ELSEVIER

Materials Science and Engineering A286 (2000) 298–311

MATERIALS SCIENCE & ENGINEERING A

Recovery stress generation in shape memory $Ti_{50}Ni_{45}Cu_5$ thin wires

P. Šittner [a,*,1], D. Vokoun [b], G.N. Dayananda [b], R. Stalmans [b]

[a] *Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 182 21 Prague 8, Czech Republic*
[b] *Department of Metallurgy and Materials Engineering, Katholieke Universiteit Leuven, De Croylaan 2, B-3001 Heverlee, Belgium*

Received 5 November 1999; received in revised form 28 January 2000

Abstract

The recovery stresses evolving in constrained $Ti_{50}Ni_{45}Cu_5$ (at.%) shape memory wires were investigated in thermomechanical experiments performed in combination with electric resistance measurements. The hysteretic stress–temperature responses of the wires in constrained thermal cycles were analyzed by comparing the experimental results with simulated responses using a phenomenological algorithm developed for prediction of uniaxial thermomechanical SMA behaviors. The effects of individual SMA material parameters, constraint parameters, test boundary conditions and thermomechanical history on the evolution of recovery stresses in SMA wires are predicted. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Martensitic transformation; Shape memory alloy; Recovery stress; Hysteresis modelling

1. Introduction

Recovery stresses generated by shape memory alloys (SMAs) deformed in the martensitic state and subsequently heated with constrained shape are, besides the pseudoelasticity and shape memory effects, the most useful and unique property of these materials. It is a basis on which many very successful commercial SMA applications have been designed [1]. Since the ability to generate large recovery stresses does not decrease with decreasing dimensions of the SMA element, this unique property has recently gained much attention in the design of SMA microactuators and SMA hybrid composites. An excellent older review [1] only deals with engineering aspects of the recovery stress generation in SMAs. Qualitatively, the origin of the phenomenon seems to be well understood. The recovery stresses are generated by a constrained SMA element containing a mixture of austenite and oriented martensite variants, as a response to the heating that drives the reverse martensite to austenite phase transformation. The recovery stresses typically increase almost linearly with increasing temperature. The slope of the measured $\sigma = \sigma(T)$ dependence was on specific conditions found so close to the slope of the well known Clausius–Clapeyron equation, Eq. (1), that some authors [1] even considered the recovery stress measurements as an additional experimental method to determine the characteristic slope s for SMA materials.

$$s = \frac{d\sigma^{tr}}{dT} = -\frac{\Delta S}{\varepsilon^{tr} V} \tag{1}$$

Eq. (1) says that the uniaxial stress, σ^{tr}, required to induce the martensitic transformation (MT) in SMA is linearly dependent on the temperature T. Strictly speaking, however, Eq. (1) is valid only on the microlevel of the oriented crystal lattice or in a single variant transforming SMA single crystal. s is basically a material parameter related to the type of structural transition involved. The parameters ΔS, V and ε^{tr}, are, respectively, the entropy change associated with the MT, the molar volume and the crystallographic transformation strain of the MT in the load axis direction. Since the magnitude of ε^{tr} in Eq. (1) strongly depends both on orientation and sign of load for most of the SMAs, the slope s also depends on the load axis orientation [2] and tension/compression sense of load [3] for SMA single

* Corresponding author. Tel.: +42-2-66052657; fax: +42-2-821227.
E-mail address: sittner@fzu.cz (P. Šittner)
[1] Visiting scientist at MTM KU Leuven in spring 1999.

PII: S0921-5093(00)00816-9