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INFLUENCE OF STRAIN RATE AND COOLING RATE ON THE MECHANICAL BEHAVIOUR SHAPE MEMORY POLYURETHANE WITH *Tg* = 65 °C

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1. Introduction

Shape memory polymers (SMP) are stimuli-responsive smart materials that are able to fix its temporary shape and recover the original shape when exposed to an appropriate external stimulus, e.g. heat, light, water. Due to the properties, the SMP have attracted tremendous attention and are applied in various areas, such as biomedical, smart textiles, food protection, toys, as well as aircraft and space industry [1]. Polyurethane shape memory polymer (PU-SMP) is specially distinguished and characterized by a good processability, wide-range of shape recovery temperature and high recoverable strain, resulting in the high mechanical and the related functional properties [2, 3]. The purpose of this paper is to discuss selected results of investigation of the PU-SMP in order to demonstrate how significantly its mechanical properties change at various strain rates during the loading and deformation. This investigation helps to predict the PU-SMP behavior in application. Moreover, PU-SMP is extremely sensitive to the surrounding conditions [2]. Therefore, the effect of cooling rate during the initial thermal treatment is also taken into consideration. The obtained results will be useful in further investigation of the PU-SMP shape memory properties, since the strain rate and thermal treatment before the loading are influential factors which determine their shape memory performance.

2. Materials and experimental procedure

The investigation was conducted on shape memory polyurethane with glass transition temperature T_g = 65°C, manufactured by *SMP Technologies Inc.*, Japan. For the initial characterization of the PU-SMP and establishing the nature of transition, such as relaxation, melting or crystallization, the multifrequency dynamic mechanical analysis (DMA) in the temperature range from -150°C to 160°C was performed.

The tension loading was conducted on Instron 5969 testing machine at room temperature till rupture with various strain rates: 10^{-3} s^{-1}, 10^{-2} s^{-1}, 10^{-1} s^{-1} and 100 s^{-1}. Before the loading, the PU-SMP specimens were heated up to 80°C (T_g +15°C) during 30 minutes in order to uniform their microstructure and erase the mechanical history. After that, some of the specimens were cooled down quickly to the room temperature by taking them out from the thermal chamber, whereas others were cooled down slowly inside the thermal chamber.

3. Results and discussions

The obtained DMA results, namely the temperature dependencies of storage modulus E' and loss factor tan δ, are presented in Fig. 1a. The glass transition is followed by a phenomenon which is frequency independent. Considering decrease of E' by increase of the temperature in the temperature region of 100°C - 150°C, it is very probable to have a succession of overlapping melting and crystallization phenomena. The glass transition temperature, determined as the tan δ peak, is equal to 65.2°C. The value is in agreement with T_g value given by the PU-SMP producer.

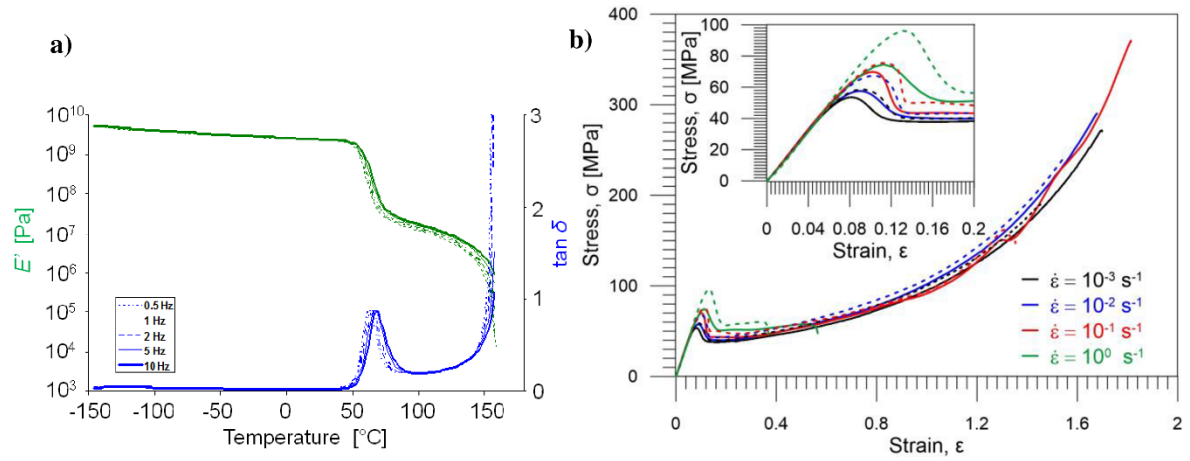

Fig. 1. a) Multifreqency DMA diagram: storage modulus E' and loss factor tan δ tan vs. temperature; b) stress vs. strain obtained during the PU-SMP tension till rupture conducted at various strain rates - 10^{-3} s^{-1} (black), 10^{-2} s^{-1} (blue), 10^{-1} s^{-1} (red) and 100 s^{-1} (green): the solid and dashed lines correspond to specimens cooled down quickly and slowly, respectively; insert shows the part of this graph obtained till strain value 0.2

The experimental results of the PU-SMP tensile loadings performed till rupture at various strain rates are presented in Fig. 1b. As it is noticed, the obtained stress becomes higher with the increase in the strain rate, since the deformation process of the polymer is more dynamic. This tendency is observed both for the specimens cooled down quickly and slowly. The stress values of the specimens which were cooled down slowly, are higher than those of the specimens cooled down quickly at all the strain rates applied, which is related to the special microstructure of the polymer. Before the loading, during the heating process of the specimen to the temperature above T_g, the soft segments of the polyurethane chains, located between the hard segments, become highly flexible and the rotations of the segments around the bonds are significantly increased. By cooling down the polymer to the temperatures below T_g the flexibility and mobility of the polymer chains become limited and PU-SMP reaches its glassy state. Slow cooling allows the polymer reach this state more completely. Thus, a slower cooling rate gives the material more time to evolve to an equilibrium configuration during the cooling process. This phenomenon improves their mechanical properties.

4. Conclusions

It was experimentally demonstrated how significantly the polyurethane shape memory polymer PU-SMP (T_g=65°C) is affected by the strain rate and the cooling rate, which is closely connected with the polymer microstructure evolution.

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