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ADVANCES IN INVESTIGATION OF THE NUCLEATION AND PROPAGATION OF PHASE TRANSITIONS IN A TINI SHAPE MEMORY ALLOY

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Infrared thermography (IT) is a novel way to investigate the nucleation, developing and the further evolution of the phase transformation fronts in shape memory alloys (SMAs) subjected to loading and showing, so called, pseudoelasticity or shape memory effect. Shape memory materials indicate the ability to remember their shapes after deformation up to 8% in the case of the shape memory alloys and even much higher, in the case of shape memory polymers. SMAs, e.g.TiNi, demonstrate two interesting behaviors: shape memory effect and superelasticity. When the shape memory material can be seemingly permanently mechanically deformed at a temperature below a certain transition temperature and revert to its original shape after heating at the temperature above the phase transition temperature, it is called a shape memory effect. Such phenomena can be applied to medicine, stomatology as well as during the design of robots, solid-state heat engines, etc. Pseudoelasticity is the ability of material to be strained much above the elastic limit and return to its initial shape during unloading, showing a hysteresis loop. Such features like nonlinear elastic behavior, high yield stress or significant internal damping lead to increasing application of these materials to actuators, damping elements or other “smart” structures. Since the elements are working in various conditions, the thermomechanical properties of the shape memory materials are very important. Experimental studies of the phenomena of initiation and kinetics of phase transformation fronts were discussed in Shaw and Kyriakides [1], Shaw [2], Tobushi et al. [3,4] and others. It was shown experimentally that when the SMA is tested below temperature A_f or above M_d, the temperature distribution measured on the surface of specimens is uniform, what indicates the homogeneity of the phase transformation process. Deformation at temperature $A_f < T < M_d$ leads to heterogeneous field of temperature; it was pointed out that the nucleation and further development of the martensitic transformation is no homogeneous. Nevertheless, the phenomena of the origin and further development of the new phase is still a subject of current studies. The attention of the present paper is focused on the aid provided by IT for investigation of the process of nucleation and propagation of the phase transitions in a TiNi SMA. Taking advantages of the SMA produced by Furukava Co with the A_f (austenite finish) temperature below the room temperature and Flir Co infrared camera Therma-Cam™ PM 695, the detailed monitoring of the martensite and austenite phase transitions were performed. The sheet samples of TiNi SMA: 160 x 10 x 0.4 mm, were subjected to strain controlled tensile test, with the strain rate $10^{-2}s^{-1}$(Fig.1). In order to assure the higher and uniform homogeneity the specimen was covered by a carbon powder. The obtained images of the temperature distributions were stored for further analysis; such approach enables to observe, register and analyze the kinetics, thermodynamics and thermomechanical couplings that occur during the phase transitions (Fig. 2). It can be observed that just after the uniform temperature distribution registered in the elastic range, the temperature slightly increases in the central area of the sample which is followed by the sudden occurrence of the first, inclined line of significantly higher temperature (Fig. 2a), probably related to the nucleation of the new, martensite phase. After a while, a few such lines parallel to each other occur towards the sample borders, as well as the next "family" of them, developing in the perpendicular direction (Fig. 2b). As the strain grows, the regions of higher temperature became less clearly defined (Fig. 2c), most likely because of the further martensite phase developing in the whole volume of material and the heat flow. When the martensitic transformation is completed, the temperature of the specimen surface becomes almost homogeneous again.

The heterogeneous field of temperature distribution has been observed also during the unloading of TiNi SMA, while the reverse transformation takes place (Fig. 2d), which was surprising in comparison to the previously obtained results [5].

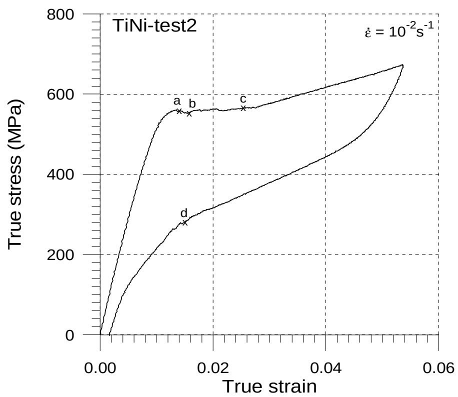

Fig. 1. Stress-strain curve under strain controlled conditions of SMA

The martensitic transformation process during loading of TiNi is accompanied by significant increase in temperature, up to 30 K in some area. During unloading, as a result of the reverse transformation (martensite into austenite), the temperature of the specimen falls down with the drop up to 5 K below the initial state. This thermomechanical behavior of SMA reflects the exothermic character of the austenite into martensite transformation and endothermic character of the reverse one. However, the mechanisms of stress induced phase transitions are still not recognized quite well and require further studies, also under a stress controlled tensile tests.

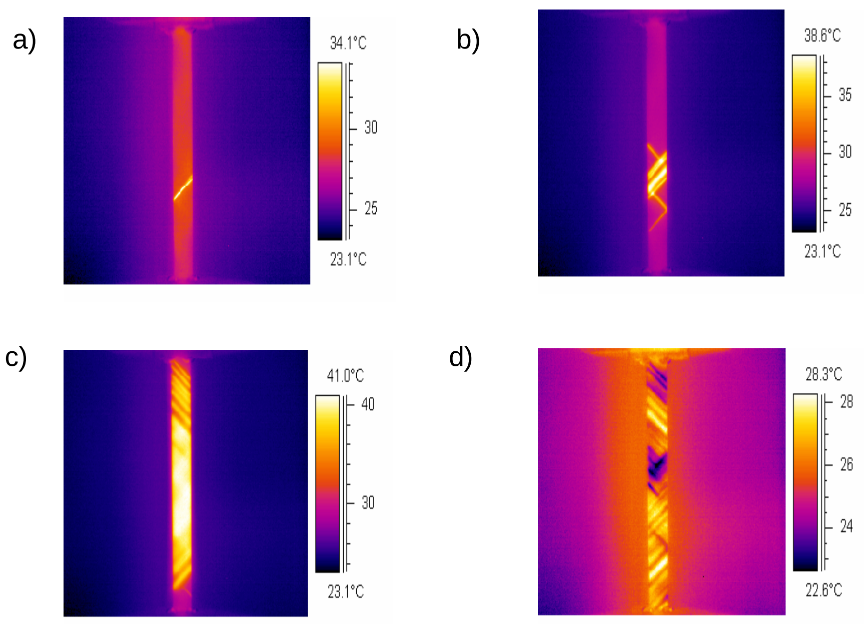

Fig. 2. Thermograms showing the temperature distribution on the surface of NiTi specimen subjected to uniaxial tensile test at room temperature. The numbers correspond to the proper points at the stress-strain curve shown in Fig.1; a, b, c – during martensite transformation, d – during the reverse transformation.

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