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Harnessing swelling-induced forces for autonomous actuation

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Abstract

Stimuli-responsive hydrogels that swell under constraints such as spatial geometric confinement exert forces on the near environment, and are therefore employed in many applications, including biomedical devices and actuators, to perform mechanical work. In this talk, we present a method to quantify the swelling-induced stress by using 3D-printed boxes with rigid and elastic walls. Measurements of wall deformation, combined with elastic plate theory, revealed how wall stiffness and confinement geometry govern the stress profiles and anisotropic swelling of gels. This framework provides a quantitative foundation for validating constitutive models and designing mechanically coupled gel systems. To employ the swelling-induced forces for actuation, we built on this method and designed3D-printed actuators comprising responsive (gels) and non-responsive (elastic rods) components that are activated using hydration and are capable of lifting weights through the buckling of the rods. Specifically, as the gels swell, they generate forces that compress the elastic rods and cause their buckling. Such systems are advantageous since (1) they do not require an external power source and (2) the separation between the swelling and mechanical components enables tunable self-sustained actuation. These studies establish guidelines for the design of soft autonomous water-actuated actuators and highlight how understanding constraint-induced stresses can be used to guide the engineering of programmable, reversible, and energy-efficient hydrogel devices.

Keywords:

hydrogels actuation swelling-induced forces

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