Society of Engineering Science 51st Annual Technical Meeting

1–3 October 2014

Purdue University, West Lafayette, Indiana, USA

Finite element analysis of stable crack growth in shape memory alloy actuators

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ABSTRACT

Shape memory alloys (SMAs) are a special class of intermetallic alloys that, because of their capability to recover large strains when subjected to thermal or mechanical loads, have been extensively used for actuation purposes. Because of their high work output per unit volume, SMA-based actuators are a better alternative compared to conventional electromagnetic actuators when a large force is required and thermodynamic efficiency is not important. As such, for better design and functioning of SMA-based actuators, it is imperative to understand the phenomenon of crack-initiation and growth during thermal actuation in SMAs. In this study, finite element analysis is carried out to study stationary and advancing cracks in an infinite, center-cracked shape memory alloy specimen subjected to thermal variations under constant plane strain mode-I tensile loading. Abaqus finite element suite is employed to compute mechanical fields close to the static crack and assuming linear elastic fracture mechanics and virtual crack closure technique is used to calculate the crack-tip energy release rate. An increase in the energy release rate during cooling by approximately an order of magnitude when compared with that due to constant mechanical loading is observed, which is attributed to the stress redistribution at the crack-tip induced by global phase transformation during cooling. Crack growth during actuation may thus occur when the crack-tip energy release rate reaches a material specific critical value. Fracture toughening behavior is observed during crack growth and is mainly associated with the energy dissipated by the progressively occurring phase transformation close to the moving crack tip. A sensitivity analysis of this toughening behavior with respect to key thermomechanical parameters is presented. Lastly, the effect of crack configuration on fracture toughness enhancement is studied by investigating static and advancing cracks in compact tensile and three-point bending SMA geometries as well.