A NEW APPROACH IN CONSTITUTIVE MODELING OF SHAPE MEMORY ALLOYS

AMIR SADJADPOUR* AND KAUSHIK BHATTACHARYA†

* Division of Engineering and Applied Science
California Institute of Technology
Pasadena, CA 91125, USA
amirs@caltech.edu

† Division of Engineering and Applied Science
California Institute of Technology
Pasadena, CA 91125, USA

Shape memory alloys (SMAs) exhibit a strongly nonlinear thermo-mechanical behavior associated with abrupt changes in their lattice structure called martensitic phase transformation. Two common manifestations of this phase transformation is the shape-memory effect and superelasticity which are consequences of a martensitic phase transformation, which is a diffusionless first-order phase transformation between a high temperature austenite phase and a low-temperature martensite phase. A key difficulty in the constitutive modeling of these materials is to find an effective means of describing this evolution, especially in polycrystals.

In the model presented in this work, we address this issue by introducing the idea of the effective transformation strain. It is the average transformation strain of the different variants averaged over a representative volume element (RVE) containing multiple grains after the material has formed an allowable microstructure. It is allowed to take any value in the set of effective transformation strains which depends on the material and the texture of the specimen. In one dimension, it is the interval from the recoverable compressive strain to the recoverable tensile strain and in three dimensions it is the convex dual of the transformation yield surface.

This model builds on micromechanical aspects of the mechanics of shape memory alloys and is capable of being implemented in standard stress analysis software while incorporates realistic physics. In this work, instead of adopting the traditional phenomenological point of view, in which a functional relation is proposed and fitted to the experiments, we propose micromechanics inspired kinetic relations that cover a wide range of strain rates. It is applicable in a broad range of temperatures so that it captures both the shape-memory effect and superelasticity; it is adaptable to many materials and textures and finally, since phase transformation often competes with plasticity in shape-memory alloys, it incorporates that phenomenon as well. With careful consideration of the model parameters and underlying features of the material behavior, this constitutive framework can be adopted for the study of a broader range of materials as it has already been implemented for modeling the shear deformation of iron under dynamic loading.

Keywords: shape memory alloys, micromechanics, constitutive modeling