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THE EFFECT OF SHAPE MEMORY BEHAVIOR ON THE MICROSTRUCTURE OF THE PU-SMP (T_g = 45°C)

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1. Abstract

In this study, the mechanical deformation and shape recovery of the polyurethane shape memory polymer (PU-SMP) with T_g of 45°C are investigated from the microscopic point of view. For this purpose, the influence of the shape memory effect on the microstructure of the PU-SMP was studied by Scanning Electron Microscope (SEM) and Differential Scanning Calorimetry (DSC). The results proved that the macroscopic deformation and recovery of the PU-SMP are resulted from the microstructure changes induced during the loading, and further thermal shape recovery processes.

2. Introduction

Shape memory polymers (SMPs) are stimuli-responsive materials that have attracted great attention as smart materials due to their high shape recovery characteristics. The SMP is capable of recovering the original shape, which is changed by mechanical loadings by exposing the SMP to an external stimulus, such as heat. Polyurethane shape memory polymers are especially distinguished owing to their good shape memory and high mechanical properties [1]. The mechanical deformation of the PU-SMP specimen and shape recovery of the original shape are resulted from the microstructural changes and mechanical reinforcement during the tension and stress relaxation during the heating [2]. In this study, the effect of one and five cycles of tensile loading-unloading and thermal shape recovery on the microstructure of the PU-SMP with *Tg* of 45˚C are studied, by using SEM and DSC analysis.

3. Materials and characterization methods

The investigation was conducted on the PU-SMP with T_g of 45˚C, produced by the *SMP Technologies Inc.*, Tokyo, Japan. The tensile mechanical loading program of PU-SMP was conducted by INSTRON 5969 testing machine at room temperature. The cycles of the loading were performed with strain rate of 10^{-2} s^{-1} within the strain range of 0.33. The DSC measurement was carried out by power-compensation calorimeter Pyris1 DSC (Perkin-Elmer., USA) the samples were heated from -20°C to 200°C, at the rate of 10 K/min. SEM investigation of the PU-SMP surface was conducted using a scanning electron microscope JEOL JSM-6390LV. Before the measurement the samples were sprayed with 8 nm layer of gold in order to obtain a better conductivity.

4. Results and discussion

The SEM images of the specimen surface under tension in 5 states are presented in Fig. 1. Fig. 1a represents the surface roughness of the PU-SMP specimen before the loading. Fig. 1b shows the formation of the micro-cracks in the direction of the loading on the surface of the same specimen after one cycle of tensile mechanical loading-unloading at room temperature. As seen in Fig. 1c, the surface of the specimen looks smooth without the presence of micro-cracks after the thermal shape recovery at the temperature above T_g (T_g+15°C). Therefore, besides macroscopic shape recovery of the deformed specimen by heating, the defects are also healed in the microscopic point of view.

Fig. 1d displays the surface of the specimen after 5 cycles of loading-unloading. Despite the absence of micro-cracks on the surface of the specimen, the effect of strain hardening and orientation in the tension direction is quite visible. Fig. 1e shows the surface of the specimen represented in Fig. 1d after the heating and thermal shape recovery at $T_g + 15°C$. No big difference is noticed between the surface of the specimen before and after the thermal shape recovery in the specimen subjected to five loading-unloading cycles.

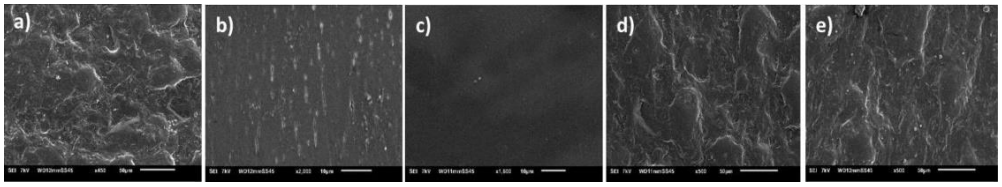

Fig. 1. SEM images of the PU-SMP specimen surface in 5 states: a) before loading b) after one cycle of loading-unloading c) after thermal shape recovery d) after five cycles of loading-unloading e) after thermal shape recovery.

The effect of deformation and shape recovery on the microstructure of the PU-SMP were also investigated by DSC. In order to not change or erase the microstructure of the specimens after the loading, the results obtained during the 1st heat flow were considered. Therefore, the quantity of T_g differs from the given quantity by the producer (45°C). As demonstrated in Fig. 2, all the specimens except of the undrawn one, show the stress relaxation peak right after the T_g step. The second endothermic peak which happens in about 80˚C in all 5 specimens, attributes to melting crystallization (MC) peak. The peak area is increased in PU-SMP1 in comparison with the peak in PU-SMP0 due to strain-induced crystallization. The MC peak is decreased in PU-SMP2 compared to PU-SMP1, because of the shape recovery of PU-SMP1 after the heating. However, there is no huge difference in the MC peaks in PU-SMP3 and PU-SMP4, before and after shape recovery when the specimen is deformed in a cyclic deformation.

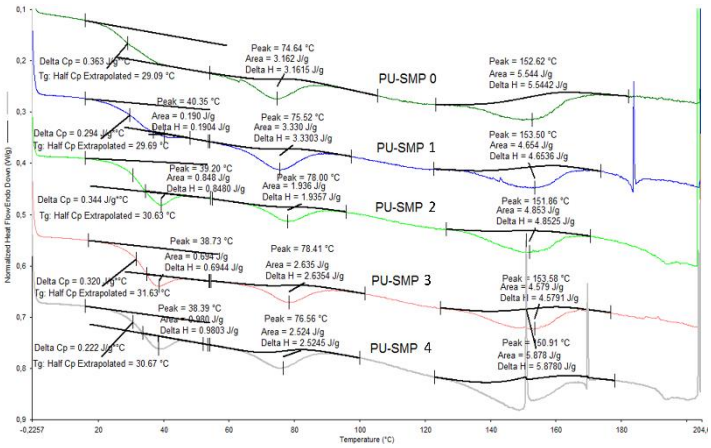

Fig. 2. DSC measurement of the PU-SMP specimen in 5 states: a) before loading (**PU-SMP0**) b) after one cycle of loading-unloading (**PU-SMP1**) c) after shape recovery (**PU-SMP2**) d) after five cycles of loading-unloading(**PU-SMP3**) e) after shape recovery (**PU-SMP4**)

5. Conclusion

In this study it was demonstrated that, the macroscopical shape memory behavior of the PU-SMP subjected to loading, is resulted from the microstructure changes that occur during the deformation and shape recovery, namely the strain-induced crystallization, melting crystallization and healing effects.

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6. References

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