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Thermomechanical coupling in shape memory alloys under cyclic loadings: Experimental analysis and constitutive modeling

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ABSTRACT

In this paper, we examine the influence of thermomechanical coupling on the behavior of superelastic shape memory alloys subjected to cyclic loading at different loading rates. Special focus is given to the determination of the area of the stress-strain hysteresis loop once the material has achieved a stabilized state. It is found that this area does not evolve monotonically with the loading rate for either transient or asymptotic states. In order to reproduce this observation analytically, a new model is developed based on the ZM model for shape memory alloys which was modified to account for thermomechanical coupling. The model is shown to predict the non-monotonic variation in hysteresis area to good accord. Experimentally observed variations in the temperature of SMA test samples are also correctly reproduced for lower strain rates.

1. Introduction

Shape memory alloys (SMAs) exhibit interesting properties when subjected to mechanical or thermal loadings. For instance, SMAs can accommodate large recoverable strains, or recover their shape by simple heating after being inelastically strained. These properties promote their use in a wide variety of applications, from the biomedical field to the aeronautics industry. In the last two decades, constitutive modeling of SMAs has been the topic of a large number of publications (cf., e.g., Pan et al., 2007; Wang et al., 2008; Reese and Christ, 2008; Popov and Lagoudas, 2007; Peng et al., 2008; Kan and Kang, 2009; Arghavani et al., 2010; Thamburaja et al., 2009; Thamburaja, 2010).

It is well-known that the unusual behavior of SMAs is mainly due to the solid–solid martensitic transformation driven by either thermal or mechanical loading. This first-order, displacive transformation is accompanied with a production of entropy and heat, which can influence the temperature of the material. Chrysochoos (1987) and Peyroux et al. (1998) later on, used infrared thermography to investigate heat exchange during martensitic transformations in SMAs. They concluded that intrinsic dissipation can be neglected before latent heat. Building on the findings of Chrysochoos, Entemeyer et al. (2000) developed a micro–macro constitutive model for SMAs that links the rate of martensite formation to the amount of latent heat exchanged during phase change. Only a few models take into account both intrinsic dissipation and latent heat (see, e.g., Auricchio and Sacco, 2001; Bouvet et al., 2004). Müller and Bruhns (2006) developed a finite strain model for SMAs that accounts for thermomechanical coupling and for the formation of inner loops. The model was used to simulate the response of SMAs to a number of loading cases, considering isothermal and adiabatic situations. From an experimental point of view, Shaw and Kyriakides (1995) conducted experiments on SMAs in air and in water. Their results show a stronger dependence

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