A multiscale phase field fracture approach for rubber-like materials

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In recent years, the phase field method has developed rapidly for modeling fracture in various materials, including concrete, steel, biological tissues, and rubber-like materials. This method approximates cracks by a smooth auxiliary scalar field and has proven to be effective in simulating complex fracture phenomena such as crack nucleation, propagation, branching, and merging. In the case of rubber-like materials, modeling their fracture behavior is crucial for understanding and designing against failures in fields like stretchable electronics, self-actuators, and implantable sensors. However, there exist several challenges when adopting the phase field fracture approach to highly deforming materials like rubber.

Firstly, accurately capturing the fracture behavior in these materials is hindered by their incompressible behavior, which can cause numerical instabilities. To address this issue, a multiscale polymer model is coupled with the phase field approach and formulated using mixed elements to capture the fracture behavior in incompressible rubber-like materials. At the microscale, non-Gaussian statistics is used to model the chain behavior, while the phase field approach is used to model the damage caused by the failure of chain segments. A 3-field mixed formulation is employed for numerical stability, and the incompressibility constraint is enforced in the undamaged regions using augmented Lagrangian iterations. The model's performance is validated by comparing the simulation results with experimental data.

Secondly, although there are many micromechanically motivated models for capturing their failure characteristics, many utilize network models which predict an isotropic network response for bridging deformations at the two scales. However, they may not effectively capture effects on the fracture behavior of microscale phenomena like strain-induced crystallization, which have been found to produce anisotropy in the network behavior [1, 2]. Therefore, in this study, a multiscale polymer model, which is bridged using the maximal advance path constraint [3] network model, is coupled with the phase field approach for modeling crack propagation in elastomers. At the microscale, non-Gaussian statistics is utilized for modeling the chain behavior while accounting for the internal energy due to molecular bond distortions. The non-affine maximal advance path constraint network model, modified for damaged systems [4], is utilized to bridge the deformations at the two scales. The phase field approach is used for modeling the damage, which is assumed to be caused mainly due to the failure of chain segments. Using micromorphic regularization, dual local-global damage variables are introduced and connected using the augmented Lagrangian method. The performance of the model is validated by comparing the simulation results with experimental data.

References

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