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MODELLING AND INITIAL TESTS OF THE DYNAMIC PROPERTIES OF VIBROINSULATION MATS

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Abstract: *The paper demonstrates the mathematical model of polyurethane vibroinsulation mat tested using the dynamic mechanical analyser (DMA) method. The mechanical model is necessary to search for the analogy between different sample sizes of the objects tested. The aim of the study was to determine damping properties. The damping properties of vibroinsulation material are characterised by the loss factor* $\tan\delta$. *The value of the loss factor* $\tan\delta$ *was determined depending on the frequency of forced vibrations.*

Keywords: DMA, Loss factor, Polyurethane foam, Damping.

1. Introduction

The process of vibration transmission can be prevented mainly by installing flexible elements between the source of vibration and the surroundings (Adamczyk & Targosz, 2011). Modern flexible materials used for the vibroinsulation of solid materials and air vibrations, are the polyurethane mats made of spring part of composite with a mixed pore structure, i.e. open and closed pores.

The study of dynamic mechanical analyser (DMA) has been carried out to determine the usefulness of the polyurethane mats. The problem faced during the study is the high cost of testing equipment in accordance with the DIN 45673-5 standard. It is primarily the problem of samples sizes. The authors have at their disposal a very precise device DMA 242 NETZSCH that is adapted for testing even much smaller samples.

2. Mathematical Modelling of the Sample

Due to the fact that the test results have to be transferred to a much larger products than the samples, it is necessary to design a mathematical model of the sample. The sample in its basic part consists of polyurethane foam surrounded by coating which is formed in the modelling process of the sample (Fig. 1).

The equations of motion for the system are

$$\begin{aligned}
& m_3\left(\ddot{x}_3-\ddot{x}_1\right)+b_3\left(\dot{x}_3-\dot{x}_1\right)+k_3\left(x_3-x_1\right)=F\left(\omega\right)\\
& \left(m_1+m_2\right)\left(\ddot{x}_1-\ddot{x}_4\right)+\left(b_1+b_2\right)\left(\dot{x}_1-\dot{x}_4\right)+\left(k_1+k_2\right)\left(x_1-x_4\right)=\\
& =m_3\left(\ddot{x}_3-\ddot{x}_1\right)+b_3\left(\dot{x}_3-\dot{x}_1\right)+k_3\left(x_3-x_1\right)\\
& m_4\ddot{x}_4+b_4\dot{x}_4+k_4x_4=\left(m_1+m_2\right)\left(\ddot{x}_1-\ddot{x}_4\right)+\left(b_1+b_2\right)\left(\dot{x}_1-\dot{x}_4\right)+\left(k_1+k_2\right)\left(x_1-x_4\right)
\end{aligned} \tag{1}$$

where: $i=1,2,3,4$ is respectively upper layer of foam coating, basic foam, side layer of foam coating, and bottom layer of foam coating; x – displacement, m; m – mass, kg; b – damping coefficient, Ns/m; k – stiffness, N/m.

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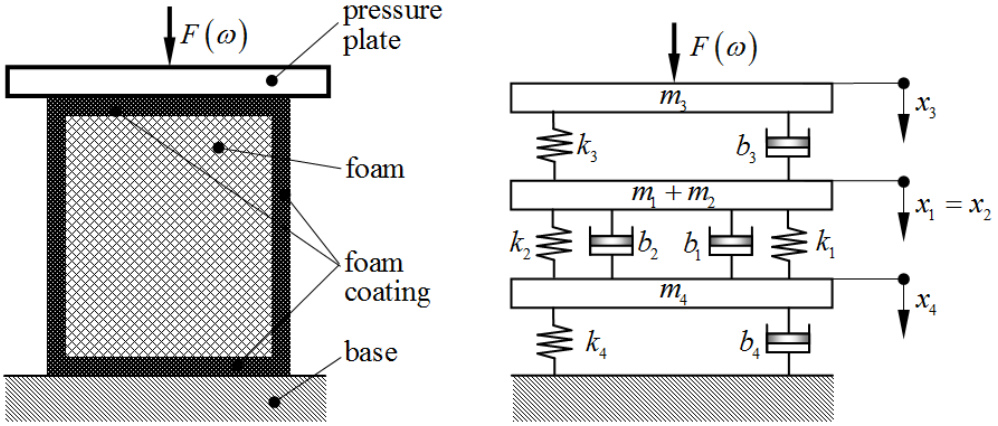


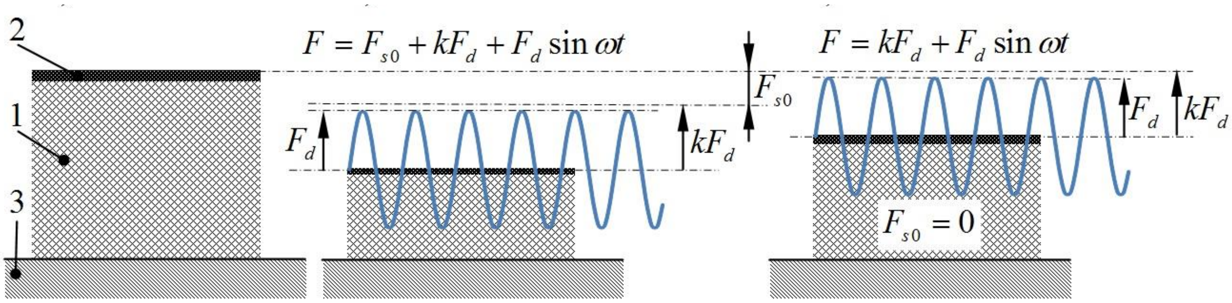
a) b)

Fig. 1: Sample tested: a) Cross-section of the actual sample; b) Mathematical model.

The model defined by system (1) allows for determining the relationship between the input in the form of sinusoidal vibrations and the output in the form of transfer function. Spectral transfer function consists of real and imaginary part. The real part is an equivalent of storage modulus E' while the imaginary part refers to the loss modulus E'' known from the DMA method.

3. Materials and Methods

The research materials were vibroinsulation polyurethane mats with the density of $250\,\text{kg/m}^3$ and dimensions as $650\times650\times25\,\text{mm}$, produced in Polyurethane Foams Factory Ltd. in Bydgoszcz (Wytwórnia Pianek Poliuretanowych Sp z o. o. w Bydgoszczy). The cylindrical samples 20 mm in diameter and thickness of 5.6 mm were cut at randomly chosen locations of the polyurethane mat. Before testing, the samples were thermostated at 23 ± 3°C for 16 hours.

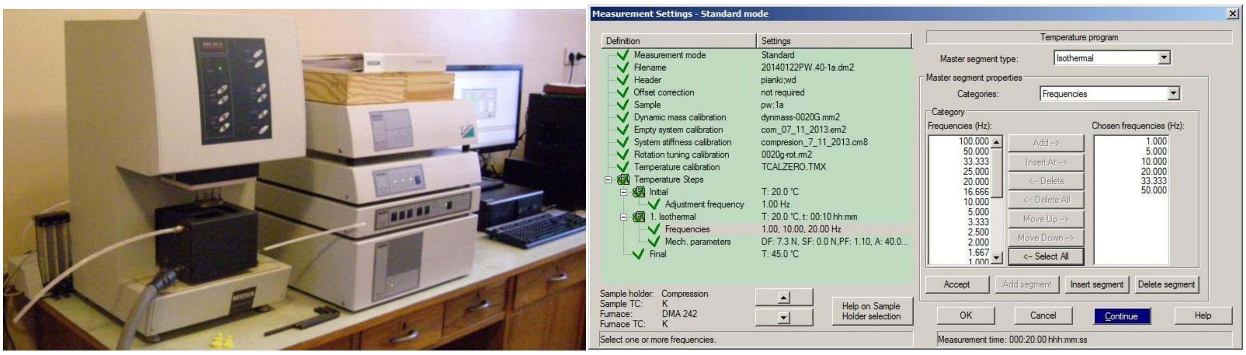


a) b) c)

Fig. 2: Load scheme: a) Unloaded sample cut from mate; b) General load scheme; c) Scheme used during experiments.

Fig. 2 shows the sample and its load scheme. Fig. 2a presents the uncompressed sample cut from the mat. It is characterised by only one coating as opposed to the formed sample shown in Fig. 1. Fig. 2b demonstrates a possible course of excitation force used during testing of damping properties in accordance with the standard. That force consists of constant static load F_{s0}, static load which depends on the amplitude of sinusoidal dynamic force kF_d where k is a proportionality factor resulting from the fact that static force always has to be higher than the amplitude of change. As a result, at least a slight compression of the sample will be ensured during testing. Fig. 2c shows the course of extortion used during testing, where $F_{s0}=0$, and $k=1.1$.

Testing the dynamic properties of the vibroinsulation mat was carried out with the use of DMA 242 device produced by NETZSCH company (Fig. 3). The aim of this study was to determine a real part which corresponds to the spring properties of the material and the imaginary part corresponding to damping properties (energy dissipation). The analysis of the results was supported by NETZSCH Proteus software. The real part was designated as storage modulus E' while the imaginary part was designated as loss modulus E'' (Menczel & Prime, 2009).



Measurement Settings - Standard mode

Definition	Settings
Measurement mode	Standard
Filename	20140122PW.40-1a.dm2
Header	pianki;wd
Offset correction	not required
Sample	pw;1a
Dynamic mass calibration	dynmass-0020G.mm2
Empty system calibration	com_07_11_2013.em2
System stiffness calibration	compresion_7_11_2013.cm8
Rotation tuning calibration	0020g-rot.rm2
Temperature calibration	TCALZERO.TMX
Temperature Steps	
Initial	T: 20.0 °C
Adjustment frequency	1.00 Hz
1. Isothermal	T: 20.0 °C, t: 00:10 hh:mm
Frequencies	1.00, 10.00, 20.00 Hz
Mech. parameters	DF: 7.3 N, SF: 0.0 N,PF: 1.10, A: 40.0...
Final	T: 45.0 °C

Sample holder: Compression
Sample TC: K
Furnace: DMA 242
Furnace TC: K

Select one or more frequencies.

Temperature program
Master segment type: Isothermal
Master segment properties
Categories: Frequencies
Category
Frequencies (Hz): 100.000, 50.000, 33.333, 25.000, 20.000, 16.666, 10.000, 5.000, 3.333, 2.500, 2.000, 1.667, 1.000
Chosen frequencies (Hz): 1.000, 5.000, 10.000, 20.000, 33.333, 50.000

Measurement time: 000:20:00 hhh:mm:ss

a) *b)*

Fig. 3: Test stand: a) Dynamic mechanical analyser DMA 242 NETZSCH; b) Research software settings.

An important issue in the evaluation of the dynamic properties of a material is the measurement of the damping properties (Koszkul et al., 2002). In DMA method, this size is expressed as the tangent of the angle of phase shift δ also known as the tangent of the angle of mechanical loss.

$$tg\delta = \frac{E''}{E'} \tag{2}$$

The value of phase shift δ describes the ratio of the energy dissipated per cycle of ε strain to the energy stored during this process. The study consisted in the compression of the sample at specific frequencies. The German standard DIN 45673-5 Mechanical vibration - Resilient elements used in railway tracks - Part 5: Laboratory test procedures for under-ballast mats were used to determine research frequencies. Vibration frequencies 5, 10, 20, 30, and 40 Hz are used in the standard to examine the dynamic properties. In the research software, the parameters were established to be as close as possible to the recommended frequencies, i.e. 1 Hz, 5 Hz, 10 Hz, 20 Hz, 33.33 Hz and 50 Hz (Fig 4).

The amplitude of ε strain was 40 µm and the maximum dynamic force acting on the sample was 7.272 N. Isothermal conditions were maintained during testing, with the temperature at the level of 23 ^{o}C±3^{o}C. The measurement time was 10 minutes.

4. Results

Fig. 4 presents the course of changes in the storage modulus *E'*, loss modulus *E''*, and tan*δ* of an the angle of mechanical loss depending on the time. The figure shows the results of measurement at vibration frequencies of 1, 5, 10, and 20 Hz. The values of storage modulus as well as loss modulus and the angle

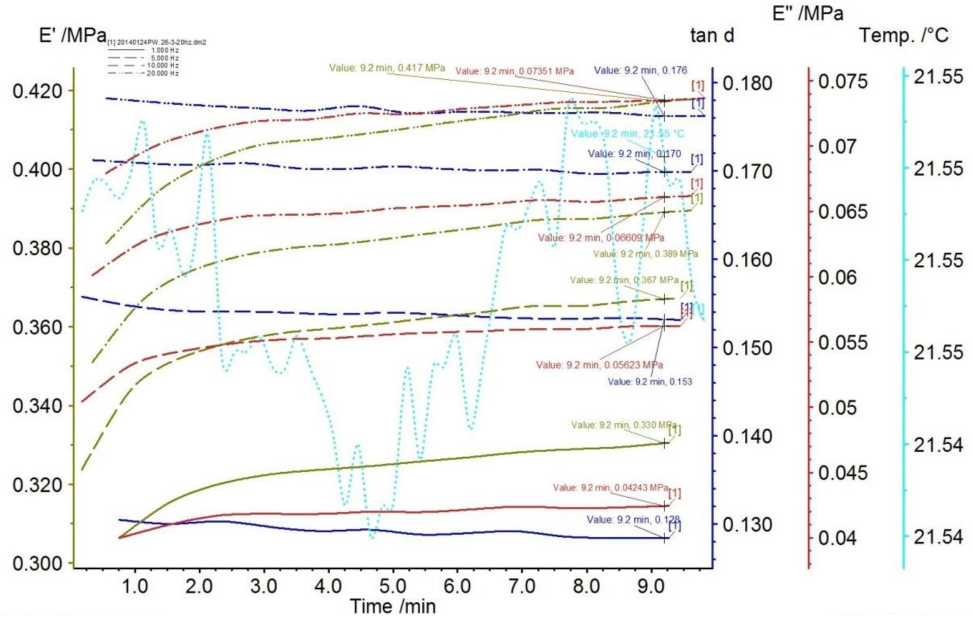


Fig. 4: Results of the sample obtained applying the NETZSCH Proteus software.

of mechanical loss depend on the vibration frequency. It is noted that the higher the frequency, the higher the values. After an increase of vibration frequencies from 1 Hz to 20 Hz there is observed an increase in value of tgδ by 37.5 %, loss modulus of approximately 26%. The largest increase is recorded for the measurement of mechanical loss modulus E'', by 73%.

The results of tanδ measurements are shown in a diagram form, depending on the frequency selected (Fig. 5). Fig. 5 presents average values of five measurements for each frequency.

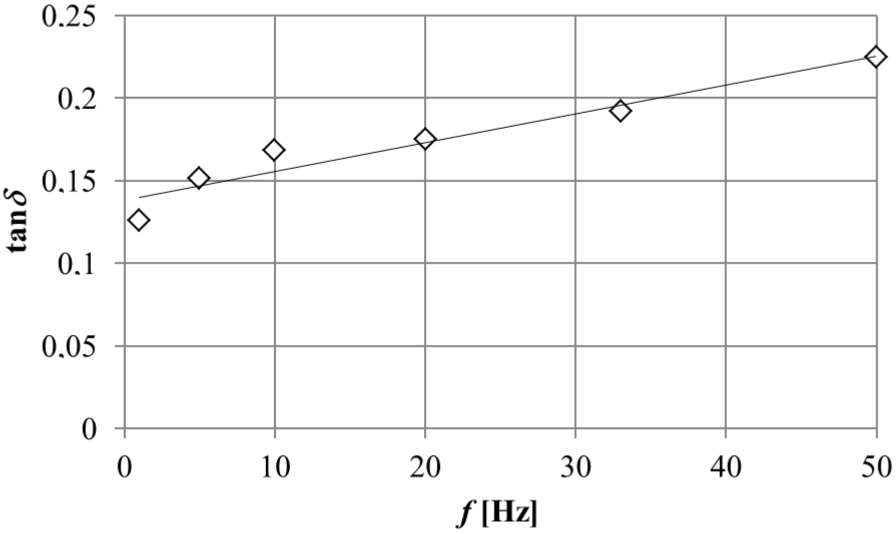


Fig. 5: Course of value tanδ *depending on the frequency selected.*

There can be seen a significant increase in value along with the frequency. The difference between the minimum and maximum value is 78% of the absolute value. The largest spread of the results between the extreme values, up to 27%, is observed for measurements of samples at the vibration frequency of 50 Hz. This frequency maybe is too high to obtain adequate repeatability of the results. It may also be related to the violation of the porous structure of the vibroinsulation mat during the measurement.

5. Conclusions

DMA is a measurement method which is increasingly used for the polyurethane material analysis. It allows testing the dynamic properties under the influence of an applied force in a function of temperature, frequency and time. This procedure allows the measurement of components of complex Young's modulus E^* – storage modulus and mechanical loss modulus. These values refer to damping characteristic of viscoelastic polymer properties.

According to the literature (Hatakeyama & ZhenHai, 1998) polymer materials are characterised by good damping properties if the value of the mechanical loss factor falls in the range $0.1 \leq \text{tg}\delta \leq 0.2$. Based on that it can be concluded that the tested vibroinsulation mats tested show the properties in the range of vibration frequency from 1 Hz to 33.3 Hz.

It should be noted that those are preliminary studies aiming to determine the relationship between dynamic properties and selected frequencies. Later the authors want to investigate the reaction of the vibroinsulation mat in variable temperature conditions as well as to find the correlation of the results in respect to laboratory tests according to DIN 45673-5.

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