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ESTIMATION OF SHAPE FIXITY AND SHAPE RECOVERY – CRUCIAL PARAMETERS FOR SHAPE MEMORY POLYMER APPLICATIONS

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1. Introduction

Shape memory polymers (SMP) are new unique and attractive materials which demonstrate shape memory properties. It means that the materials, as a result of an external stimulus such as temperature, can recover their original (permanent) shape from deformed (temporary) shape. The mechanical characteristics of SMP, e.g. the elastic modulus and the yield stress, change significantly below and above their glass transition temperature T_g. It can be explained by differences of molecular motion of the polymer chains below and above T_g [1, 2]. Two phenomena due to this can be observed in the SMP. The first one is a shape fixity which means that it is possible to fix a temporary shape by cooling the deformed SMP below T_g. The second phenomenon, called a shape recovery, denotes the property that the original shape, changed due to deformation, is recovered during subsequent heating above the SMP T_g temperature. Preliminary estimation of these two parameters, crucial to assess SMP potential applications, is the subject of this paper [1].

2. Experimental procedure, results and discussion

The research was carried out on a new shape memory polyurethane PU-SMP, produced by SMP Technologies Inc., Tokyo, Japan. In order to learn more about the new material, a dynamic mechanical analysis (DMA) was performed. The characteristics of the SMP shown in Table 1 suggest that the material fulfills some preliminary demands to function as shape memory polymer. Namely, a high glass elastic modulus E'_g (1500 MPa) that renders good shape fixity of the polymer, proper value of the rubber modulus E'_r (15 MPa) that ensures both large deformations in the rubbery state and high elastic recovery at high temperatures, as well as a high ratio of E'_g/E'_r (100) were obtained. The SMP glass transition temperature T_g defined by a midpoint of glass transition temperature region is equal to approximately 25°C.

Table 1. DMA results: values of elastic modulus E'_g, rubber modulus E'_r, T_g and E'_g/E'_r ratio.

Sample	E'_g	T_g (determined as midpoint of glass transition temperature region)	E'_r	E'_g/E'_r
PU-SMP	1500 MPa	25°C	15 MPa	100

The thermomechanical properties, such as the shape fixity and the shape recovery, crucial for the SMP applications, were estimated.

Initial thermomechanical tests were performed for the SMP samples subjected to tension on MTS 858 testing machine in thermal chamber at various temperatures. The loading and unloading rates were 2×10^{-3} s^{-1} and 2×10^{-4} s^{-1}, respectively. The SMP sample temperature was controlled by three thermocouples located at the sample area as well as in upper/lower grips of testing machine.

At first, max. strain (20%) was applied at high temperature $T_h = 45°C$ ($T_g + 20°C$). Next, while maintaining the strain, the sample was cooled down to $T_l = 5°C$ ($T_g - 20°C$) and then unloaded. During the subsequent heating from T_l to T_h under no-load conditions the SMP sample almost recovered its original shape; however a residual strain $\varepsilon_{\mathrm{ir}}$ was recorded. Schematic of the PU-SMP investigation is presented in Fig. 1.

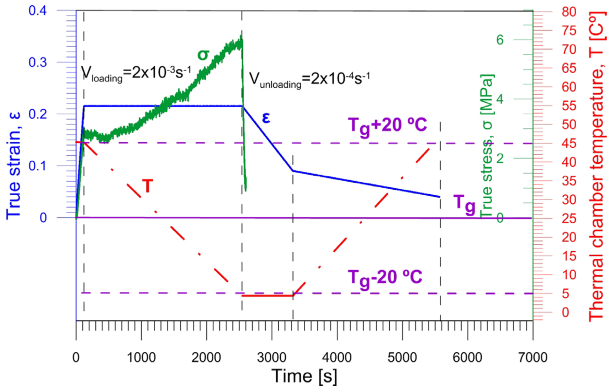

Fig. 1. Schematic of thermomechanical test; strain ε, stress σ and chamber temperature T vs. time.

The shape recovery R_r and shape fixity R_f parameters were calculated by following equations respectively:

$$R_r = \frac{\varepsilon_{\mathrm{max}} - \varepsilon_{\mathrm{ir}}}{\varepsilon_{\mathrm{max}}} \cdot 100\%, \qquad R_f = \frac{\varepsilon_{\mathrm{un}}}{\varepsilon_{\mathrm{max}}} \cdot 100\%, \tag{1}$$

where $\varepsilon_{\mathrm{max}}$ is maximum strain, $\varepsilon_{\mathrm{un}}$ denotes the strain obtained after unloading at T_l and $\varepsilon_{\mathrm{ir}}$ is irrecoverable strain, i.e. strain obtained after heating up to T_h under no-load conditions [1].

An example of estimated shape fixity and shape recovery parameters is presented in Table 2.

Table 2. Example of shape fixity and shape recovery parameters estimated for PU-SMP.

Sample No.	Shape fixity parameter, %	Shape recovery parameter, %
1	97.1	72.1
2	96.9	79.6
3	95.8	83

3. Conclusions

Results of dynamic mechanical analysis confirm the PU-SMP good shape memory properties.

Initial estimation of the PU-SMP application parameters, e.g. shape fixity and shape recovery, carried out at 20% max strain and at temperature range $T_g - 20°C$, $T_g + 20°$, gave reasonable values.

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