THREE-DIMENSIONAL FINITE-ELEMENT SIMULATION OF SHAPE-MEMORY ALLOYS USING A THERMODYNAMICALLY-BASED THEORY OF MARTENSITIC PHASE TRANSFORMATIONS

C. Jannetti [a], **J.L. Bassani**[a], and **S. Turteltaub**[b]

[a]Department of Mechanical Engineering and Applied Mechanics
University of Pennsylvania
Philadelphia, PA 19104-6315
jannetti@seas.upenn.edu, bassani@seas.upenn.edu

[b]Department of Aerospace Engineering
Delft University of Technology
Kluyverweg 1, 2629 HS Delft
s.r.turteltaub@lr.tudelft.nl

Shape-memory alloys (SMA) derive their unique properties from reversible, solid to solid, diffusionless phase transformations on the crystal lattice. To model shape-memory alloys for use in applications on the size scale of devices such as stents, sensors, and actuators, a continuum-model is the ideal choice. However, since the underlying mechanism for the unique properties of SMAs is the microscale rearrangements that occur on the crystal lattice, a link between the microscopic phenomena and its influence on the more macroscopic response is required. To that end, we propose a model that treats a material point as a composite, consisting of a collection of distinct phases of the SMA, in order to homogenize the effects of the atomic-level phase transformation to the larger scale.

This presentation includes the development of a thermodynamically-consistent, inelastic, continuum model for SMAs based upon the framework for irreversible processes associated with structural rearrangements, as put forth by Rice (1971). Central to the constitutive model is the notion that the rate of progression of any microscale structural rearrangement is taken to be dependent on the stress state only through the thermodynamic force conjugate to that rearrangement. Our model has similarities with that of Thamburaja and Anand (2001), but there are also several notable differences. One of these differences is the analytical form for the thermodynamic force conjugate to the phase change.

We derive an expression for the thermodynamic force that, unlike the expression derived by Thamburaja and Anand (2001), takes into account the change in elastic strain energy, and then we use this force in rate-dependent type kinetic relations. The kinetic relations directly account for dissipation, which can be determined from experimentally observed stress-strain behaviors. Our model has been integrated with the finite-element software ABAQUS through the use of a user defined material subroutine (UMAT). Using ABAQUS/Standard we have been able to obtain results of three-dimensional, non-linear, finite-element simulations that capture the effect of the microscopic phase transformation on the macroscopic material response.

References

[1] Rice, J.R. "Inelastic constitutive relations for solids: an internal–variable theory and its application to metal plasticity", *J. Mech. Phys. Solids*, **19**, pp. 433-455, 1971.
[2] Thamburaja, P. and Anand, L. "Polycrystalline shape-memory materials: effect of crystallographic texture", *J. Mech. Phys. Solids*, **49**, pp. 709-737, 2001.
[3] ABAQUS Reference manuals, Providence, RI, 2003.