Introduction

Magnetic shape memory alloys (MSMA) are known for their large recoverable strains (typically around 6%) which can be controlled by applying a magnetic field. The mechanism involved is the twinning of the martensite structure of the MSMA. When exposed to a magnetic field, the martensite re-orientates in order to align the magnetic dipole moment, which is strongly bound to the short lattice axis, with the field, resulting in an observable strain.

A typical MSMA is NiMnGa. MSMAs are interesting candidates for actuators and damping systems, but are not ideal in form of bulk due to their brittleness and cost. In addition, the shape memory behavior is only observable in single crystals, which are laborious to produce. Therefore, it could be of interest to develop MSMA composites.

Constitutive modeling of the MSMA is important to understand the mechanisms governing their behavior, as well as to predict the magnetic shape memory effect when designing composites.

Objectives

- Develop a constitutive model describing the behavior of NiMnGa alloys
- Implement the model in the finite element program Abaqus through a user material subroutine (UMAT)
- Characterize experimentally a NiMnGa single crystal to find the model parameters
- Simulate NiMnGa - epoxy composites to predict their actuation and damping

Constitutive Model

- Two driving forces for martensite re-orientation are considered:
  - A magnetostress \( \sigma_{mag} (H) \) representing the effect of the magnetic field \( H \)
  - An external mechanical stress \( \sigma_{mech} (\epsilon) \)
- The effect of both stresses is coupled.
- The pseudo-elastic constitutive model for MSMA was implemented in Abaqus as a user subroutine (UMAT) in the framework of small deformations.
- A limit function is used to determine if martensite re-orientation is possible.

Constitutive equations were integrated as an elasto-plastic material using a backward Euler scheme.

Simulation of Composites

The actuation capacity of four NiMnGa single crystals embedded in an epoxy matrix was simulated. Contour plots show the twin distribution in the single crystal at a magnetic field of 1.6 T for three epoxy matrices with different elastic modulus E. A significant MFIS is observed until \( E = 150 \) MPa. For higher E, twinning is considered to be blocked.

Summary

- A 3D constitutive model simulating the magnetic shape memory behavior was developed
- The model is based on equations of plasticity
- The principle of a magnetostress was introduced to describe the effect of the magnetic field
- Experimental characterization of the single crystal was carried out in order to determine the model parameters
- The model was implemented as a UMAT in Abaqus and the behavior of a NiMnGa single crystal was simulated
- Numerical simulations were able to predict accurately the experimental results in single crystals

Perspectives

- A more detailed experimental characterization of NiMnGa may allow an even higher precision of the numerical simulation
- Comparison with experimental results on the activation of NiMnGa composites will allow verification of the established model

Acknowledgements: Funded by the PNR62 project of the Swiss National Fund