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A thermodynamic consistent damage and healing model for self healing materials

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ABSTRACT

Thermodynamics of the damage and the healing processes for viscoplastic materials is discussed in detail and constitutive equations for coupled inelastic-damage-healing processes are proposed in a thermodynamic consistent framework. Small deformation state is utilized and the kinematic and the isotropic hardening effects for the damage and healing processes are introduced into the governing equations. Two new yield surfaces for the damage and healing processes are proposed that take into account the isotropic hardening effect. The computational aspect for solving the coupled elasto-plastic-damage-healing problem is investigated, and the mechanical behavior of the proposed polymeric based self healing system is obtained. Uniaxial compression tests are implemented on a shape memory polymer based self healing system and the damage and the healing are captured by measurement of the changes in the modulus of elasticity. It is concluded that the proposed constitutive equations can model the damage and healing effectively and the mechanical behavior of a shape memory polymer based self healing system can be precisely modeled using this formulation.

1. Introduction

Micro-structural rearrangements such as twinning, diffusion, microcracking and crystalline slip are involved in deformation of solids. Basically the damage in materials represents the degradation of the strength until failure occurs at both the micro- and macro-scale levels. Some macro-scale damages can be captured by classical fracture mechanics. Continuum damage mechanics provides a general approach to incorporate different types of micro-scale damages including micro-cracks and micro-cavities, debonding between fiber and matrix and breakage of bonds in polymeric materials, corresponding to the respective loading conditions and the inherent material defects. Damage can be categorized as brittle, ductile, creep, and fatigue (Lemaitre and Dufailly, 1987). Here one considers ductile damage corresponding to large plastic strains with the application to low cycle fatigue. Damage inside the material at the micro-scale level can be evaluated by measuring changes in elastic modulus (Lemaitre and Dufailly, 1987; Lubarda and Krajcinovic, 1993; Voyiadjis and Kattan, 2009), and this task is accomplished by using damage variables. This concept is incorporated to evaluate the healing performance at the micro-scale levels for a self healing system and a new healing variable is introduced by Voyiadjis et al. (2011). The self-healing of damage is a recent concept for advanced materials where they heal damages both at the macro- and micro-scale (Li and Uppu, 2010; Plaisted and Nemat-Nasser, 2007).

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