Analysis of strain-dependent elasto-capillary necking and bulging in hyperelastic cylinders based on a one-dimensional model

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Abstract

Surface effect attracts more and more attention as the rapid development of soft materials, structural miniaturization and micro/nono-technology. Various works model the surface effect in solids as a constant surface tension. However, the assumption of constant surface stress is not applicable for solids due to the low mobility of atoms/molecules. Experimental evidence for strain-dependent surface effect has been reported. Investigating the elasto-capillary behaviors in solids with strain-dependent surface effect is imperative. The post-bifurcation response of elasto-capillary instability in solid structures with strain-dependent surface effect remains unexplored either analytically or even numerically. To address this, we derive a one-dimensional (1d) gradient model from three-dimensional (3d) finite-strain formulation for characterizing the necking/bulging instabilities in a hyperelastic cylinder with strain-dependent surface effect. With the aid of the 1d reduced model, the fully nonlinear evolutions of the necking/bulging behaviors can be obtained very easily. A finite-element scheme of the 3d formulation is also proposed to validate the efficiency of the reduced 1d model. Three typical loading scenarios are considered to reveal the effects of surface tension, surface elasticity, surface compressibility, axial force and geometrical size on the surface-bulk interactions. This work lays a theoretical foundation for the further investigation of strain-dependent surface-stress problems and provides substantial suggestions for tuning the surface effect in soft solids by structure and composition designs.

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