THERMOMECHANICAL COUPLING AND TRANSFORMATION-INDUCED STRESS-RELAXATION EFFECTS IN TiNi SHAPE MEMORY ALLOY

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Summary Thermomechanical coupling effects accompanying SIMT in TiNi SMA were studied during tension with imposed breaks. At the advanced stage of the martensitic forward/reverse transformation, a strain level was kept constant during 3 min. while the current load and the specimen temperature were recorded continuously. Stress and temperature drop significantly during the induced loading breaks. Using IR system, we recorded as a film the nucleation and development of multidirectional transformation bands.

RESULTS AND DISCUSSION

Belt type specimens of TiNi shape memory alloy (SMA) (55.3 wt.% Ni) characterized by A_f =283K were subjected to tension at room temperature with a strain rate of $5x10^{-2}s^{-1}$ and within a strain range of 8%. The latent heat released in the specimen due to the stress-induced martensitic transformation (SIMT) at this strain rate raises the specimen temperature. It is followed by an increase of the stress value required to develop the transformation. Similar phenomena, though in opposite direction, are observed for the reverse transformation, since the stress-induced martensitic forward and reverse transformations are exothermic and endothermic, respectively [1-5]. On this basis, two approaches were applied to investigate transformation-induced stress-relaxation effects in the SMA. Namely, during loading/unloading process, after attaining the strain value of 4%, the strain level was kept constant during 3 min. while the load was measured and the infrared radiation was recorded by a very fast and sensitive infrared camera (IR). The true strain, true stress and average temperature variations of the specimen were calculated [4, 5]. The obtained results are presented in Fig. 1. Before the loading break, the mechanical and the temperature curves reveal a typical behavior: the stress and the temperature increase during the loading and decrease during the unloading [4, 5, 8]. Due to the loading break, for both tests monotonic stress drops of 170 MPa and 80 MPa were obtained, respectively. The specimen temperature also drops monotonically by 14 K on the loading and by 13 K on the unloading branch. Once the unloading process is completed, the specimen temperature drops by about 10 K below its initial temperature (Fig. 1b). The observed effects were discussed in terms of the thermomechanical coupling and microstructure evolution, related to the SIMT.

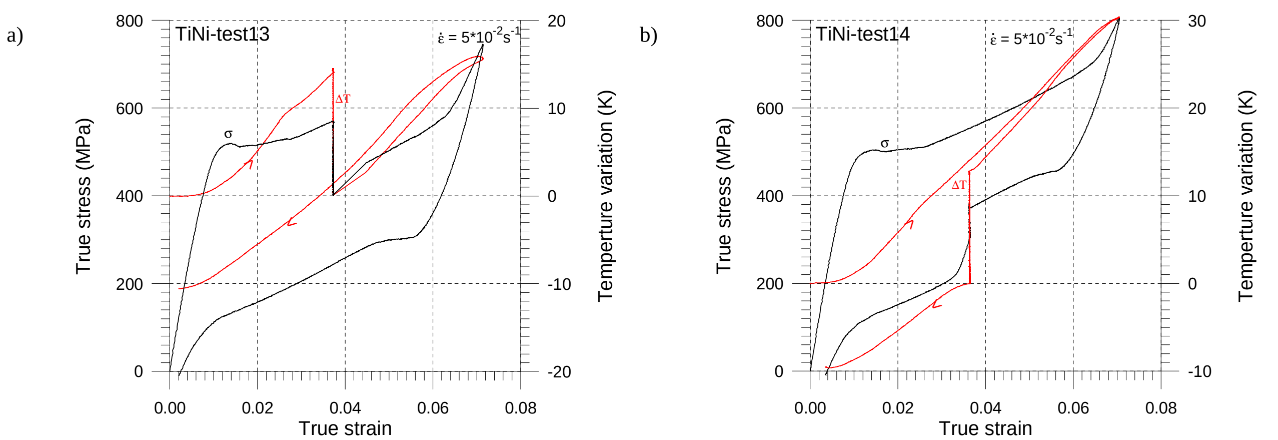

Fig. 1. Stress and average temperature changes vs. strain for TiNi SMA with stress relaxation breaks induced in branch of a) loading, b) unloading

Stress and average temperature changes vs. strain curves recorded for TiNi SMA subjected to complete loading-unloading tension cycle at strain rate $10^{-2}s^{-1}$ and strain range 8% accompanied by infrared imaging of macroscopic transformation bands, are presented in Fig. 2. Before the tension started, the specimen temperature was uniform and equal to the ambient temperature (1st thermogram). At a certain level of the stress and strain state, the specimen temperature starts to grow slowly, however its thermal image remains uniform, indicating the homogeneous nature of the initial phase transformation process (2nd thermogram). At higher strains, inclined at approximately 48° bands of significantly higher temperature (of about 8 K) are observed, appearing in the specimen grip areas and developing in two almost perpendicular directions towards the specimen center (thermograms 3-7). They are also called transformation bands or Luders-like deformation [3-7]. As the strain grows, the bands gradually widen and overlap. The average specimen temperature change increases very fast due to the instantaneous heat production related to the exothermic martensitic transformation, for this strain rate up to 40 K. Moreover, due to the overlapping effects the specimen thermal image becomes more uniform at this advanced transformation stage (thermograms 8-9). In the course of the SMA unloading, the specimen temperature decreases. Bands of significantly lower temperature are developed (thermograms

10-16). The bands also develop in two directions and are inclined by a slope similar to the one observed during the martensitic forward transformation. For the first time, at the stage of advanced martensitic both forward and reverse transformation, a new generation of much thinner transformation bands is observed. They appear to nucleate in regular distances from the formerly developed wider bands, creating "radiator-like" effects (13^{th} thermogram).

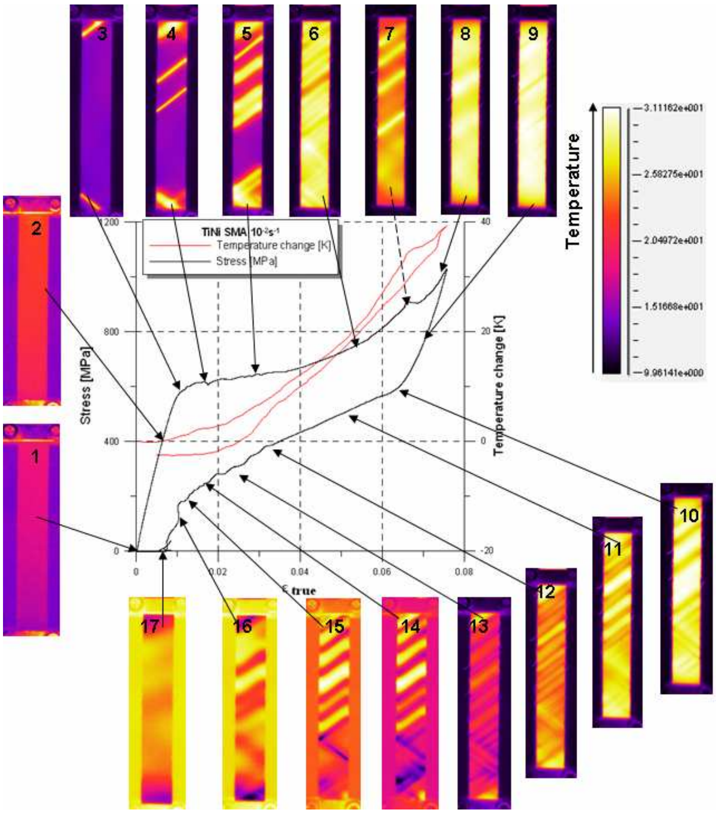

Fig. 2. Stress and temperature changes vs. strain curves obtained for TiNi SMA specimen during tension at strain rate $10^{-2}s^{-1}$. Thermograms show in infrared a nucleation and evolution of macroscopic transformation bands, related to martensite forward and reverse transformation.

CONCLUSIONS

We have used a high-performance infrared camera to study the thermomechanical coupling of both stress-relaxation effects and martensitic transformation inhomogeneity, accompanying stress-induced transformation in TiNi SMA. We have found that stress-relaxation effects occur in the alloy due to the martensitic transformation. During the reloading processes, the transformations develop starting at lower stress levels on both forward and reverse branches. We have observed nucleation of the initial macroscopically uniform transformation and development of the transformation bands consistent with the work of other researchers, however, for the first time the stress-induced multidirectional bands were presented.

Acknowledgments

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