International Journal of Solids and Structures 48 (2011) 2005–2014

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

A finite element analysis of the morphology of the twinned-to-detwinned interface observed in microstructure of the Cu–Al–Ni shape memory alloy

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ARTICLE INFO

Article history:
Received 18 January 2011
Received in revised form 3 March 2011
Available online 12 March 2011

Keywords:
Shape-memory alloys
Finite element method
Energy minimization
Microstructure

ABSTRACT

A detailed morphology of the twinned-to-detwinned interface in microstructure of 2H-martensite phase of the Cu–Al–Ni shape memory alloy is observed by optical methods (optical microscopy, white-light interferometry). Based on these observations, a finite element model of the transition layer is constructed and applied to calculate the elastic stress distribution inside the observed microstructure. The results show that the real micromorphology does not correspond to the minimum of the sum of the elastic and surface energy, and that the maxima of the stress field necessary for the existence of this morphology are comparable to the elasticity limits of the 2H-martensite.

1. Introduction

The thermoelastic martensites, i.e. the low-temperature phases of shape memory alloys (SMAs), are known to be able to form fine, regular microstructures (Otsuka and Wayman, 1998; Bhattacharya, 2003). Among these microstructures, the geometrically simplest ones and also the most frequently observed ones are the 1st-order laminates (Bhattacharya et al., 1999), which are the microstructures consisting of parallel lamina of two variants of martensite with alternating thicknesses. Under some special conditions, the 1st-order laminates can form macroscopically planar interfaces with the high-temperature phase (these interfaces are called *the habit planes*), with single variants of martensite (so-called *twinned-to-detwinned interfaces*), or with other 1st-order laminates (e.g. the macrotwin boundaries in the laminates of higher orders). When the macroscopic compatibility over such interfaces is analyzed by a mathematical model, it is usually assumed that these macroscopic interfaces are exactly sharp. More precisely, these interfaces are typically modeled by approaching the infimum of the Helmoltz free energy of the material by some minimizing sequence of microstructures $\{\mathbf{M}_n\}_{n=1}^{\infty}$, whereby the thickness of the transition layer between the two homogeneous microstructures forming the interface is proportional to $1/n$ (see Ball and James, 1987, 1992 for more details). This does not, however, always exactly reflect the experimental observations. For example, Chu (1993) observed the interfaces between differently oriented laminates of compound twins of the Cu–Al–Ni alloy during a mechanically induced reorientation (see Abeyaratne et al., 1996; James et al., 1995; Li and Luskin, 1999) for a further discussion and analysis of these observations), and the widths of the transition layers (i.e. of the layers outside which the neighboring microstructures can be considered as homogeneous) in this case were up to few millimeters. In Chu (1993), the morphology of these transition layers is documented by detailed optical micrographs: when approaching the interface, the lamina of one of the variants involved in the laminate are narrowing and forming thin needles with sharp tips ending at the interface (Fig. 1a). Furthermore, the tips of the individual needles are slightly bended from the original orientation of the laminate, and there can be also some branching of the needles occurring within the transition region.

Similar morphology of the transition layer has been described in the literature repeatedly and for various SMAs: Basinski and Christian (1954a,b) have observed and discussed the tapering and bending needles at the twinned-to-detwinned interfaces (Fig. 1b) in the In-Tl alloy. Exactly the same phenomena (although at a completely different scale) were observed by Schryvers (1993), Schryvers et al. (2001, 2002), Boullay et al. (2001) at the macrotwin boundaries between two 1st-order laminates in the Ni–Al alloy.

There have been many attempts to analyze the micromorphology of the transition regions by means of geometrically non-linear elasticity. Besides the detailed discussions of this topic for the above mentioned macrotwin boundaries in Ni–Al given in Schryvers (1993), Boullay et al. (2001) and the finite-elements models of the macroscopic transition regions in Cu–Al–Ni described in James et al. (1995), Li and Luskin (1999), let us point

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doi:10.1016/j.ijsolstr.2011.03.007