PHASE FIELD MODELING ON ELASTOMERS CONSIDERING THE NONLINEAR MATERIAL VISCOSITY

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Abstract

With inevitable flaws, elastomers are susceptible to rupture leading to the reduction in stretchability and loss of functionallity. In the present work, a finite element (FE) framework is proposed with the incorporation of polymer dynamics into the phase field modeling (PFM). The driving force to the fracture of viscoelastic elastomers is identified and the micro-mechanism of material viscosity is further accommodated with the consideration of polymer chain breakage to capture the disentanglement before fracture. The FE model is validated with comparison with existing experimental data, and is expected to provide guidance for the design of elastomer based transducers.

1. Introduction

Elastomers have attracted great research interests with high compliance and large deformation capacity. It has been recognized that the overall performance of elastomer devices is not only affected by constitutive behaviors but also by the fractures especially when elastomers function as supporting and actuating structures. Free of the requirement of pre-defined crack nucleation and path, the phase field modeling (PFM) have been widely adopted for the fracture simulation of elastic brittle materials by introducing an auxiliary phase field variable that varies from 0 to 1 for cracked and intact states. However, the corresponding numerical research on fracture behaviors of viscoelatic polymers such as elastomers is still in tentative stage faced with challenges in extreme large deformation, volumetric locking due to material incompressiblity, and the identification of the driving forces to fracture. In this present work, we revisit the existing experimental observations, and identify the sole contribution of the elastic deformation energy of the crosslinked polymer network to the fracture of elastomers. With further consideration of polymer chain breakage, we connect the phase field variable to the topology constraint on the polymer chain reptation and hence reformulated the material viscosity to be dependent on the phase field variable. The phase field framework is then discrentized following standard finite element procedure and iteratively sovled with staggered algorithm. Finally, the established model is verified with experimental observations from literatures.

2. Results

The numerical studies on elastomeric material VHB 4905 were first conducted with precut at different loading rates to reveal the effects of material viscosity on fracture behaviors. The total dimensions of VHB4905 film were set as 150mm×10mm×0.5mm and the initial flaw was defined to be 20mm in length with width of 0.1mm. The loading rates were 1/min, 10/min and 100/min respectively.

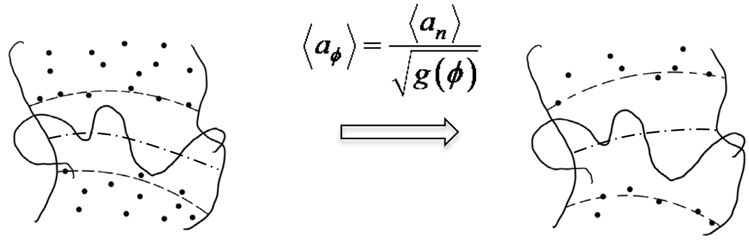


Fig. 1 Demonstration of effects of polymer chain breakage on reptation of free chains.

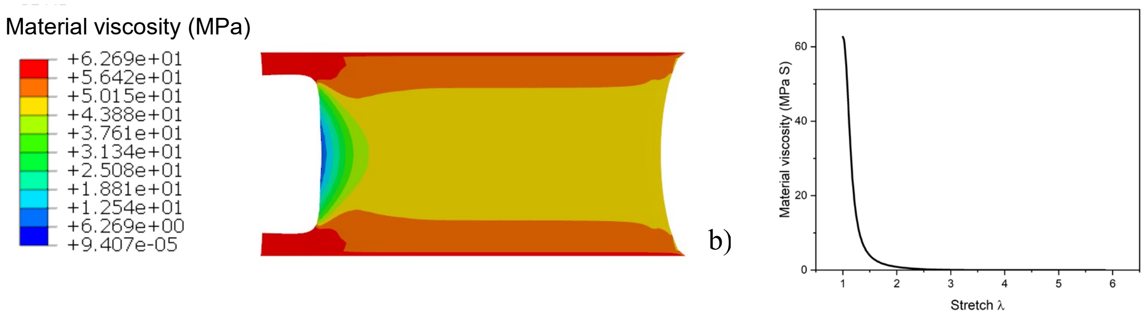
a) 

Fig.1 a) Material viscosity distrubtion at onset of crack. b) Material viscosity evolution at the crack tip.

With the identification of the sole contribution of elastic deformation energy of crosslinked ground network, the simulation results agreed well with the experimental observation that, at different loading rates, the critical stretches for the cracks to occur almost keep constant. The resultant forces however differ due to the rate-dependent viscoelasticity. Meanwhile, the disentanglement of polymer chains was also reflected in the simulation results. With the connection between the polymer chain breakage and phase field variable, the tube modeled was further modified as indicated in Fig. 1. When fracture is approached, the material viscosity vanishes due to the loss of constraints on the reptation of polymer chains as shown in Fig. 2.

In order to further validate the accuracy of the proposed model, the geometry sensitivity test was also simulated. With the same precut, the heights of the VHB4905 specimen were set from 10mm to 50mm with 10mm interval. The simulation results also showed a good agreement with existing experimental data. With the increase of the specimen height, the critical stretch decreases. When the height is large enough (≥40mm), there is no obvious change in the onset of crack. The phase field evolutions at the crack tip are plotted in Fig. 3 as illustration.

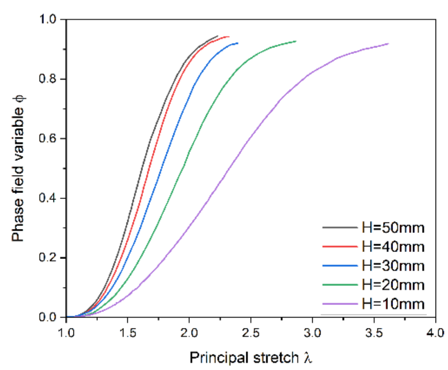


Fig. 3. Phase field evolution at crack tips with different heights.

3. Conclusions

The proposed FE framework is capble to simulate the fracture behaviors of viscoelatic elastomers, and can capture the rate-insensitivity of the onset of fracture despite the rate-dependent viscoelasticity. The material viscosity is reformulated to take into account both the deformationa dn material damage so that the disentaglement of polymer chains can be modeled. When the crack is approached, the material viscosity at the crack tip vanishes.

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