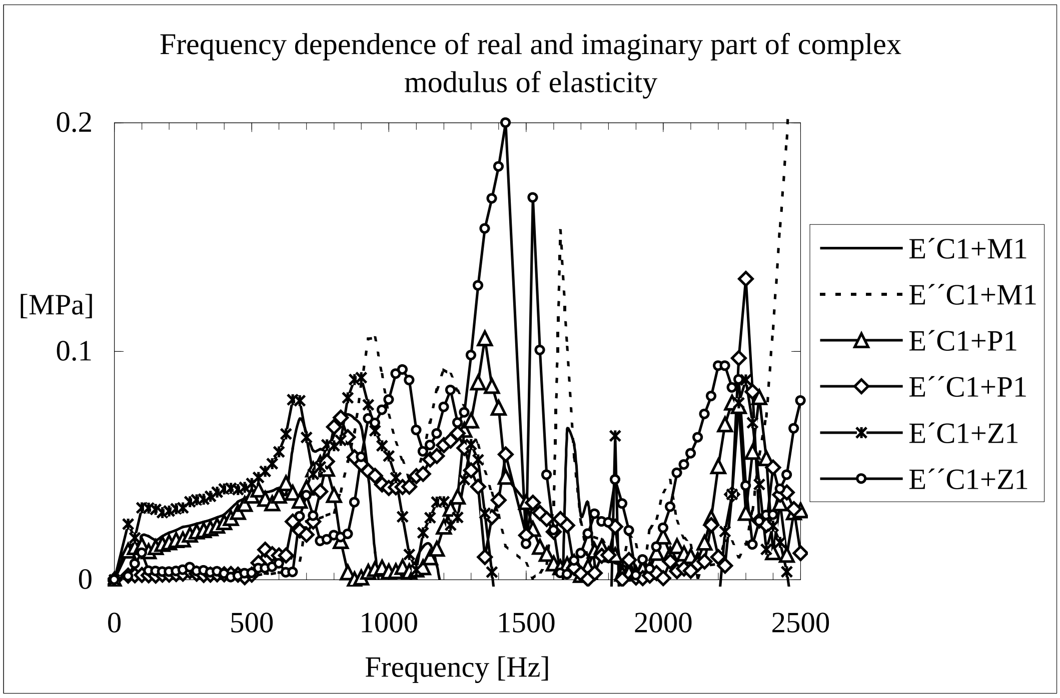

Figure 4. Frequency dependence of the real and imaginary parts of the dynamic modulus of elasticity for tested sandwich structure articles (for sample marking see Table 1).

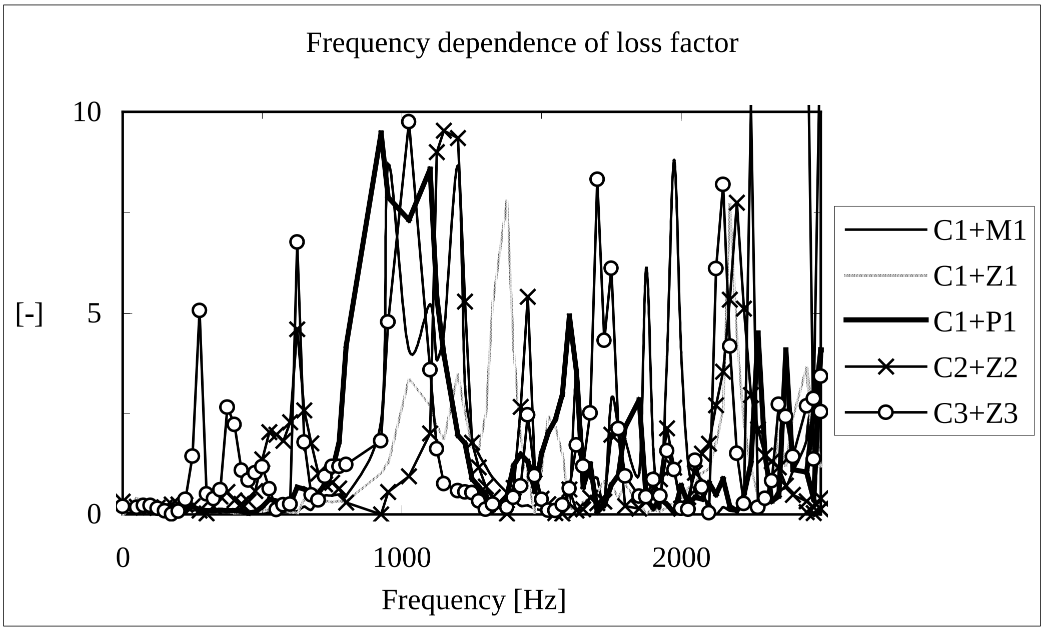

Figure 5. Frequency dependence of the loss factor for tested sandwich structure articles (for sample marking see Table 1).

Results of the complex modulus of elasticity frequency dependences are shown in Fig. 4. Here the clear fact was found, that the highest modulus as well as the energy dissipation was found for the combination of the sample of the highest rigidity (sample C1+Z1) at the pulse entrance side. The highest total dissipation was found for the combination of sandwich C1+P1, i.e. the sample of medium rigidity. With increasing softness of the macromolecular chains, the loss factor is shifting to higher frequencies, while the total dissipative ability decreases (Fig. 5).

SUMMARY

It was found in this study, that the synergistic combination of the chemical structure variations with respect to the matrix mechanical rigidity, porosity, damping layer thickness and their mutual combination in the construction of the sandwich like damping articles is allowing selective tuning of the sound absorption maxima and the vibration damping in such a way, which is enhancing a total energy dissipation of the system to be maximum.

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