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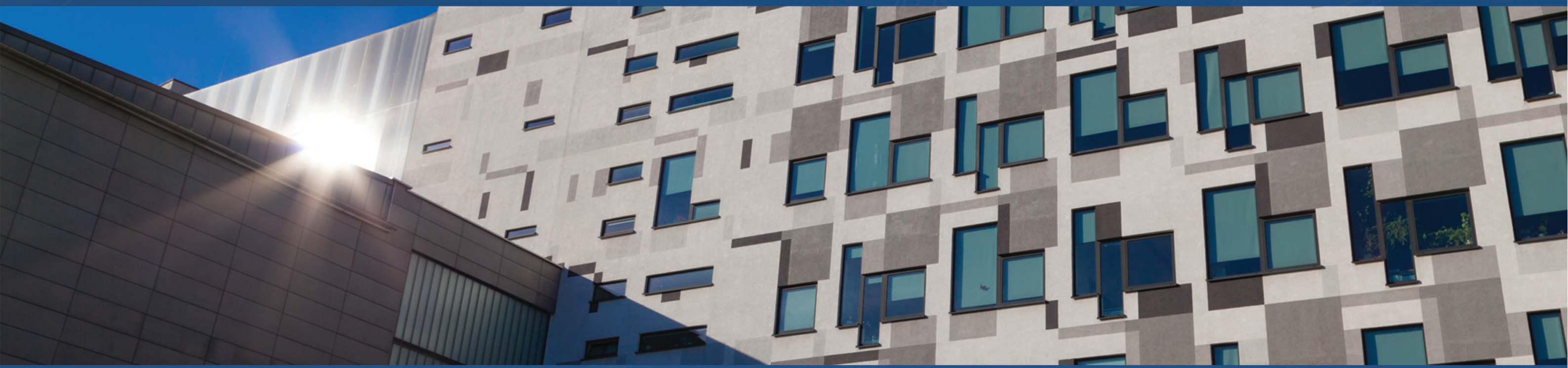

41ST SOLID MECHANICS CONFERENCE

BOOK OF ABSTRACTS

Editors: K. Wiśniewski, T. Burczyński

Co-editors: B. Błachowski, M. Nowak, P. Tauzowski

41st SolMech 2018

Warsaw, Poland

August 27-31, 2018

ESTIMATION OF ENERGY STORAGE AND DISSIPATION IN SHAPE MEMORY POLYMER DURING ITS DEFORMATION

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1. Introduction

Shape memory polymer (SMP) is a class of stimuli-responsive material with high application potential which can rapidly change its shape under the influence of external stimulus. Among these materials, shape memory polyurethane has attracted worldwide attention. Shape memory properties of shape memory polyurethanes often are triggered by temperature. The temperature at which the polymer returns to the original shape is usually its glass transition temperature T_g [1].

During deformation some part of external mechanical energy is dissipated, while the other part is remained in the material after unloading as stored energy E_s. The stored energy denotes a change in internal energy of deformed materials and can be determined as difference between the energy of inelastic deformation W_{in} and dissipated energy W_d during the process of deformation. The transformation of the mechanical work into heat, its dissipation and the stored energy contribute to better understanding of the mechanisms of material deformation [2]. To the best the authors knowledge, the results on energy investigation of shape memory polymers, especially shape memory polyurethane, has not been reported in literature so far. Therefore, the goal of the paper is to estimate energy during shape memory polyurethane loading and deformation.

2. Materials and experimental details

Shape memory polyurethane PU-SMP with glass transition temperature $T_g \approx 25°C$, manufactured by *SMP Technologies Inc.*, Japan, was investigated. The tension tests were performed on MTS 858 testing machine at room temperature. The fast and sensitive infrared camera ThermaCam Phoenix was used in order to determine in contactless manner the temperature distributions on the SMP surface and to obtain temperature changes. The energy estimation was performed during PU-SMP loading with two strain rates of $2\cdot10^{-1}$ s^{-1} and $2\cdot10^{0}$ s^{-1}, for which the process conditions could be considered as adiabatic. The investigation was conducted for two strain ranges 0.6 and 1.18, where the deformation was macroscopically homogeneous.

3. Results and discussion

Scheme of the methodology for estimation of energy during loading of PU-SMP with $T_g \approx 25°C$ used in the research is presented in Fig.1. Force F in function of displacement Δl obtained for strain rate of $2\cdot10^{-1}$ s^{-1} is shown in Fig. 1a, whereas for the strain rate of $2\cdot10^{0}$ s^{-1} in Fig.1b, respectively.

The external mechanical energy W_{ext} (*OAB*) delivered to the gauge part of the sample during deformation can be decomposed into a recoverable energy W_{rec} (*DAB*) and an inelastic one W_{in} (*OAD*) [3]. In the case of shape memory materials W_{rec} consists of the elastic energy W_e (*CAB*) and the energy required for the shape memory effect W_{SM} (*DAC*). Whereas W_{in} can be decomposed into the dissipated energy W_d and the energy stored in the material E_s. In this analysis, the heat exchange with the environment, as well as heat losses resulting from the conductivity to the grips of the testing machine, were neglected. The deformation process was assumed as adiabatic and the dissipated energy denoted as Q was equal to the sample temperature change ΔT multiplied by the specific heat value c_v. Assuming that the process is adiabatic, the energy balance includes an additional energy component E_{th}, associated with the drop in temperature (thermoelastic effect), which accompanies the elastic loading and unloading of the material.

a) b)

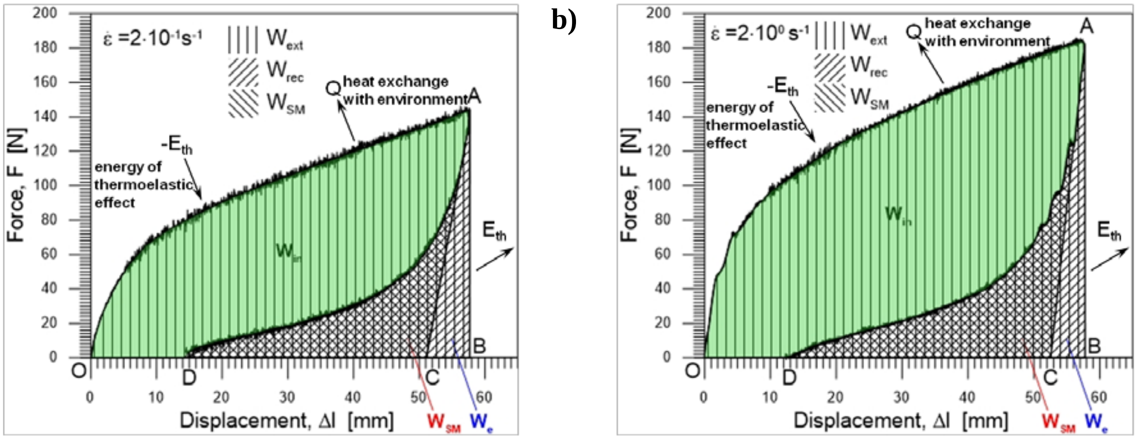

Figure 1: Scheme of energy estimation during PU-SMP loading-unloading cycle: a) $2{\cdot}10^{-1}\,s^{-1}$; b) $2{\cdot}10^{0}\,s^{-1}$.

The estimated energies for the SMP during the tension loading-unloading process are plotted in Fig. 2.

a) b)

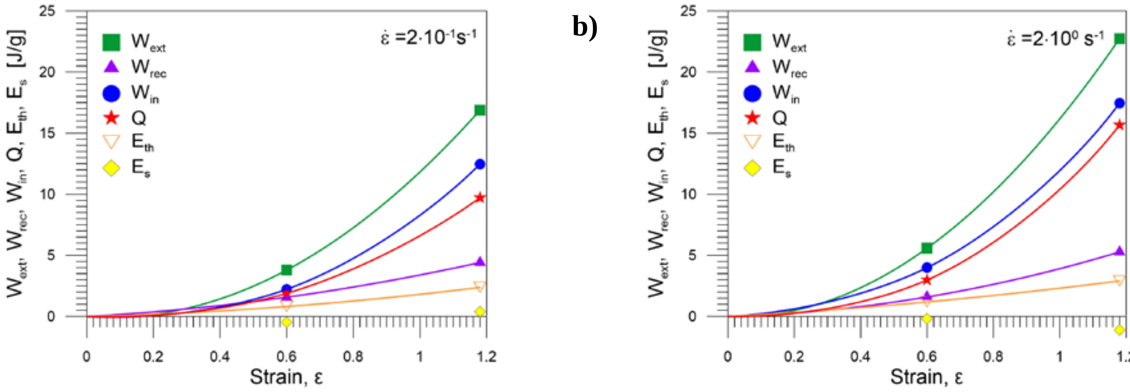

Figure 2: Comparison of estimated W_{ext}, W_{rec}, W_{in}, Q, E_{th}, E_s vs. strain for strain rates: a) $2{\cdot}10^{-1}\,s^{-1}$; b) $2{\cdot}10^{0}s^{-1}$.

4. Conclusions

A quantitative energy estimation was performed for polyurethane shape memory polymer ($T_g \approx 25$°C) loading with two strain rates under room conditions.

It was found that the mechanical energy W_{ext} provided to the sample during the deformation process, the inelastic energy W_{in} , as well as the dissipated energy Q, depend on the strain rate applied. The higher strain rate, the higher energy values were obtained. However, the values of recoverable energy W_{rec} and the energy of thermoelastic effect E_{th} almost did not depend on the strain rate. The estimated values of the stored energy E_s for both two strain rates and two strain ranges were close to zero. Therefore, it can be conclude that the energy was not stored in this polymer during the deformation process, but it was only dissipated, i.e. totally converted into heat. It should be also noted that as a result of the structural investigation, the crystalline phase was not found in the SMP in the examined strain range, considered as macroscopically homogeneous.

Acknowledgments The research has been carried out with support of the Polish National Center of Science under Grant 2014/13/B/ST8/04280. The authors are grateful to H.Tobushi for many helpful comments, to L.Urbański and M.Maj for obtaining mechanical and thermal data, as well as to S.Hayashi, SMP Technologies Inc., Japan, for providing PU-SMP.

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