Title: Analysis of the Mullins effect in buckling instability of double-network hydrogel beams under swelling equilibrium

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Abstract:

Due to their outstanding physical and mechanical properties, double-network (DN) hydrogels have gained a most attention among various synthetic tough hydrogels. The Mullins effect and buckling instability are two frequent phenomena that may occur simultaneously in slender DN hydrogel structures as high load-bearing candidates. The swelling/deswelling degree of the DN hydrogel affects the coupling phenomena. It is essential to understanding the interplay between these behaviors. For this, we develop a physically based damage constitutive model for a DN polymer under water-diffusion equilibrium and cyclic loadings. This theory of coupled swelling and load-induced deformations show good capability in capturing the Mullins effect of swollen DN hydrogels and the corresponding swelling ratio. The model parameters are determined by fitting experimental data of a freely swollen DN hydrogel under cyclic compression. Based on the constitutive model and determined parameters, the buckling instability of DN hydrogel beams is studied via the analytical formula of incremental modulus. The stability diagrams of the virgin DN hydrogel beam and damaged DN hydrogel beams with five historically compressive stretches are presented. The influences of stress softening, strain stiffening and chemical potential on buckling conditions for compressive stress and slenderness ratio are thoroughly analyzed. It is found that the stress softening is dramatically against the stability of the beam, but the strain-stiffening effect would conversely help widen the stable range. Besides, it sees that a DN gel beam immersed in a sufficient low chemical potential environment has better buckling stability. These theoretical results are valuable in the preparation and structural design of DN hydrogels for repeated use purpose.