Modelling of localization and propagation of phase transformation in superelastic SMA by a gradient nonlocal approach

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A R T I C L E   I N F O

Article history:
Received 19 March 2010
Received in revised form 14 February 2011
Available online 4 March 2011

Keywords:
Shape memory alloy
Superelasticity
Nucleation
Softening
Localization
Instability
Nonlocal gradient models
Finite element

A B S T R A C T

In this work, a nonlocal phenomenological behavior model is proposed in order to describe the localization and propagation of stress-induced martensite transformation in shape memory alloy (SMA) wires and thin films. It is a nonlocal extension of an existing local model that was derived from a micromechanical-inspired Gibbs free energy expression. The proposed model uses, besides the local field of the internal variable, namely the martensite volume fraction, a nonlocal counterpart. This latter acts as an additional degree of freedom, which is determined by solving an additional partial differential equation (PDE), the effect of martensitic localization on the superelastic global behavior of SMA wire and holed thin plate, subjected to tension loading, is analyzed. Numerical results show that the developed tool correctly captures the commonly observed unstable superelastic behavior characterized by nucleation and propagation of martensitic phase. In particular, they show the influence of the internal length parameter, appearing in the nonlocal model, on the size of the localization area and the stress nucleation peak.

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1. Introduction

The specific behavior of SMAs on the shape memory effect and pseudoelasticity at one hand and their high mechanical work/volume ratio on the other hand make them particularly well adapted for the design of microcomponents. Various models are available in the literature, that are dedicated to the macroscopic description of the thermomechanical behavior of bulk SMAs. Among these models, we mention those reported in (Raneyeki and Kyriakides, 1997), the radius/length ratio in the case of a tube specimen (He and Sun, 2009a,b; Cai and Dai, 2006), or the width/length ratio for plate (He and Sun, 2010).

Various models are available in the literature, that are dedicated to the macroscopic description of the thermomechanical behavior of bulk SMAs. Among these models, we mention those reported in (Tanaka, 1986), (Tanaka et al., 1995), (Raneyeki and Kyriakides, 1998), (Bekker and Brinson, 1998), (Thamburaja, 2005), (Panico and Brinson, 2007), (Popov and Lagoudas, 2007), (Zaki and Moumni, 2007), (Pelletier et al., 2006), (Saint-Sulpice et al., 2009), (Arghavani et al., 2010). These models developed within a local context (based on the assumption of a uniform Representative Elementary Volume (REV)) fail to describe the aforementioned softening and localization phenomena. In fact, the material response predicted on the basis of such modelling will suffer from the pathological problem shown in many experimental works since the one of Shaw and Kyriakides (1995) (see Fig. 1 for a schematic of this behavior). This particular behavior is the consequence of a material-level instability of the phase transformation at the macroscale, it is also influenced by geometric factors such as wire thinning (Shaw and Kyriakides, 1997), the radius/length ratio in the case of a tube specimen (He and Sun, 2009a,b; Cai and Dai, 2006), or the width/length ratio for plate (He and Sun, 2010).

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