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SHAPE MEMORY ALLOYS AND POLYMERS STUDIED IN TENSION BY ADVANCED INFRARED TECHNIQUE

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1. Introduction and methods

In order to contribute to solving the problems of recourses, energy and environment of the earth, the development of multifunctional smart materials is required. In the intelligent materials, investigation of shape memory alloy (SMA) and shape memory polymer (SMP) has attracted high attention due to their functional properties and high potential in practical applications. In SMA, the shape memory property appears based on the martensitic transformation (MT) in which the crystal structure varies depending on the variation in stress or temperature [1]. In SMP, the elastic modulus and the yield stress are high at temperatures below the glass transition temperature T_g and low at temperatures above T_g. The shape memory property appears based on the glass transition in which the characteristics of molecular motion vary depending on the variation in temperature. Among the shape memory polymers, the polyurethane has been most often practically used [2, 3].

In this paper, investigation of stress-induced martensitic transformation in TiNi SMA and thermomechanical behavior of SMP (T_g = 19 °C) in tension at room temperature (≈22°C) are presented.

2. Experimental procedure

Shape memory materials were subjected to strain-controlled tension tests with various strain rates on Instron and MTS Testing machines. During the loading process, the infrared radiation from the specimens surface was recorded by fast (538 Hz) and sensitive (0.025 K) Phoenix infrared camera. The stress and strain quantities were related to the current values of the specimen cross-section, obtaining true stress and true strain values.

3. Shape memory alloys – Infrared imaging

Since the forward MT is exothermic whilst the reverse one exhibits endothermic property, the thermovision camera turned out to be very useful for investigation of SMAs. Infrared imaging of nucleation and evolution of macroscopic transformation bands, related to martensite forward (a) and reverse (b) transition is shown in Fig. 1.

a) Loading b) Unloading

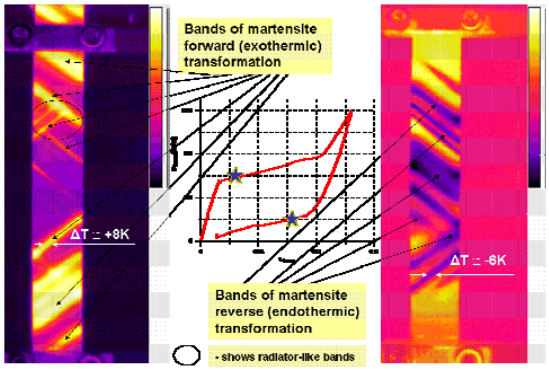

Fig. 1. Infrared imaging of transformation bands developing during a) loading and b) unloading of SMA.

At the certain level of the stress and strain state, the temperature starts to grow, indicating the homogeneous nature of the initial transformation process [5, 6]. At higher strains, inclined bands of higher temperature (ΔT≈8 K) are observed, starting usually in the specimen grip areas and developing towards the specimen center. They were called transformation bands or Luders-like deformation [6]. In the course of the SMA unloading, the specimen temperature decreases significantly and bands of lower temperature (ΔT ≈ - 6 K) nucleate, always from central part of the specimen [6].

4. Shape memory polyurethane - Effects of thermomechanical couplings.

Stress σ and temperature change ΔT versus strain obtained for SMP tensile test performed with various strain rates till rupture are presented in Fig. 2. The elongation limit of the SMP is over 180 % in case of true strain. The SMP turned out to be very flexible and it was not so easy to deform it till rupture. One can notice looking at Fig. 2 that the SMP exhibits a smooth, hardening-like behaviour at all the tested strain rates applied. This is probably a result of the reorientation of the polyurethane molecular chains that induces crystallization in the polymer structure [2, 3]. The higher strain rate, the higher temperature changes were obtained, since the process of the loading was more close to adiabatic conditions.

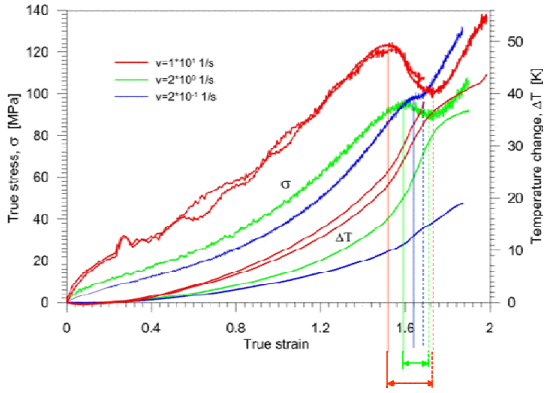

Fig. 2. Stress σ and temperature change ΔT versus strain for SMP tension with various strain rates.

At higher strains, a maximum of stress was recorded, especially pronounced at higher strain rates. Next, the stress drops are observed, followed by its increase, leading to the sample necking and rupture. The maximal temperature changes of the SMP, accompanying the specimen rupture, were quite significant; 18 K for $2x10^{-1}s^{-1}$, 38 K for $2x10^{0}s^{-1}$ and 44 K for $10^{1}s^{-1}$ of strain rate.

Stress and temperature changes related to particular stages of the SMP loading, namely the stress peak and the stress of the specimen rupture, are shown in Table 1.

Strain rate	Stress peak [MPa]	Temp. change str. peak [K]	Stress rupture [MPa]	Temp. change str. rupt. [K]
$2x10^{-1}s^{-1}$	128	25	139	44
$2x10^{0}s^{-1}$	100	20	132	38
$1x10^{1}s^{-1}$	102	14	108	18

Tab. 1. Stress and temperature changes related to the SMP stress peak and the specimen rupture.

5. Concluding remarks

- The obtained results emphasize high sensitivity and usefulness of the infrared camera to study the effects of thermomechanical couplings in shape memory alloys and shape memory polymers.
- Stress-induced martensitic transformation develops in TiNi SMA in tension via narrow bands of higher temperature. Nucleation of the localized martensitic forward transformation in shape memory alloy takes place either in the stress-concentrated area of the specimen grip or in any other area, whereas the reverse transformation always initiates in central part.
- The elongation limit of the shape memory polyurethane is over 180 % in the case of true strains. The higher strain rate, the higher temperature changes were obtained, since the process was more close to adiabatic conditions.

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