A phase-field theory for fracture of elastomeric materials

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Abstract

Phase-field modeling of brittle fracture of linear elastic solids has been the subject of several studies in the past 25 years. In the phase-field approach to model fracture one introduces a scalar order-parameter or “phase-field,” which affects the energy storage and stiffness characteristics of the material. If $\varphi = 0$ at a point then that point is intact, while if $\varphi = 1$ at some point, then that point is fractured. Values of $\varphi$ between zero and one correspond to partially-fractured material. All fields remain continuous until the critical condition $\varphi = 1$ is reached, and this gives rise to the nucleation of a “crack” with attendant small zones of high gradients of $\varphi$ and therefore stiffness. In the phase-field approach the evolution of $\varphi$ depends not only on $\varphi$ and other locally-defined variables, but also on the gradient of the phase-field parameter $\nabla \varphi$. An attractive feature of this approach to model fracture is its seamless ability to simulate the complicated fracture process of nucleation, propagation, branching and merging of cracks in arbitrary geometries — propagating cracks are tracked automatically by the evolution of the smooth phase-field $\varphi$ on a fixed mesh.

Miehe and Schänzel (2014) have recently formulated a phase-field theory for fracture of elastomeric materials undergoing large deformations using a variational approach. In this talk we will present a theory which is formulated using an alternative approach. Specifically, we formulate the balances in our theory by following the pioneering virtual-power approach of Fremond and Nedjar (1996) and Gurtin (1996, 2002). This approach leads to “macroforce” and “microforce” balances for the forces associated with the rate-like kinematical descriptors in the theory. These macro- and micro-force balances, together with a standard free-energy imbalance law under isothermal conditions, when supplemented with a set of thermodynamically-consistent constitutive equations provide the governing equations for our theory. We specialize our general theory to formulate a simple continuum model for fracture in finitely deforming elastomeric materials.

We have numerically implemented our theory in a finite element program, and we will present representative numerical examples which show the ability of the simulation capability to qualitatively replicate the failure of elastomeric materials in some technically relevant geometries.

References


