Finite Deformation Thermomechanical Constitutive Modeling and Numerical Implementation of Triple Shape Polymeric Composites Due to Dual Thermal Transitions

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Shape memory polymers (SMPs) are a class of smart materials that can fix their temporary shape and recover to their permanent shape in response to environmental stimuli such as heat, electricity, irradiation, moisture or magnetic field, among others. Along with strong interests in conventional "dual-shape" SMPs which can recover from one temporary shape to the permanent shape, multi-shape SMPs that can fix more than one temporary shapes and recover sequentially from one temporary shape to another and eventually to the permanent shape, start to attract increasing attention. Two approaches have been used to achieve multi-shape SM behaviors. The first approach uses SMP with a wide temperature range of glass transition whilst the second method employs multiple transition temperatures, most notably, uses two distinct transition temperatures to obtain triple shape memory effects (t-SMEs). Recently, Mather's group reported a triple shape polymeric composite (TSPC), which is composed of an amorphous SMP matrix (epoxy), providing the system the rubber-glass transition to fix one temporary shape, and a crystallizable fiber network (PCL) providing the system the melt-crystal transition to fix the other temporary shape. Here, we present a three-dimension (3D) finite deformation thermomechanical constitutive model. In the model, the multi-branch approach is used to describe the viscoelasticity of the amorphous SMP matrix and the thermomechanical behavior of the fiber network during the melt-crystal transition is described by a set of branches with different deformation histories. Simple experiments, such as uniaxial tensions, thermal expansions and stress relaxation tests were carried out to identify parameters used in the model. Using a implemented user material subroutine (UMAT), the constitutive model successfully reproduced the triple-shape memory behavior exhibited in experiments. The model was also able to simulate complicated applications, such as a twisted sheet demonstrating t-SME.

Keywords: *multi-shape memory polymers; triple-shape memory effects; tripe-shape memory polymeric composite; three-dimension model.*