Modelling of transformation patterns in pseudoelastic shape memory alloys

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Propagating instabilities and the corresponding transformation patterns are commonly observed in polycrystalline shape memory alloys (SMAs), in particular, in pseudoelastic NiTi alloys under predominantly tensile loading. These effects result from the non-monotonic (up-down-up) intrinsic material response, which leads to strain localization and propagation of macroscopic phase transformation fronts. The deformation patterns then resemble the Lüders bands in plasticity, although more complex patterns are also observed, and the overall load–displacement response features a characteristic plateau.

In order to model the related effects, we developed a gradient-enhanced thermomechanical model of pseudoelasticity [1, 2]. In this model, the free energy function involves a new term that depends on the volume fraction of the martensite phase. This introduces a characteristic length scale and provides the required regularization. In line with the general approach [3], a micromorphic formulation is employed to facilitate the practical implementation of the model within the finite-element framework. Our finite-strain model includes a number of important features, notably the tension–compression asymmetry, anisotropy (transverse isotropy) of the transformation strain, and strain-dependent hardening/softening response. The model is formulated within the incremental energy minimization framework.

The model is able to describe several experimentally observed effects, such as the effect of loading rate on the number of martensite bands in a dog-bone specimen under tension [2] and the formation of multi-prong interfaces in NiTi tubes subjected to combined tension and torsion [2, 4], including the associated size effects [5]. We have also shown [4] that, when realistic boundary conditions are applied and residual stresses are taken into account, the model is able to predict longitudinal localization bands in NiTi tubes under torsion-dominated loading, an effect that has been experimentally observed but not fully understood or modeled.

References

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