SHAPE MEMORY POLYMER - INFLUENCE OF TEMPERATURE, STRAIN RATE AND THE LOADING HISTORY ON THE STRESS-STRAIN CURVES

***E.A.Pieczyska*[1], *M.Staszczak*[1] , *H.Tobushi*[2], *K.Takeda*[2], *R.Matsui*[2] and *S. Hayashi*[3]**
[1] *Institute of Fundamental Technological Research, Warsaw, Poland*
[2] *Aichi Institute of Technology, Toyota, Japan*
[3] *SMP Technologies Inc., Tokyo, Japan*

1. Introduction

The mechanism of exhibiting shape memory property in polymer is different from that observed in shape memory alloy, since the crystallographic phase transformation does not occur in polymers. The functional characteristics of shape memory polymer (SMP), e.g. rigidity, elastic modulus and coefficient of thermal expansion, change significantly above and below its glass transition temperature (T_g) due to molecular motion of the polymer chains which differs drastically below and above T_g. These properties allow to apply SMP in biomedical, textile, housing, transportation, aviation industries [1, 2]. A goal of this paper is to discuss selected results of the SMP investigation and demonstrate how significantly its mechanical properties change in various conditions; influence of temperature, strain rate and loading history were taken into consideration.

2. Experimental procedure

The material used in the experiment was the polyurethane shape memory polymer, characterised by T_g of approximately 45°C and the degree of crystallinity of approximately 5%. Photographs of the specimens demonstrating shape memory properties are shown in Fig. 1.

a) b)

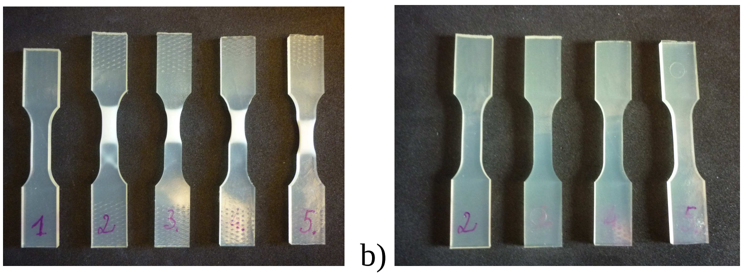

Fig. 1. SMP specimens (a) before (1), after loading (2-5); b) after loading and heating at T_g+20°C

3. Results and discussion

The SMP functional parameters derived from the ultrasound tests (UT), dynamic mechanical analysis (DMA) and differential scanning calorimetry (DSC) are presented in the Table.

Density	Results of UT		Results of DMA				Results of DSC
ρ (g/cm^3)	E (MPa)	ν	E'_g (MPa)	T_g (°C)	E'_r (MPa)	E'_g/E'_r	degree of crystallinity (%)
1.241	3200	0.412	1250	45	12.1	103	5

Examples of experimental results of the SMP tensile loadings performed at various programs are presented in Fig. 2 a, b and c. Fig. 2a presents results of the loading obtained in thermal chamber in isothermal conditions at the temperature below, equal and above T_g. Fig. 2b shows influence of the strain rate on the grounds of the results obtained at three various strain rates. Fig. 2c demonstrates how the mechanical properties of the SMP depend on the post-loading heating. To this end, seven tension tests were conducted on the same sample with the same strain rate $10^{-2}s^{-1}$ within the same strain range 6.45% (only the first curve denoted by 10_2_1 was conducted with much larger nominal strain 30%). After the loading-unloading 5 tensile cycles, the sample was heated at temperature T_g+20°C during 30 min. After that it was subjected to the subsequent tension.

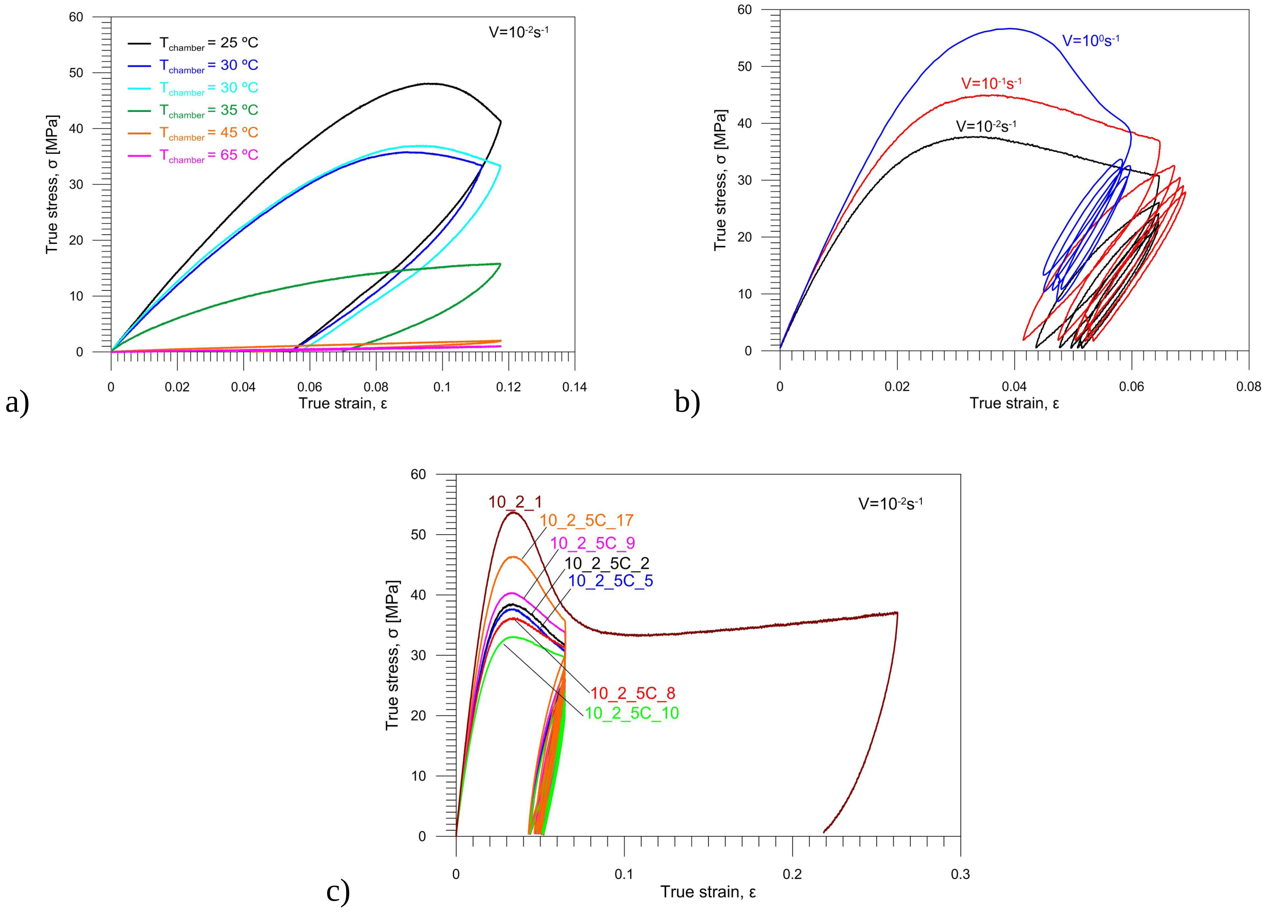

Fig. 2. Comparison of stress σ vs. strain ε for SMP during a) tension with strain rate $10^{-2}s^{-1}$ at various temperatures: 25°C, 30°C, 35°C, 45°C, 65°C; b) tension with various strain rates: $10^{-2}s^{-1}$, $10^{-1}s^{-1}$ and $10^{0}s^{-1}$; c) tension with strain rate $10^{-2}s^{-1}$ with various loading-heating history.

The results plotted in Fig. 2c indicate that the maximal stress decreases with the loading-unloading-heating history. The maximal stress values, obtained for the curves denoted by 10_2_5C_2 (specimen after 1st heating), 10_2_5C_5 (the same specimen after 2^{d} loading-unloading-heating), 10_2_5C_8 (after 3rd heating), 10_2_5C_9 (4 heatings), 10_2_5C_10 (5 heatings), are gradually lower. Only the test 10_2_5C_17 (specimen after 7 heatings) reaches higher stress value. It was conducted 10 days later, so the SMP had more time to recover its properties.

4. Conclusions

It was experimentally demonstrated how significantly the polyurethane shape memory polymer T_g=45°C is sensitive to the temperature, strain rate and loading-unloading-heating history.

5. References

[1] H. Tobushi, R. Matsui, K. Takeda, E. Pieczyska (2013). *Mechanical Properties of Shape Memory Materials*, Materials Science and Technologies, NOVA Publishers, New York.

[2] E.A. Pieczyska, M. Staszczak, M. Maj, K. Kowalczyk-Gajewska, K. Golasinski, M. Cristea, H. Tobushi, S. Hayashi, Investigation of thermomechanical couplings, strain localization and shape memory properties in shape memory polymer subjected to loading at various strain rates, Smart Materials and Structures, 2016,: Paper references SMS-102972 (in print).