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Thermo-mechanically coupled phase field model for simulating shape memory alloys response

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ABSTRACT

Polycrystalline NiTi Shape Memory Alloys (SMAs) have been experimentally shown to exhibit some important features and effects under pure tension and more complex loading. These features are either rate dependent or connected to moving interface between austenite and martensite phases. They include observed peak and valley in stress during loading and unloading respectively, propagation stress plateaus, inhomogeneous deformation (transformation localization and front propagation) during transformation, stress relaxation, etc. It has also been experimentally observed that polycrystalline NiTi wires, strips, and tubes develop transformation strain via nucleation and growth of macroscopic martensitic domains under mechanical loading. Associated with these responses during transformation evolution are complex interactions between mechanical work, heat production, and loading rates. These interactions will affect the performance of SMAs when deployed as active components. Modeling effort is, therefore, needed to better understand this behavior. This study is a worthwhile contribution towards modeling these experimentally observed features and their effect so as to aid SMA design and applications. A 3D thermodynamically consistent, thermomechanical, macroscopic phase field model capable of modeling kinetics of phase transition and hysteretic response of SMAs is presented. Based on the notion of configurational (accretive) forces and their balance, a kinetic law similar to that of Ginzburg-Landau is developed. A scalar order parameter (a field variable) is used in this study to describe the local phase of the SMA (austenite or martensite). To demonstrate the capability of this model, SMA response was studied. Presented herein is the effect of latent heat, loading rates as well as that due to constant stress and strain during transformation for the SMA. Remarkable agreement between simulation for the SMA and experimental results reported in literature was observed.