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CRACK TIP TRANSFORMATION ZONE MORPHOLOGY IN SMA MATERIALS WITH TRANSFORMATION SOFTENING

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Abstract

The pseudoelastic effect due to martensitic transformation in polycrystalline shape memory alloys is simulated with a phenomenological constitutive model based on a kinematic hardening framework with a gradient enhancement to regularize moving austenite-to-martensite boundaries that arise in softening materials. This constitutive modeling framework introduces a length scale within the theory which has yet to be deteremined experimentally. Calculations are presented for the evolution of the transformation zone around a stationary crack tip. The calculations uncover the interplay between the length scale associated with the size of the transformation zone around the crack tip and the material length scale inherent to the consistutive model. The calcualtions show that localized "fingers" or "needles" of deformation emenate from the transformation zone at a specific level of the applied stress intensity, which provide a comparison to experimental observations that then can be used to quantify the sie of the material length scale.

1. Introduction

The pseudoelastic effect due to martensitic transformation in polycrystalline shape memory alloy is modeled with a new constitutive model based on a kinematic hardening framework with a gradient enhancement to regularize moving austenite-to-martensite boundaries that arise in softening materials. The model captures the tension/compression asymmetry through the definition of a transformation hardening potential that is dependent on both the transformation strain and a newly introduced "phase" variable that describes the extent of transformation. The governing equations for the mechanical variables model include the standard equilibrium and kinematics equations governing the stresses, strains and displacements, a yield surface and associated flow rule governing the evolution of the transformation strains, and a back stress potential that is used to derive the back stresses associated with the kinematic hardening aspects of the constitutive model. Figure 1 shows the uniaxial tensile and compressive behaviors of the model. Additionally, a phase variable μ is introduced to regularize the boundaries between the austenite and martensite regions that arise due to the softening behavior in tension. A micro-force balance equation is developed that governs the distribution of μ in a thermodynamically consistent fashion.

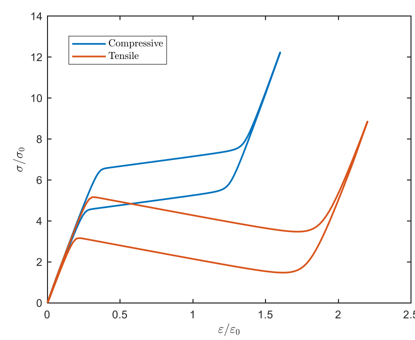

Figure 1. Uniaxial stress-strain response of the proposed model.

$$\xi_{i,i} + \pi + \gamma = 0 \rightarrow \mu - l_0^2 \mu_{,ii} = \bar{\varepsilon}^T \tag{1}$$

Here $\bar{\varepsilon}^T$ is the effective transformation strain and l_0 is the regularization length scale.

Finite element calculations are carried out for the canonical problem of a semi-inifinite crack loaded remotely by mode I K-field displacements.

2. Results

The evolution of the transformation zone around the crack tip is shown in Figures 2 and 3. The results indicate that for low levels of applied loading the transformation zone looks similar to that which would arise for a hardening material. However, at larger load levels the localizing effects of the softening behavior in tension can be seen in the formation and propagation of fingers or needles of the martensite phase into the surrounding austenite. The dimensionless parameter that can be used to determine the material length scale l_0 is, $K_I^2/\sigma_t l_0$. Here, K_I is the applied mode I stress intensity factor, and σ_t is the austenite to martensite transition stress in tension. When $K_I^2/\sigma_t l_0$ is small, the transformation zone will not develop fingers, but as $K_I^2/\sigma_t l_0$ grows, fingers will develop as shown in Figure 2 and grow as shown in Figure 3. The load level at the development of the fingers can be used to approximate l_0.

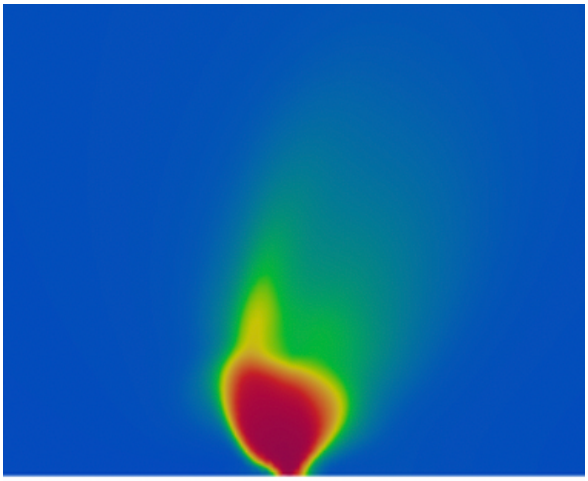

Figure 2. The transformation zone at the crack tip for $\frac{K_I^2}{\sigma_t l_0} = 200$.

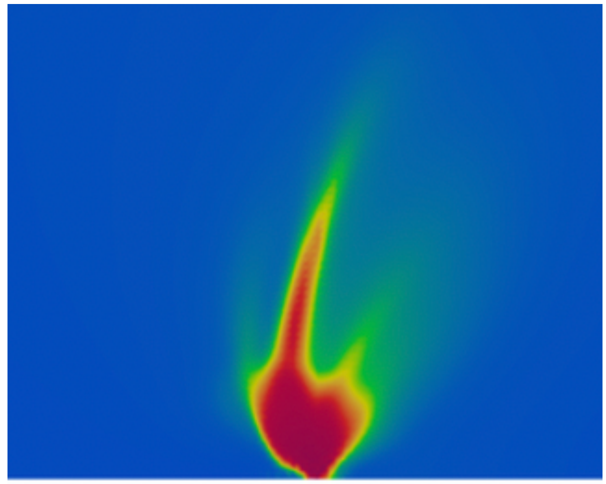

Figure 3. The transformation zone at the crack tip for $\frac{K_I^2}{\sigma_t l_0} = 400$.

3. Conclusions

A gradient regularizing model was used to study the interactions between the size of a phase transformation zone near a crack tip and the characteristic material length scale in a tensile-softening shape memory alloy material. These results can be applied as a comparison to experiments in order to quantitatively determine the material length scale.

Acknowledgements

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