Experimentální Analýza Napětí 2009
Experimental Stress Analysis

MECHANICAL PROPERTIES OF SLOW SPRING BACK FOAM

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Abstract: Article deals with mechanical properties of slow spring back polyurethane foam. The specimen of the foam was dynamically compressed by harmonical kinematical course of displacement with warying frequency. Also relaxation tests were carried out. Results are evaluated and compared with properties of conventional polyurethane foam from qualitative and quantitative point of view.

1. Introduction

During the research of mechanical properties of polyurethane (PU) foam from the sitting comfort point of view there have also been investigated properties of slow spring back foam. It is the foam which was developed in 1966 by NASA to absorb shock and, thus, offer improved protection and comfort in NASA's airplane seats (see [1]). Slow spring back foam was used subsequently medically as wheelchair seat cushions, hospital bed pillows and paddings.

The aim of this article is to find out if this material differs from conventional PU foam. While quantitative difference is possible to assume, there is a question if this foam differes also qualitatively.

2. Experimental part

The specimen investigated was cut from inner part of pillow Twinsaver which was bought in common trade network. It is of a cuboid shape with dimensions of base (100 x 100) mm and height 50 mm. Material density is 71 kg/m^3. The specimen was dynamically compressed by harmonical course of displacement x given by equation (1) with mean value A_0=25 mm, amplitude A=5 mm and exciting frequency $f \in \{0.1, 0.5, 0.7, 1, 1.5, 3\}$ Hz. Angular frequency is $\omega = 2\pi f$. Relaxational tests were carried out with constant deformation $A_0 \in \{15, 25, 30\}$ mm. The temperature during measurement was 24º C, humudity 84 % in case of dynamical compression and 88 % in case of relaxational tests.

$$x(t) = A_0 + A\sin(\omega t). \tag{1}$$

3. Method

Generally the force response F during dynamical compressing of PU foam specimen by defined signal of displacement x has the shape of hysteresis loop as shown in Figure 1 at the top. Let us assume that the damping force F_d is distributed around the skeleton curve of hysteresis loop symmetrically. Let us also assume that this skeleton curve represents just restoring force F_R. Area of hysteresis curve (in Figure 1a) marked by gray) represents energy dissipated in foam during one loading period. It is given by mechanical work W_d of damping

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force defined by eqn. (2). Work W_R of restoring force F_R is defined by eqn. (3) where x_{min} represents minimum and x_{max} maximum value of deformation $x(t)$ during one loading period. In case of harmonic signal (1) it is possible to express them theoretically by relations x_{min} =0 and $x_{max} = A_0 + A$. Practically the integration is computed within limits given by inner and top dead center of hydraulic actuator, though. The difference between theoretical (desired) and real values represents control deviation of hydraulic actuator. Work W_R is then given as d ouble of hatched area in Figure 1a).

Another important quantity for evaluating properties of PU foam is also ratio between dissipation work of damping force W_d and work of restoring force W_R defined by eqn. (4) as δ_W.

In Figure 1b) there is course of damping force F_d in dependence on displacement x. This dependency shows a typical pear-like character with significant extreme value at position x_e.

As from earlier published results in case of conventional foam (see [2]) is known dependence of both W_d and δ_W on exciting frequency have linear character. Then values W_R must be independent on this frequency. Thus we express W_R as the only value which is given by average value of W_R measured for individual frequencies, and standard deviation in absolute and relative form is evaluated (see equation (5), (6), (7), where q represents general quantity - in this case $q = W_R$, subscript i = 1...N = 6 represents measurement for individual frequencies). In the same manner position of extreme of damping force x_e is evaluated which is also possible to be assumed independent on exciting frequency (then $q = x_e$ in eqn. (5), (6), (7)).

$$W_\mathrm{d} = \oint F(x)\,\mathrm{d}x\ , \quad W_\mathrm{R} = 2\int_{x\,\mathrm{min}}^{x\,\mathrm{max}} F_\mathrm{R}(x)\,\mathrm{d}x\,, \quad \delta_W = \frac{W_\mathrm{d}}{W_\mathrm{R}}\ , \qquad (2,3,4)$$

$$\bar{q} = \frac{1}{N}\sum_{i=1}^{N} q_i\ , \quad S_q = \sqrt{\frac{1}{N+1}\sum_{i=1}^{N}(q_i - \bar{q})^2}\ , \quad s_q = \frac{S_q}{\bar{q}}100\%\ . \qquad (5,6,7)$$

The significant behavior of PU foam is stress relaxation during constant deformation. Force responce then is degressive curve as in ilustrative Figure 2. In case of this type of loading the following physical quantities are evaluated. First one is percentual expression of force decrease during time of relaxation. It is called δ_{Rt_δ} and is defined by eqn.(8) where $F(t = 0)$ is measured force at the beginning of relaxational process and $F(t = t_\delta)$ is force measured after test duration t_δ which was set at 200 seconds.

Another investigated quantity is maximum relaxation speed $v_{F\max}$ given by eqn. (9). It is maximum absolute value of first derivation of measured force with respect to time. Its physical unit is [N/s] and in principle it has negative sign.

For evaluating of quantity which is called relaxation time t_R it is supposed that maximum speed of relaxation comes always at the beginning of relaxational process thus when $t = 0$. Relaxation time is defined by eqn. (10) and in Table 2 is presented in seconds. In graphical representation it is possible to mark t_R as an intersection of time axis and line which is tangent to the relaxational curve at the beginning (Figure2).

$$\delta_{Rt_\delta} = \frac{F(t=0) - F(t=t_\delta)}{F(t=0)}\cdot 100\,\%\,, \quad v_{F\,\max} = \min\left(\frac{\mathrm{d}F}{\mathrm{d}t}\right), \quad t_\mathrm{R} = \frac{F(t=0)}{\left|v_{F\,\max}\right|}\,. \qquad (8,9,10)$$

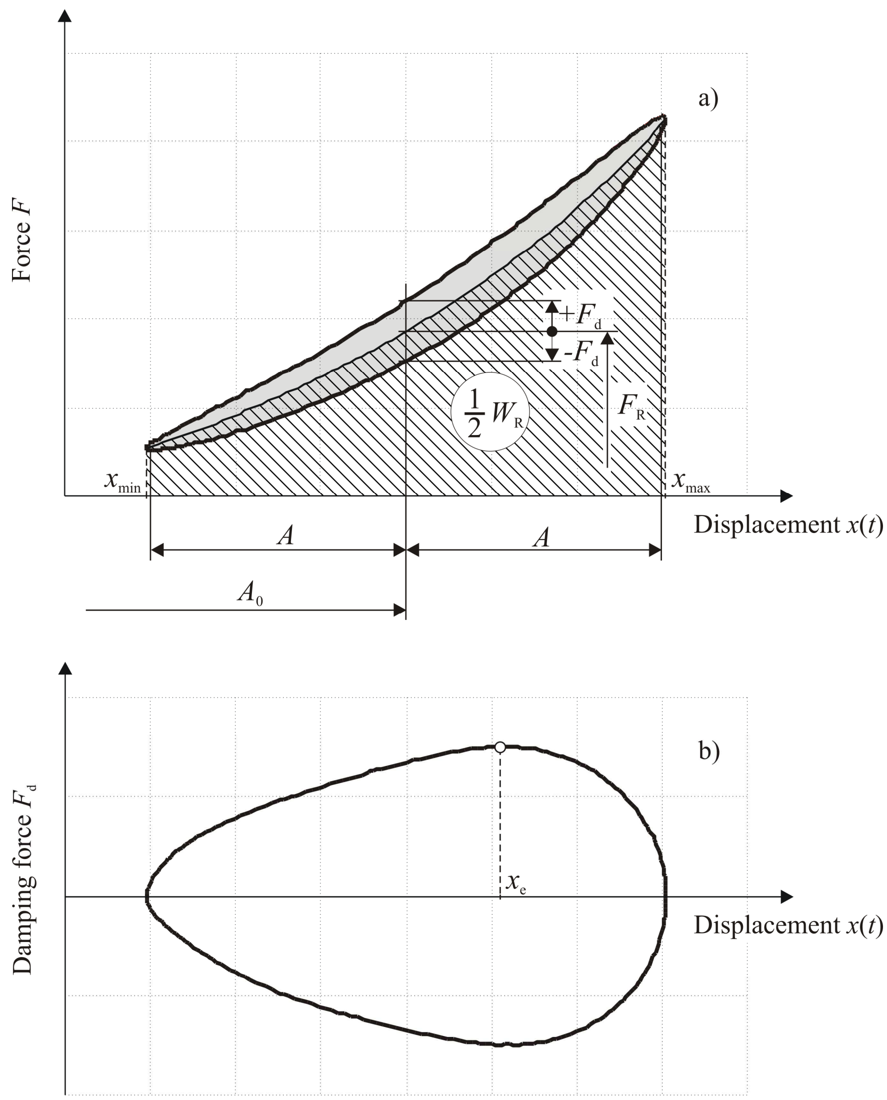

Figure 1: *Measured force responce and its decomposition*

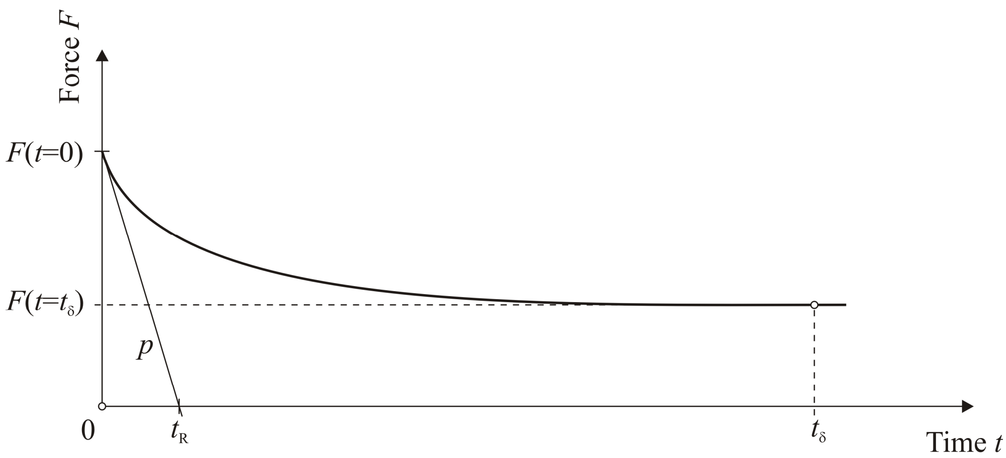

Figure 2: *Characteristics of relaxational process*

4. Measured quantities

In Figure 3 there is measured total force F which shows dependency on exciting frequency. In comparison with conventional foam it achieves even less values. In case of f=3 Hz its values are even near zero. If the loading frequency were higher, it would lead to losing contact between specimen and compression platten because velocity of elastic recovery is very low. Average work of restoring force W_R achieves value 106.1501 mJ with relative standard deviation 6.5916 %. In case of conventional foam it would be around 1000 mJ.

In Figure 4 there are courses of damping force F_d. Their characteristics qualitatively fully corresponds to conventional foam. Increasing of work of damping force with frequency is pictured in Figure 5. Using linear regression to fit this dependency we get coefficient of determination higher than 0.95 which means that it is possible to consider it as linear. Position of extreme of damping force x_e does not show systematic change with frequency, therefore it is possible to consider it being indepent on this parameter even if with higher standard deviation in comparison with conventional foams (Table 1).

In Figure 6 there is ratio betwen work of damping force and restoring force defined by eqn. (4) in dependency on frequency. Same as in case of conventional foam it is possible to consider it linear, but it achieves even higher values ([0.23; 0.62] – slow spring back foam, [0.05; 0.12] – usually with conventional foams).

In case of relaxational test the characteristics are qualitatively the same as in case of conventional foams (Figure 7). In accordance with former paragraphs initial force $F(t=0)$ is low, percentual force decreace δ_{R200} is very high (approximately 60 % - slow spring back foam, around 25 up to 35 % - conventional foams). Relaxation time t_R is approximately 1.5-3 times lower in comparison with common foams and relaxation speed is higher. Measured values are in Table 2.

Table 1: *Characteristics of slow spring back foam in case of dynamical loading*

Quantity	Value
x_e [mm]	27.1338
S_{x_e} [mm]	0.5706
s_{x_e} [%]	2.1030
W_R [mJ]	162.1501
S_{W_R} [mJ]	10.6883
s_{W_R} [%]	6.5916

Table 2: *Characteristics of slow spring back foam in case of relaxational process*

Quantity	A_0 [mm]		
	15	25	30
$F(t=0)$ [N]	14.8145	20.3435	27.7339
δ_{R200} [%]	60.5107	60.2581	58.3981
t_R [s]	0.6773	0.7486	0.5103
$v_{F\max}$ [N/s]	-21.87	-27.17	-54.35

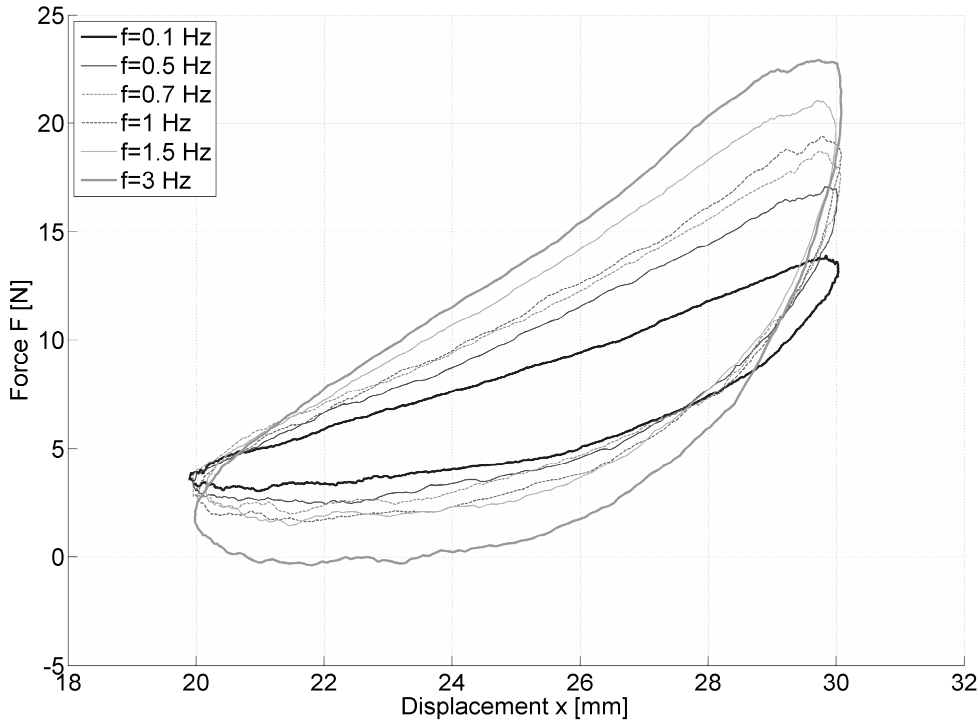

Figure 3: *Total force response*

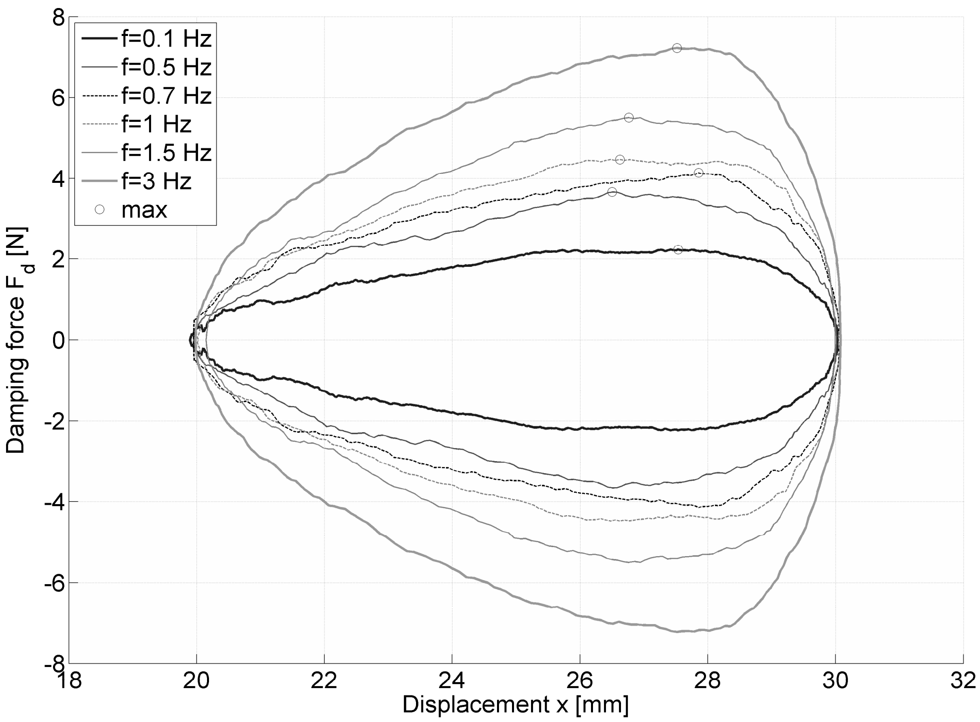

Figure 4: *Damping force response*

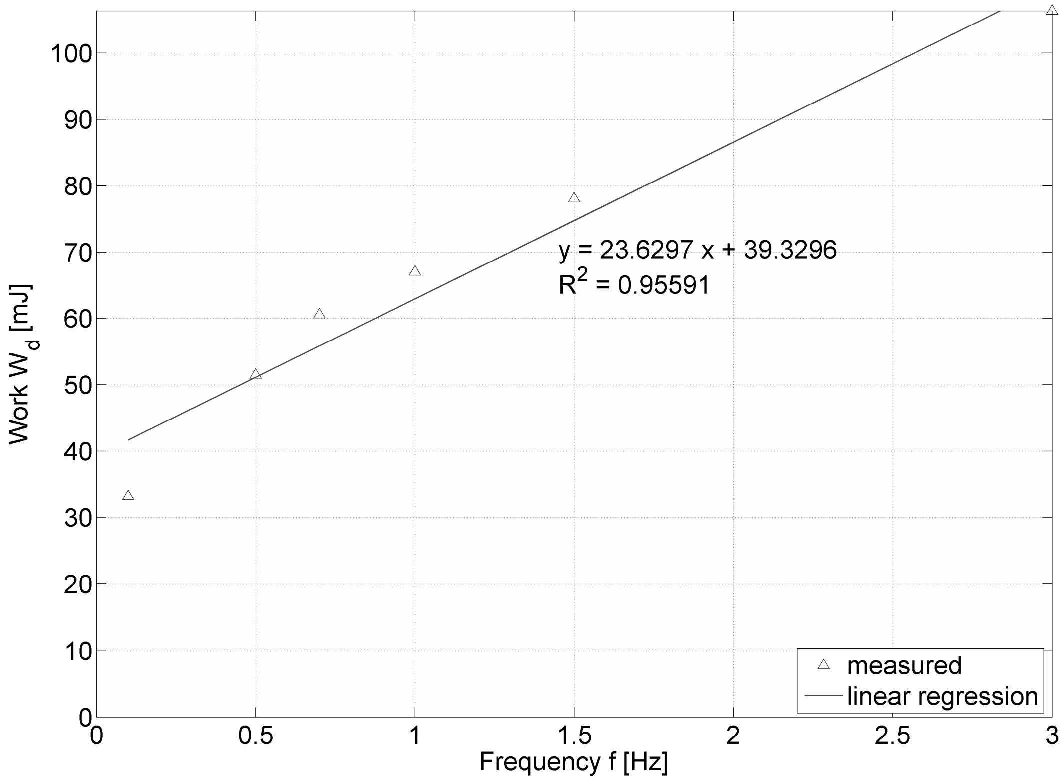

Figure 5: *Dependence of work of damping force W_d on exciting frequency f*

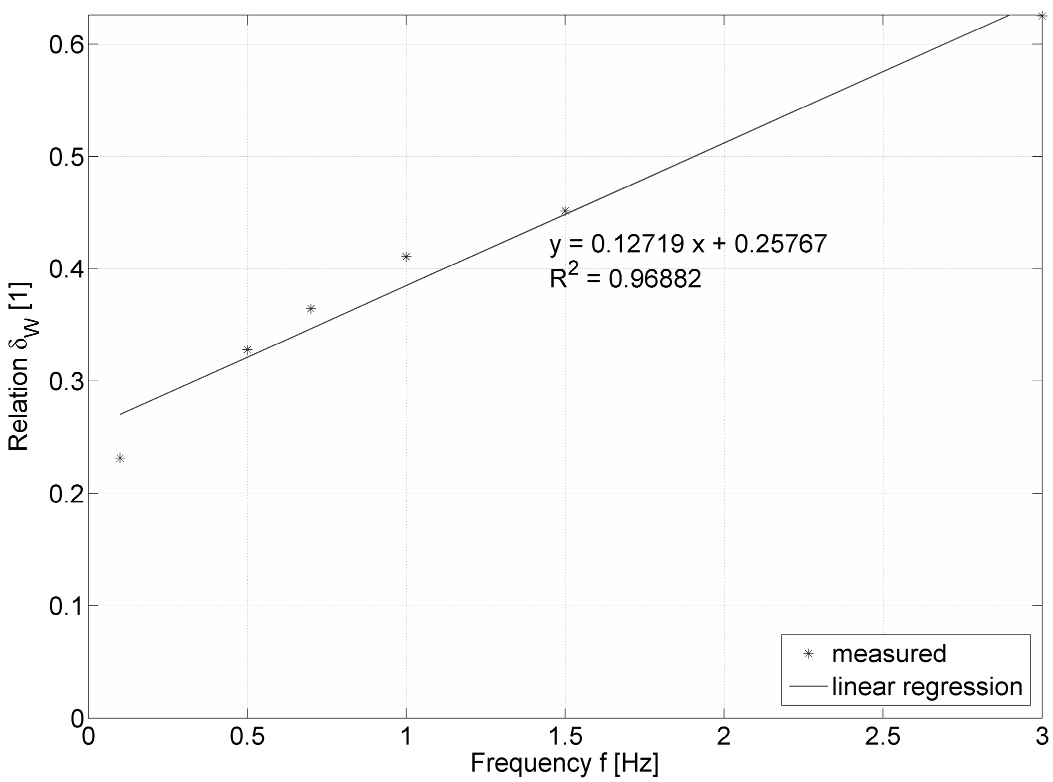

Figure 6: *Dependence of relation δ_W on exciting frequency f*

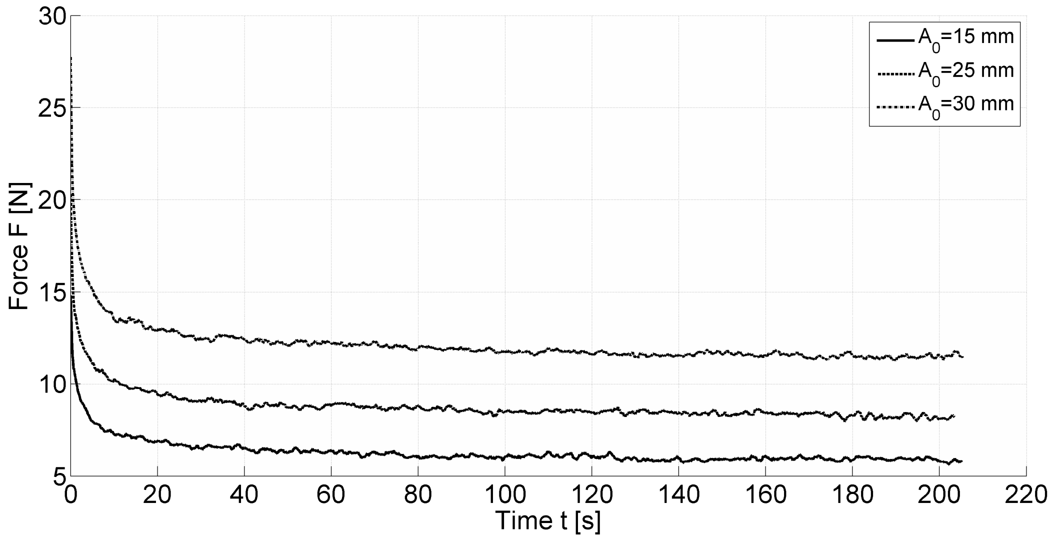

Figure 7: *Measured relaxation forces*

5. Conclusion

Measurement has shown that characteristics of slow spring back PU foam qualitatively fully correspond to conventional PU foams. That is:

- linear dependency of work of damping force on frequency,
- linear dependency of ratio δ_W on frequency,
- independency of position of damping force extreme x_e and work od restoring force W_R on frequency.

This material is characteristic with its high damping and low stiffness. From the quantitative point of view it is extreme form of PU foam.

Tests of slow spring back foam were carried out with temperature 24º C. Near this working point it would be obviously possible to use the model of mechanical properties derived for conventional PU foam (see [3], [4]).

Change of slow spring back foam properties with varying temperature has not been investigated in this article, although it is possible to assume it and it is generally declared.

Acknowledgement

This work was supported by the subvention from Ministry of Education of the Czech Republic under Contract Code MSM 4674788501.

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