# Measurement of the Acoustic Properties of PUR Based Damping Materials

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## Abstract

Effect of the different climate environments on the sound and vibration damping properties as well as on mechanical strength of PUR based foams used both in automotive and aerospace industries was presented. Influence of the different temperature and humidity conditions on frequency dependence of complex modulus of elasticity, damping, sound absorption coefficient, thermal stability and selected mechanical characteristics (hardness, deformability, tensile strength, Young´s modulus etc.) were discussed. It was found that the latter physico-chemical parameters are strongly dependent on applied climate conditions. For acoustic measurements were used Brüel & Kjaer measuring setups (Kund´s tube, vibrator and signal analyzer). Thermal stability both in air as well as nitrogen atmospheres was determined on DTG 60/60H, Shimadzu, mechanical properties on tensile test machine Instron.

## 1 Introduction

Polyurethane based materials are commonly used in many products in automotive and aerospace applications [1-4]. They serve as the vibration and sound damping material, e.g. seats, bolstering etc. In the latter applications the material is exposed to different heat, moisture and various aggressive environments, which might strongly affect the desired functional properties. For that reason in this study we have performed study on the effect of the aging/weathering of the PUR based materials commonly used in the automotive/aerospace industry on their mechanical, thermal, acoustic and vibration damping characteristics.

## 2 Theory

Samples during testing are loaded by defined cyclic stress:

$$\sigma = \sigma_0 \cdot \cos(\omega \cdot t + \delta) \tag{1}$$

where: $\sigma_0$ – stress amplitude, $\omega$ - circular frequency, $t$ – time, $\delta$ - loss coefficient (i.e. mechanical loss angle). A part of incident energy is changed into the heat. Therefore deformation $\varepsilon$ is out of phase against stress by formula:

$$\varepsilon = \varepsilon_0 \cdot \cos(\omega \cdot t) \tag{2}$$

where: $\varepsilon_0$ – deformation amplitude. Then it is possible to determine complex modulus of elasticity of sample material:

$$E^*(i \cdot \omega) = \frac{\sigma_0}{\varepsilon_0} \cdot \cos\delta + i \cdot \frac{\sigma_0}{\varepsilon_0} \cdot \sin\delta = E'(\omega) + i \cdot E''(\omega) \tag{3}$$

where: $E'(\omega)$ – real component of complex modulus of elasticity, $E''(\omega)$ – imaginary component of complex modulus of elasticity. The absolute value of complex modulus of elasticity is determined by the formula:

$$\left|E^*(i \cdot \omega)\right| = \sqrt{[E'(\omega)]^2 + [E''(\omega)]^2} \tag{4}$$

Mechanical loss factor □ was determined from the real component $E'(\omega)$ and the imaginary component $E''(\omega)$ of complex modulus of elasticity.

$$\eta = tg\,\delta = \frac{E''}{E'} \tag{5}$$

Then was determined material damping according to the formula in our case:

$$D = 20\log\frac{v_0}{v} = 20\log\frac{a_0}{a} \tag{6}$$

where: $v_0$ – excitation velocity amplitude, $v$ – exit velocity amplitude, $a_0$ – excitation acceleration amplitude, $a$ – exit acceleration amplitude.

## 3 Experimental

*PUR samples* (commercially available) were treated for ageing for 24 and 300 hours at two different temperatures (45 and 85 ºC) and two different relative humidity conditions (43 and 80 %).

*Tensile testing* was performed at the ambient temperature (25 ºC) on Instron type 1122 tensile test machine.

*Dynamic modulus of elasticity and damping measurements* were performed at 25 ºC on two channel signal analyzer Brüel & Kjær type 2034 in combination with vibration exciter B&K 4810 in the frequency range of 50 to 2500 Hz.

*Thermal analysis TG, DTG a DTA* was performed both in the atmosphere of the nitrogen and the air on DTG 60/60H Shimadzu instrument. Measurements were performed from 50 to 450 ºC, heating rate 10 deg/min.

## 4 Results and discussion

Aging of the PUR based porous materials is strongly influencing the microstructure of the porous pattern (cell distribution) of the matrix, especially when the latter is loaded by cyclic stress. This is consequently influencing both mechanical as well as acoustic properties of the original material. It is well known that after cyclic loading the deformation band and band front is created with destructed porous structure. A typical pattern for frequency dependence of damping is shown in Figure 1. For original material prior to the conditioning the frequency dependence of damping was characteristic with the appearance of two maximums of 43 and 60 dB at frequencies 440 Hz and 1100 Hz. After ageing the damping properties were slightly improved what was reflected in the increased value of the second maximum of damping to 65 dB at higher frequency of 1450 Hz. Obtained pattern had much broader character and the maximum damping was preserved in the frequency range of 900 to 2400 Hz (Figure 1). Unfortunately the improved damping properties were sacrificed to the loss of elasticity and mechanical strength. Proposed mechanism of sonic energy dissipation was in the case of the original material based mainly on viscous friction what was reflected in the exceeding values of the imaginary part of the complex modulus of elasticity (Figure 2) in the whole frequency region studied. After prolonged weathering studied system behaved as a more rigid/stiff and fragile body, where real part of the modulus was slightly exceeding the imaginary part. The latter assumption was in a good agreement with tensile strength measurements, where measured hardness was increased after aging from 18 to 19.5 N, while permanent deformation was decreased from 18 to 15 %. This phenomenon was closely related to the changes of the chemical structure of the three dimensional PUR matrix, which after conditioning most probably undergoes further crosslinking of the volatile curing agent presented. The latter fact was proved by DTG and TG measurements, where better thermal stability after weathering was obtained.

## 5 Summary

It was found in this study, that weathering induced aging was strongly influencing selective mechanical and acoustic properties of commercial PUR matrix. This was due to the effect of several competitive degradation/crosslinking processes, which were taking place in the material. The latter processes were affecting damping, stiffness, deformability, dynamic modulus of elasticity and thermal stability of porous PUR based matrix.

## Acknowledgements

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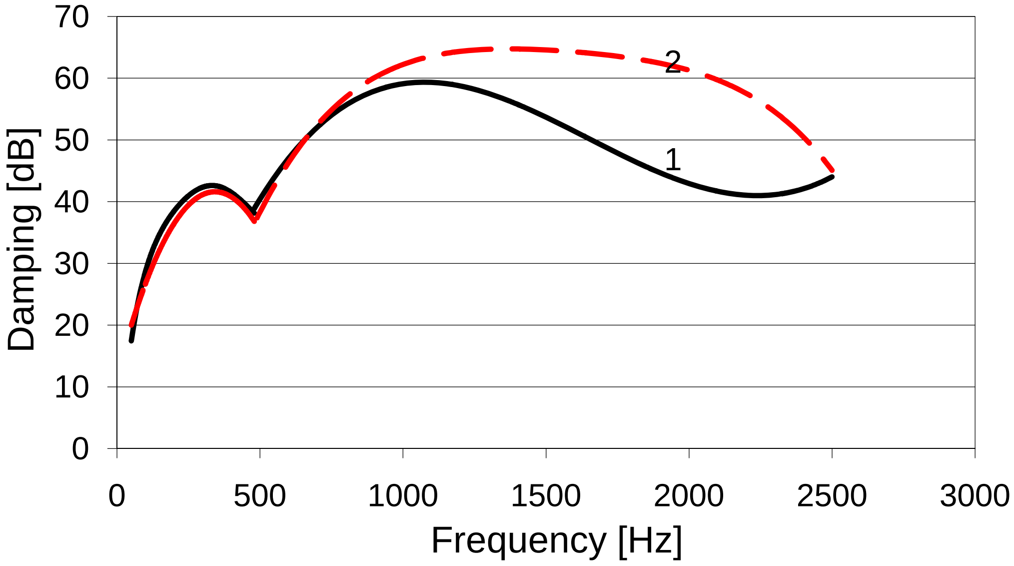

*Figure 1: Frequency dependence of damping of PUR based article: 1 – original, 2 – weathered at 35 ºC at relative humidity of 43%.*

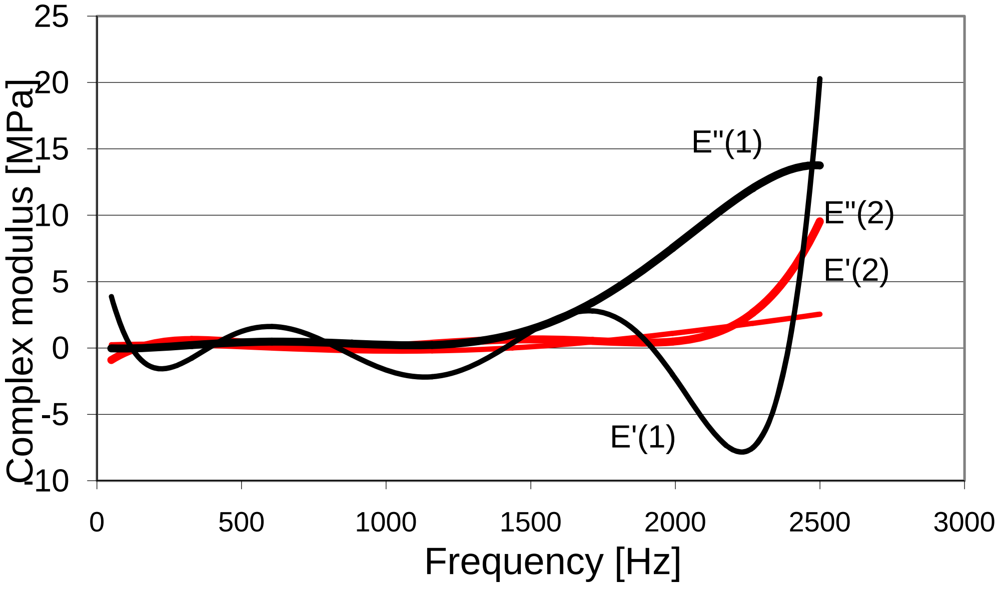

*Figure 2: Frequency dependence of complex modulus of elasticity of PUR based article: 1 – original, 2 – weathered at 35 ºC at relative humidity of 43 %.*

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