CONTACT MECHANICS OF HYDROGELS

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Abstract

Gel is composed of cross-linked polymer network and solvent molecules. Gels have broad application in many engineering fields such as drug delivery, tissue scaffold, soft robots among others. Mechanical characterization of soft gels has been challenging because of the extreme softness and its complex time-dependent behavior. Comparing with other mechanical testing techniques, indentation method provides many practical advantages, which requires minimum sample preparation and can be easily applied across a wide range of length scales, but the difficulty for using indentation is mostly in the theoretical aspect. It is a complex boundary value problem and the gels have convoluted time-and-length dependent behaviors. To interpret data, one must carry out finite element simulation for each geometry and do curve fitting often with multiple parameters to be fitted at the same time. There is a lack of a physical basis to justify whether the fitted values are intrinsic to the materials' properties. In this work, we focus on identifying the underlying physics that governs the time-dependent behavior of gels and find clear scaling relations that allow for a unified solution and master curve independent of geometry to be obtained. The parameters can be extracted definitively without curve fitting and have clear physical meanings. The ease of use of the method makes it possible for people without mechanics background to easily extract the properties of their challenging materials. Beyond the time-dependent bulk properties, we also use indentation to study the adhesion hysteresis (or aging) of hydrogels. Combining a unique multi-time and multi-length scale indentation technique and rigorous theoretical analysis, we can decouple the time-dependent adhesion from the time-dependent bulk behaviors of the gels and extract the intrinsic interfacial properties including adhesion energy, separation distance, and cohesive strength. We also, for the first time, show the transition of mechanism from uniform bond breaking to Griffith type of fracture as the contact size goes across a big range of length scales. It is also the first time that adhesion hysteresis is discovered in hydrogels.

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