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Three Dimensional Modeling and a Simulation of the Shape Memory Effect

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The paper deals with modeling and simulating the shape memory effect , one of many behaviors of shape memory alloys. The effect was first divided into three stages. Every stage has its own thermodynamic potential and constitutive equations. The martensite fraction is the only internal variable to be considered: in the first stage, it represents the fraction of detwinned martensite; in the second stage, it represents the fraction of transformed martensite into austenite, and in the last stage, it represents the fraction of the produced martensite from the austenite transformation.

For every stage, we deduced the constitutive equations using the principles of thermodynamics and a simple formalism. When the model was defined, we simulated it using the experimental data obtained by analyzing a cube specimen subjected to triaxial traction and thermal load. The obtained results of this simulation reflect the behavior of this kind of materials when thermomechanical load is applied. The main finding of this paper is that the proposed constitutive model can be used to simulate the shape memory effect.

Key words: **martensite, thermomechanical load, modelling, fraction, shape memory effect, process simulation, experimental results.**

Introduction

IN the last decades, shape memory alloys (SMA) have occupied an important place in the world of advanced materials. They have a singular behavior comparable to conventional materials - they can be largely deformed (about 10%) (Kimiecik et al, 2013), (Zhong et al, 2012) under applied mechanical stress and simple heating is sufficient to recover their previous form. With varied controlled parameters (stress and temperature), these alloys can exhibit other properties such as pseudoelasticity, two-way shape memory effect, one-way shape memory effect (Arghavani et al, 2010), (Yutaka et al,2004), (Tonga et al, 2012) and reorientation effect **(**Pan et al, 2007). In addition to the previous properties, damping could be mentioned as an important property (Abdulridha et al, 2013).

These properties have allowed an important number of applications, particularly in biomedical and aerospace fields (Lagoudas et al, 2008), and some recent studies have been conducted to apply the damping property in seismic design (Abdulridha et al, 2013),(Eunsoo et al, 2013).

To describe the shape memory alloys behavior, many models have been developed (Arghavani et al, 2010), (Ng et al, 2006)**.** The shape memory effect is one of their most important properties. It requires three different stages:

1. Mechanical loading and unloading: at this stage, the structure is largely deformed after removing load because martensite is detwinned
2. Heating: the structure recovers its previous shape because martensite is transformed to austenite
3. Cooling: the structure undergoes only a phase change i.e. austenite is transformed to twinned martensite

The aim of this paper is to build a three dimensional constitutive model to describe the shape memory effect taking into account the three stages. In every stage we have proposed an expression of Gibbs free energy and, using the principles of thermodynamics, we have extracted the laws governing this behavior. Finally, we have performed a numerical simulation on a cubic Nitinol (NiTi) specimen (Ng et al, 2006).

Methods

The expression of Gibbs free energy is written as follows

$$G(\sigma,T,f)=-\sigma:S_M:\sigma-f\varepsilon_0\sigma R+fB\left(T-M_s^0\right)+Cf(1-f) \quad (1)$$

ε_0 : Uniaxial maximum deformation

f : Fraction of martensite $f\geq 0$ and $f\leq 1$

R : 2nd order tensor of the transformation given by:

$$R_{ij}=\frac{\sigma_{ij}}{\sqrt{\sigma:\sigma}} \quad (2)$$

S_M : 4th order complaisance tensor of martensite

B et C: Constants to be determined by a tensile test of pseudoelasticity.

a) Transformation criteria:

Assuming that transformation of austenite to martensite occurs with dissipation due to a phase change i.e. to the size of martensite (a fraction of martensite).

Then the driving force can be written:

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