10th International Symposium on Mechanics of Materials and Structures

SHAPE MEMORY POLYMER SUBJECTED TO THERMOMECHANICAL LOADING - INVESTIGATION OF APPLICATION PARAMETERS

Maria STASZCZAK*, **Elżbieta PIECZYSKA***, **Leszek URBAŃSKI***, **Ibon ODRIOZOLA****, **Roberto MARTIN****

*Department of Experimental Mechanics, Institute of Fundamental Technological Research Polish Academy of Sciences, 02-106 Warsaw, 5B Pawinskiego Street, Poland
**Materials Division, IK4-CIDETEC Research Centre, Miramon 196, 20009 San Sebastian, Spain

mstasz@ippt.pan.pl, epiecz@ippt.pan.pl, lurban@ippt.pan.pl, iodriozola@cidetec.es, rmartin@cidetec.es

Key words: shape memory polymer, shape fixity, shape recovery, thermomechanical loading program

1. INTRODUCTION

Shape memory polymers (SMP) belong to an important class of new engineering and functional materials. They possess an ability to change its shape in a predefined manner when exposed to a certain stimulus, such as temperature, light, water, pH value, chemical factor. Among various types of SMP, shape memory polyurethane (PU-SMP) can be distinguished due to its good mechanical and shape memory properties, e.g. high strength, low weight, good shape fixity and recovery. The shape memory properties in this polymer are triggered by temperature. The temperature at which the polymer returns to the original shape is usually its glass transition (T_g) or transition temperature (T_{trans}) (Hayashi, 1993; Huang et al., 2012, Pieczyska et al., 2017).

This paper presents results of investigation of application properties of new shape memory polyurethane, designed and fabricated by the author within her fellowship KMM-VIN program, conducted in IK4-CIDETEC, San Sebastian, Spain. The new functional polymer, characterized by transition temperature T_{trans}≈100°C, was based on trifuctional polyurethane 6000 (PU6000) and difunctional polyurethane 4000 (PU4000).

The mechanism of shape memory effect occurring in the new shape memory polyurethane is illustrated schematically in Fig. 1: initial shape - in Fig. 1a, changed shape as a result of loading at temperature above the transition temperature - in Fig. 1b, fixed temporary shape in Fig. 1c, while recovered initial shape - in Fig. 1d.

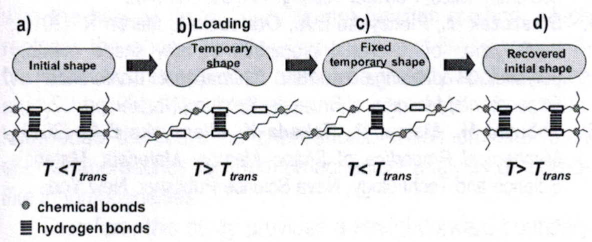

Fig. 1. Scheme illustrating the mechanism of the shape memory effect in new polymer with T_{trans}≈ 100°C

The particular elements of the polymer structure are connected by chemical and hydrogen bonds. At transition temperature T_{trans} the hydrogen bonds are destroyed, while new hydrogen bonds are formed in other places, which makes it possible to change the polymer shape (Fig. 1b). During cooling down to room temperature the temporary shape is fixed (Fig. 1c). Subsequent heating to temperature above T_{trans} of the SMP is responsible for returning of the polymer to its original shape (Fig. 1d).

2. EXPERIMENTAL PROCEDURE

Four fabricated kinds of the PU-SMP samples, characterized by T_{trans}≈100°C and various content of the PU6000 and PU4000 (Tab. 1), were subjected to a thermomechanical loading program in order to estimate their shape memory properties.

Tab. 1. Proportional composition of obtained polymer samples

Sample	Content of trifuctional PU6000, %	Content of difunctional PU4000, %
PU100:0	100	0
PU80:20	80	20
PU60:40	60	40
PU40:60	40	60

Scheme of the loading program is presented in Tab. 2.

Tab. 2. Scheme of thermomechanical loading program performed for PU-SMP

Preliminary stage	I	II	III	IV	V
Heating up to T_h = T_{trans} + 20°C = 120°C	Loading at T_h = T_{trans} + 20°C = 120°C up to ε_m	Cooling down to T_l= 20°C	Maintaining 30 min at T_l=20°C	Unloading to 0 N at T_l= 20°C	Heating up to T_h= T_{trans} + 20°C =120°C
T ↑	F ↗	T ↓	→	F ↘	T ↑

The investigation was performed in thermal chamber on MTS 858 testing machine. At first, maximum strain (≈100 %) was applied at high temperature T_h =120°C (T_{trans}+20°C). While maintaining the strain, the sample was cooled down to low temperature T_l (20°C). After holding at T_l for 30 min, the sample was unloaded at T_l. Then the sample was heated up again to T_h (120°C) under no-load conditions in order to recover its original shape. The SMP loading and unloading was conducted with strain rate of $5{\cdot}10^{-3}s^{-1}$ (Staszczak et al., 2018).

3. RESULTS AND DISCUSSIONS

Examples of the obtained results of PU60:40 and PU40:60 are presented in Fig.1. The strain ε in function of time gained during thermomechanical loading program carried out for sample with ratio of 60% PU6000-40%PU4000 is shown in Fig. 1a and of 40% PU6000-60%PU4000 - in Fig. 1b.

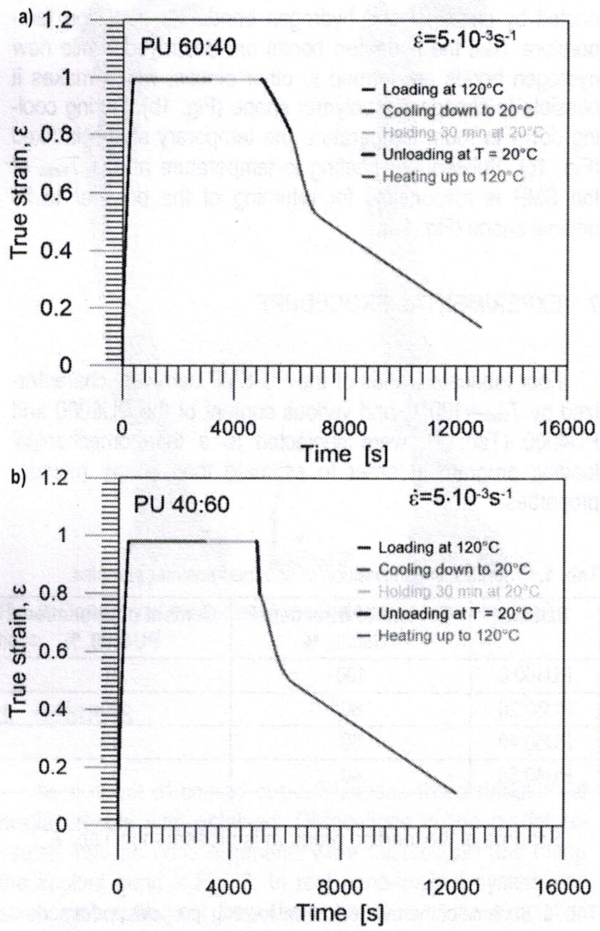

Fig. 2. Strain ε vs. time obtained during thermomechanical loading program for sample with ratio of: a) 60% PU6000: 40%PU4000 and b) 40% PU6000: 60%PU4000

Samples PU100:0 and PU80:20 were destroyed in the gauge length during first heating to 120°C or loading at 120°C, so they were not included in further analysis.

Taking into account the experimental data and using equations, proposed by H. Tobushi and S. Hayashi (Tobushi et al., 2013), the SMP functional parameters - shape fixity R_f and shape recovery R_r, were calculated:

$$R_f = \frac{\varepsilon_{un}}{\varepsilon_m} \cdot 100\%, \; R_r = \frac{\varepsilon_m - \varepsilon_{ir}}{\varepsilon_m} \cdot 100\% \qquad (1)$$

where: ε_m - the maximum strain; ε_{un} - the strain obtained after unloading at T_l, ε_{ir} - the irrecoverable strain, i.e. the strain gained after the SMP heating to T_h under no-load conditions.

The average value of the shape fixity parameter R_f for PU60:40 is about 80%, while the average value of the shape recovery parameter R_r is ≈ 85%. The average value of the shape recovery parameter R_r for PU40:60 is almost the same as for PU60:40, i.e. ≈ 85%, while the average value of the parameter R_f is a little higher - about 84%.

So, it can be concluded that both PU-SMP samples, i.e. with 60% P6000-40% PU4000 and 40% PU6000-60% PU4000, exhibit good shape fixity of temporary shape and good shape recovery to its original shape.

4. CONCLUSIONS

A new shape memory polyurethane with T_{trans} ≈ 100°C was designed and investigated by thermomechanical loading program.

The important functional parameters of the shape memory polyurethane, crucial for its applications, have been estimated quantitatively within the thermomechanical loading program. It was observed that if the PU-SMP sample deformed above the transition temperature is cooled down to room temperature, the deformed shape is fixed. The original shape is recovered markedly when the PU-SMP sample is heated again to temperature above T_{trans} under no load.

The obtained results confirmed good shape memory properties, such as shape fixity and shape recovery, of samples PU60:40 and PU40:60 with 60% trifuctional P6000-40% difunctional PU4000 and 40% trifuctional PU6000-60% difunctional PU4000.

REFERENCES

1. **Hayashi S.** (1993), Properties and Applications of Polyurethane-series Shape Memory Polymer, *Int. Progress in Urethanes*, Vol. 6, 90-115.
2. **Huang W.M., Young B. and Fu Y.Q.** (2012), *Polyurethane Shape Memory Polymers*, CRC Press Taylor & Francis Group, Boca Raton.
3. **Pieczyska E.A., Staszczak M., Kowalczyk-Gajewska K., Maj M., Golasiński K., Golba S., Tobushi H., Hayashi S.** (2017), Experimental and numerical investigation of yielding phenomena in a shape memory polymer subjected to cyclic tension at various strain rates, *Polymer Testing*, Vol. 60, 333-342.
4. **Staszczak M., Pieczyska E.A., Odriozola I., Martin R.** (2018), Investigation of functional properties of new shape memory polymer, *Proceedings of 18th International Conference on Experimental Mechanics*, Brussels, Belgium, No.199, pp.1-2
5. **Tobushi H., Matsui R., Takeda K., Pieczyska E.A.** (2013), *Mechanical Properties of Shape Memory Materials*, Materials Science and Technology, Nova Science Publisher, New York.

Acknowledgments

The research has been carried out with the support of the KMM-VIN Research Fellowship (Call 6) and the Polish National Centre of Science under Grant No. 2014/13/B/ST8/04280.