Constitutive Framework for Brittle Failure in Thermo-Chemically Aged Elastomers Using Phase-Field

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Abstract

This presentation discusses a physics- and chemistry-based constitutive framework that predicts the stress and brittle failure behaviors of thermo-chemically aged elastomers. High-temperature aging in the presence of oxygen triggers chemical reactions that significantly alter the elastomer's macromolecular network. This work directly links the evolution of the macromolecular network of elastomers to the mechanical properties governing the stress and failure responses of thermo-chemically aged elastomers. The Arruda–Boyce hyperelastic constitutive model is modified to predict the stress-strain response up to failure, incorporating a phase-field approach to capture brittle failure using a strain-based fracture criterion. Four material properties, critical to stress and failure responses, evolve based on the network evolution. The evolution of the macromolecular network, effective crosslink density in this case, is determined from chemical characterization tests for various aging temperatures and durations. The proposed constitutive framework is first analytically solved for uniaxial tension in a homogeneous bar, highlighting the interdependencies among the four material properties. It is then numerically implemented within a finite element (FE) framework using a user-element subroutine (UEL) in the commercial FE software Abaqus. Validation against experimental results from the literature demonstrates the framework's ability to accurately predict the stress-strain and failure behaviors of thermo-chemically aged elastomers. Additionally, numerical examples illustrate the influence of evolving material properties on specimens with pre-existing cracks, leveraging the phase-field approach to model brittle fracture.

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