A micromechanical model for polycrystalline shape memory alloy wires integrated into smart structures

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Thermomechanical models for shape memory alloys (SMA) can be categorized into phenomenological models ([1]) and micromechanical models ([2, 3]). Most micromechanical SMA models are 3-dimensional, computationally intensive and can only hardly be implemented in engineering codes to model smart structures. Some attempts at developing a simplified one-dimensional model have been made ([3]). However, the numerical implementation often seems to lack robustness. This research aims at providing a computationally efficient one-dimensional micromechanical model for polycrystalline SMA wires.

In the present work, the texture is described by a set of crystalline orientations along with their volume fraction. Two internal state variables characterize each crystalline orientation: the volume fraction of self-accommodated martensite, and the volume fraction of the most favorably oriented martensitic variant (with respect to the loading direction). The one-dimensional mechanical model of the wire in traction thus considers the influence of the 3-dimensional texture. The texture of Nickel-Titanium wires has been chosen in this study.

This model can describe the specific thermomechanical behavior of shape memory alloy wires, such as superelasticity, self-accommodation and reorientation of martensite, as well as the one-way shape memory effect ([4]). It has been implemented numerically in an efficient computational tool. A user-material subroutine (UMAT) resorting to numerical optimization tools inspired from [5] has been developed for the finite element software ABAQUS. Several thermomechanical experiments on Nickel-Titanium wires have been carried out in order to identify the model parameters. The model has been used to simulate the response of morphing structures including SMA wires, actuated by shape memory effect. Such structures have also been manufactured with fiber reinforced polymers, and their displacements as well as their actuation temperatures could be compared to the model predictions.

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