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Stochastic analysis of polymer composites rupture at large deformations modeled by a phase field method

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Abstract

Carbon black reinforced natural rubber is a composite material that is increasingly being used in engineering applications. Carbon black is orders of magnitude stiffer than natural rubber, resulting in a composite material with increased stiffness, but decreased fracture strain. Detailed knowledge of the relationship between the composition of reinforced rubber and its fracture toughness is important for analysis and design of various engineering systems. To this end, the Arruda-Boyce model is adopted for modeling the hyperelastic rubber matrix and a Neo-Hookean model is used for the reinforcing particles. A phase field method is then employed to simulate damage nucleation and propagation under quasi-static loading. The phase field method is well suited for such problems, since it can capture complex patterns of damage nucleation, coalescence, and propagation. The phase field hyperelastic model is validated on a set of experimental data available in the literature. To quantify the uncertainty in the failure of these materials, a Monte Carlo simulation is carried out with random ellipsoidal particles distribution. Each realization undergoes large stretching up to failure, where force displacement curves and fracture surface energies are recorded. Failure of a sample is defined as the point for which the load drops to 75% of its peak value. Numerical examples of stiff inclusions and voids are considered and the composite response is examined on an intact and pre-notched unit cells. The stochastic analysis reveals the statistical distributions corresponding to the rupture of polymer composites and provides insight into better design of these materials.

Keywords: Phase field method, crack nucleation, Monte Carlo simulation, polymer composites, hyperelasticity, large deformations

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