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INVESTIGATION OF MECHANICAL AND THERMOMECHANICAL EFFECTS IN SHAPE MEMORY ALLOY DURING TRANSFORMATION-INDUCED CREEP PHENOMENA

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1. Introduction

An interruption of the loading, due to the accidents or a shortage of energy supply, is a situation that needs to be studied to anticipate the behavior of devices made of Shape Memory Alloys (SMA) such as sensors or actuators.

Recent research on this topic, e.g. Matsui et al. [1], Pieczyska et al. [2], considered that the strain-controlled loading interruption during the SMA tension, when the strain was kept constant, leads to the stress relaxation in the loading branch of the curve, and the stress increase in the unloading one.

According to the force-controlled tensile loading Pieczyska [3] presented procedure of experimental investigation of the force-controlled tensile loading of the TiNi SMA and studied the state and progress of the stress-induced transformation based on the temperature variation, captured by infrared camera. It was demonstrated that the nature of the SMA temperature change can manifest the current stage of the phase transformation.

Takeda et al. [4] investigated transformation-induced stress relaxation and recovery in TiNi SMA They concluded that for the higher loading rates, a loading break gave higher stress variation resulting in high thermo-sensitivity of the SMA.

The general assumption is that deformations in any material occur immediately after the application of the loading. The creep behavior in steel has been described as a time-dependent inelastic deformation which induces development of the permanent strains with time [5]. In the case of SMA, the inelastic deformations results mainly from martensitic transformation. So, the occurrence of deformation in SMA while keeping the loading constant can be classified as creep-like deformation.

A goal of the research is to investigate a creep-like deformation in TiNi SMA. To this end, the modified tensile loading program was conducted under the loading force kept constant at various stages of the stress-induced transformation (SIMT). The thermo-mechanical coupled numerical analysis using the finite element method (FEM) was engaged and the creep-like phenomena were analyzed.

2. Experimental procedure and results

The TiNi SMA belt specimens of the sizes 160 × 10 × 0.40 mm and constitution Ti-55.3 wt% Ni produced by the Furukawa Electric Co. in Japan were subjected to force-controlled tensile loading at room temperature on Instron 5867 testing machine. Its austenite finish temperature A_f was ≈283 K. The stress rate of the loading and unloading process was 12.5 MPa s^{-1}. The fast and sensitive infrared camera (IR) Therma CAMtm FLIR Co. was used to record the infrared radiation from the specimen surface during the loading and estimate mean temperature of the SMA specimen for each instant of the straining with high sensitivity (0.02 K). The scheme of the experimental setup is presented in Fig. 1.

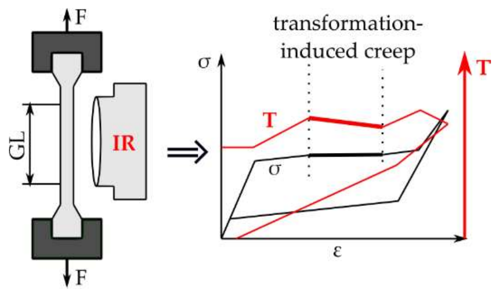

Fig. 1. Scheme of the experimental set-up for creep-like phenomena in SMA.

A difference between the mean value of temperature $T_{mean}(t)$ calculated for the gauge part of the specimen and the mean temperature of the same area before the deformation $T_{mean}(t_0)$ was obtained.

The modified process of the TiNi SMA loading proposed in the experiment was conducted according to three different programs (1)–(3) (Fig. 2), i.e., the loading force was kept constant around 3 minutes at various stages of the localized martensitic transformation stage (LMT), monitored by infrared camera by thermograms (Th.):

- Program 1 - at the beginning of the LMT (Th. 1)
- Program 2 - in the middle of the LMT (Th. 2)
- Program 3 - at the end of the LMT (Th. 3).

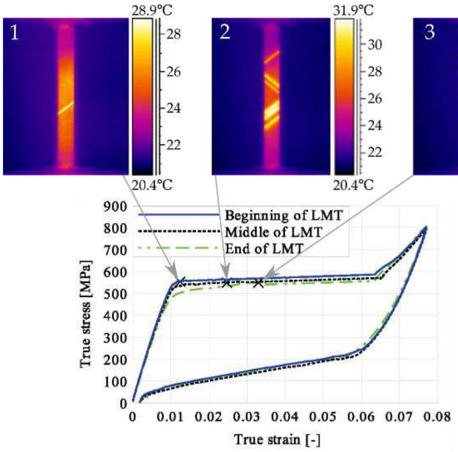

Fig. 2. Stress–strain curves of TiNi SMA; the marked points correspond to the thermograms 1, 2 and 3.

The obtained experimental (I) and numerical (II) results for TiNi SMA tension with 3-min loading interruption are compared in Fig. 3.

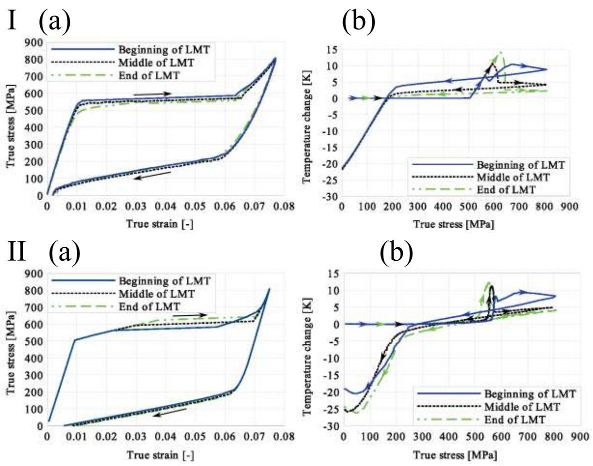

Fig. 3. Comparison of the experimental (I) and numerical (II) data for TiNi SMA tension with 3-min loading interruption induced at the beginning (1), middle (2) and end (3) of LMT: (a) stress vs. strain; (b) temperature change vs. stress.

It was confirmed by both experiment and model that thermo-mechanical coupling introduces significant influence on the transformation-induced creep phenomena in the TiNi SMA. Measuring temperature variations, accompanying the process, led to much better recognition of the phase transformation in the SMA than the mechanical characteristics. The lower temperature increase, observed during the reloading after the loading pause, pointed on the higher saturation of the martensitic transformation process during the pause.

3. Conclusions

The stress and related temperature changes demonstrated how the transformation-induced creep process started and evolved at various stages of the TiNi SMA tension loading.

The proposed model reproduced the stress, strain and temperature changes obtained during the experiment well; the latent heat production was in correlation with the amount of the martensitic volume fraction. It was demonstrated how the transformation-induced creep process occurring in the SMA under such conditions was involved in thermo-mechanical couplings and the related temperature changes.

Acknowledgements

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