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Evaluation of the properties of polymeric foams with shape memory under load

Dominik Kukla[1], Maria Staszczak[2], Elżbieta Pieczyska[3], Marcin Heljak[4], Karol Szlązak[5], Wojciech Świąszkowski[6], Mariana Cristea[7], Hisaaki Tobushi[8], Shunichi Hayashi[9]*

[1,2,3] *Institute of Fundamental Technological Research*
Pawińskiego 5b, 02-106 Warsaw, Poland
e-mail: dkukla@ippt.pan.pl [1], mstasz@ippt.pan.pl [2], epiecz@ippt.pan.pl [3]

[4,5,6] *Faculty of Materials Science Warsaw University of Technology*
Wołoska 141, 02-507 Warsaw, Poland
e-mail: mheljak@inmat.pw.edu.pl [4], kszlazak@inmat.pw.edu.pl [5], wswieszk@inmat.pw.edu.pl [6]

[7] *"Petru Poni" Institute of Macromolecular Chemistry*
Aleea Grigore Ghica Voda 41A, 700487 Iasi, Romania
email: mcristea@icmpp.ro

[8] *Aichi Institute of Technology*
1247 Yachigusa, Yagusa-cho, Toyota City, Aichi Prefecture 470-0392, Japan
email: tobushi@aitech.ac.jp

[9] *SMP Technologies Inc.*
Ebisu First Place1-22-8, Ebisu, Shibuya-Ku, 150-0013 Tokyo, Japan
email: hayashi@smptechno.com

Abstract

The paper presents the results of experimental investigation on polymer foam with shape memory properties. The research is focused on characterization of the microstructure of the foam and understanding the mechanisms of deformation under static and dynamic loading. Up till now, selected experimental techniques have been applied. Dynamic Mechanical Analysis (DMA) allows determining the extent of the value of the glass transition temperature under different load conditions, which also reveals the transformation temperature range for the SMP foam. Scanning electron microscopy (SEM) shows the foam microstructure in various scales, while X-ray tomography gave 3D microstructure results presenting in addition mechanism of the cells deformation and changes in their geometry under 30 % and 50% strain. BOSE system enables obtaining the results on dynamic loading.

Keywords: shape memory polymer foam, Dynamic mechanical analysis, Glass transition temperature, X-ray tomography

1. Introduction

Shape memory polymers (SMP), like some metal alloys exhibit the shape memory effect and belong to a group of smart materials. The functional properties of the SMP exist due to the difference between characteristics of molecular motion above and below the glass transition temperature T_g [1]. If SMP is deformed at temperatures above T_g and cooled down to temperatures below T_g by holding the deformed shape constant, the shape is fixed and the SMP can carry larger load. If the shape-fixed SMP element is heated up to temperatures above T_g under no load, the original shape is recovered [2].
Among the SMPs, the polyurethane shape memory polymer (PU-SMP) has been often practically used, since the rigidity of polyurethane is high in comparison to other polymers [3]. Especially, the polyurethane shape memory foam is recently drawing attention, since it has not only the shape memory material characteristics, but also the particular foam structure [3]. The SMP foam is characterised by impact relaxation, energy absorption and heat insulating properties. Therefore, the SMP foam is applied in aerospace and aircraft industry, biomedical elements, pharmacy; e.g. drug delivery systems, as well as in textile and responsible packaging industry.

2. Methodology

In the study, in order to learn more about the new material, some experimental investigation on the SMP foam structure and mechanical properties have been carried out.

Dynamic Mechanical Analysis allowed determining the SMP foam region of the glass transition temperature T_g.

The scanning electron microscopy illustrates of the skeletal foam structure.

X-ray tomography shows the foam structure in various micro scales, also under loading. To this end, a sample of foam was used in a state of static deformation at 30% and 50%. It allowed exploring the mechanisms of strain in the range of elastic foam. The SMP foam sample with size 10x10x10 mm was mounted in a holder of the Sky scanner Scan (?) with the spatial resolution in the range of hundreds of nanometers. In terms of volume is equal to or better than the resolution synchrotron tomography. The device uses open source X-ray of the LaB6 cathode. The test was performed in room conditions; at temperature 22°C and in humidity 45 %.

Moreover, a BOSE dynamic loading system was used in order to evaluate the foam strength and assess its suitability for characterization of the mechanical properties of the SMP foams.

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3. Results

3.1. Scanning electron microscopy SEM

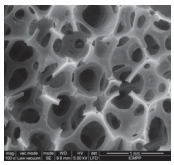

Figure 1: Microstructures of SMP foam by SEM (x 100)

Observations of the SMP foam by SEM have been conducted at magnifications x 100, x 200 and x 500. An example of the obtained microstructure with magnification x100 is shown in Figure 1. It can be noticed that the microstructure is characterized by a homogeneous distribution of regular cells with sizes in the range of approximately 300 µm - 500 µm.

3.2. Dynamic mechanical analysis DMA

Example of the results obtained by DMA for the SMP foam sample subjected to shear with frequency 1 Hz and ramp temperature increase 2 °C/min, is shown in Figure 2.

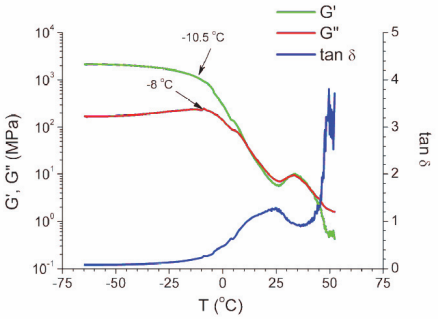

Figure 2: DMA results. Variation of storage modulus *G'*, loss modulus *G"* and loss factor *tan δ* with temperature *T*

Variation of the storage modulus (*G'*), loss modulus (*G"*) and loss factor (*tan δ*) with temperature enable to estimate glass transition temperature range, approximately from -10°C to -6°C.

3.3. X-ray tomography

X-ray tomography shows the SMP foam cells in 3D, moreover of varying geometry under static tensile load. Example of the results is shown in Fig. 3.

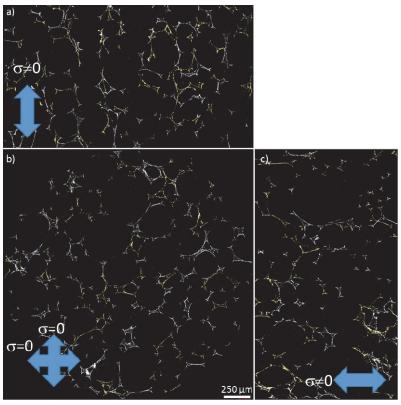

Figure 3: Reconstructed images with visible cells. By: longitudinal (a), transverse (b) and sagittal (c) intersection. White fiber - at deformed state ε=30%, yellow - at ε=50%

The obtained X-ray tomography results allowed for quantitative analysis of changes in equivalent diameters of the foam cells and expected ratio of the cells at the strain of 30% and 50%. The results were obtained using stereological image analysis techniques. Fig. 4 shows changes in the geometry of the cells in successive stages of strain as the shape factor for three selected pores.

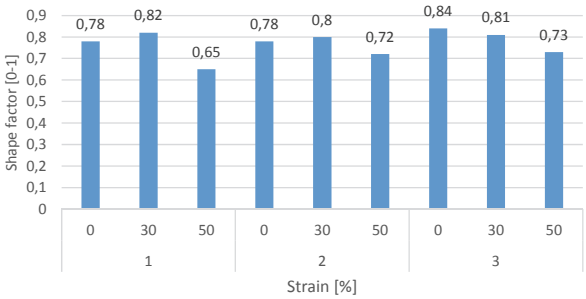

Figure 4: Shape factor of three selected cells obtained at deformation: 0, 30 and 50%

4. Conclusions

The obtained results show some properties of shape memory polymer foam – a new shape memory material with foam structure and high potential in applications.

Results of dynamic mechanical analysis allowed estimating the value of the SMP foam glass transition temperature; in the range of approximately from -10°C to -6°C.

Observations by SEM reveal that the SMP foam microstructure is characterized by a homogeneous distribution of regular cells with sizes in the range of 300 µm - 500 µm.

Analysis of the SMP foam spatial structure performed by X-ray tomography showed slight changes both in the cell geometry (shape impact) as well as in the cell size (equivalent diameter), estimated at 30% and 50% deformation. This may be caused by a negative Poisson's ratio of the foams investigated by the responsibility of their skeletal structure.

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