Nucleation and propagation of fracture in viscoelastic elastomers: A complete phase-field theory

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In this talk, I will present a macroscopic theory, alongside its numerical implementation, aimed at describing, explaining, and predicting the nucleation and propagation of fracture in viscoelastic materials subjected to quasistatic loading conditions. The focus will be on elastomers.

I will begin by summarizing the large body of experimental results – a part of which dates back to the 1950s and 1960s but seems to have been overlooked in the recent literature – on how elastomers deform, nucleate cracks, and propagate cracks when subjected to mechanical loads. When viewed collectively, the experiments make it plain that there are three basic ingredients that any attempt at a complete macroscopic theory of fracture in elastomers ought to account for: (*i*) the viscoelasticity of the elastomer, (*ii*) its strength, and (*iii*) its fracture energy. A theory will then be introduced that accounts for all these three basic ingredients by extending the phase-field theory initiated by Kumar, Francfort, and Lopez-Pamies JMPS 2018) for elastic brittle materials to seamlessly incorporate viscous energy dissipation by deformation, a generalized strength surface that is a hypersurface in stress-deformation space (and not just in stress space as for elastic brittle materials), and the pertinent Griffith criticality condition for materials that dissipate energy not just by the creation of surface but also by deformation, in this case, by viscous deformation.

From an applications point of view, the proposed theory amounts to solving an initial-boundary-value problem comprised of two nonlinear PDEs coupled with a nonlinear ODE for the deformation field, a tensorial internal variable, and the phase field. A robust scheme will be outlined to generate solutions for these equations that makes use of a non-conforming Crouzeix-Raviart finite-element discretization of space and a high-order accurate explicit Runge-Kutta finite-difference discretization of time.

To illustrate the descriptive and predictive capabilities of the theory, the last part of this talk will be devoted to presenting simulations of prototypical experiments dealing with nucleation of fracture in the bulk, nucleation of fracture from a pre-existing crack, and propagation of fracture in different types of elastomers under various types of loading conditions.