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Thermomechanical investigation of TiNi shape memory alloy and PU shape memory polymer subjected to cyclic loading

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Abstract

In applications to sensors, actuators, guide wires, special grips for handicapped people, a shape memory alloy (SMA) or shape memory polymer (SMP) are used as working elements that perform cyclic motions. In order to evaluate the reliability of the shape memory materials (SMM), cycling and fatigue deformation properties are investigated. Since the SMM are very sensitive to temperature, not only mechanical properties but also their related temperature changes accompanying the deformation process should be taken into account. The presented paper embraces experimental investigation of effects of thermomechanical couplings occurring in shape memory alloy and shape memory polymer subjected to various kinds of cycling loading. The deformation was carried out on MTS 858 Testing machine. The strain was measured by a mechanical extensometer, so the stress-strain characteristics were elaborated with high accuracy. Furthermore, a fast and sensitive FLIR Co Phoenix infrared (IR) measurement system was used in order to record infrared radiation from the sample surface. It enables obtaining temperature distribution of the sample as a function of the deformation parameters. For each strain cycle, an increase in temperature during the loading and the temperature decrease during the unloading processes was observed. It was found that the temperature increment recorded during the cyclic deformation depends on the strain rate, the kind of the material and the test conditions. The higher the strain rate the higher the stress and temperature changes were obtained, since the deformation process was more dynamic and has occurred in almost adiabatic conditions. It was shown that various deformation mechanisms are active during various loading stages.

Keywords: shape memory alloy, shape memory polymer, cyclic deformation, thermomechanical coupling, infrared camera

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1. Introduction

In the intelligent materials, investigation of shape memory alloys and shape memory polymers has attracted high attention due to their shape memory properties and huge potential in practical applications. In SMA, the shape memory property appears based on the reversible martensitic transformation in which the crystal structure varies depending on the variation in stress or temperature [1-3]. In SMP, the shape memory property appears based on the radical difference of its elastic modulus and yield point below and above the glass transition temperature T_g: the elastic modulus is high at the temperature below and low at temperatures above T_g. Such behavior is caused by a significant change of the molecular motion of the polymer chains below and above T_g temperature [1, 4]. Among the polymers, the polyurethane has been most often practically used due to its good mechanical and shape memory properties [4-6]. The goal of this research is an experimental investigation of mechanical properties and thermomechanical couplings in TiNi shape memory alloy and shape memory polyurethane subjected to cyclic tension. The scheme of the experimental set-up is shown in Fig. 1a, whereas an infrared image of the sample in grips of the testing machine in Fig. 1b. A rectangular area marked on the sample has denoted chosen area for calculation of the average temperature. The average sample temperature obtained in this manner presented vs. stress, strain or time is shown in diagrams (Figs 3-6) [2, 3, 9].

a) b)

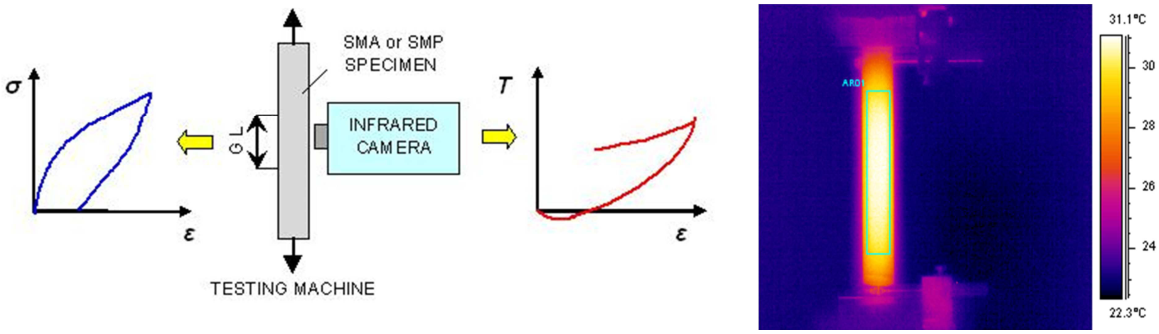

Fig. 1. a) Scheme of experimental set-up used for investigation of thermomechanical properties of shape memory alloys and polymers; b) Thermogram showing rectangular for calculation the average temperature of the sample.

2. Investigation of thermomechanical couplings in TiNi Shape Memory Alloy subjected to cyclic tension loading

Cyclic tension loading of the shape memory alloy was carried out on TiNi belts of the size 160x10x0,4 mm at room temperature, above the alloy A_f (austenite finish) temperature, so in terms of the SMA pseudoelastic behavior [1]. Stress-strain curves obtained for 10 loading-unloading cycles with strain rate $10^{-2}s^{-1}$ are presented in Fig. 2. One can notice that at the strain equal to approximately 1.5%, a material "yielding" caused by the stress-induced martensitic transformation (SIMT) is observed, starting with waving part of the stress-strain curve recorded on the stress level of 540 MPa. The observed waving of the curve is related to the nucleation and development of the localized martensitic transformation [2, 3]. At larger strains, a much smoother stress-strain curve is observed; however significantly inclined, which was caused by the increase of the sample temperature due to the exothermic martensitic forward transformation and the SMA loading with such a high strain rate. In the second loading cycles, the stress level at which the transformation starts decreases; however the values of the stress decrements are getting smaller in the subsequent loading cycles. It means that thermodynamic conditions of the SIMT are stabilizing. On the other hand, the residual strains increases with each cycle of the SMA loading, which is caused by accumulation of the micro-structural defects and increasing amount of the residual martensite in the subsequent loading-unloading cycles (Fig. 2).