Fluid effects on the fracture toughness of gels

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Abstract

The fracture of polymeric gels has been of growing interest in the last two decades, in particular in applications to biological tissue. Well established continuum theories that couple large deformations and fluid diffusion have been applied to gels to determine crack tip fields and the energy release rate. Some studies have combined experiment and calculations to determine the fracture toughness of gels and have shown that fluid effects make a substantial contribution to the toughness. Here we adopt a micro-mechanical view to estimate the fracture toughness of gels, defined as the critical (total) energy release rate, and show how the initiation toughness can be written as a combination of contributions from fiber scission and of fluid-solid demixing at the crack tip. This estimate is based on knowledge of a critical stretch and a volumetric strain when fracture is incipient and reveals dependencies on material properties including the solid volume fraction of gels. There have been no known ways to measure the de-mixing contribution directly from experiment, but the results in this paper provides a methodology. We also show how dissipation due to fluid motion as the crack propagates can contribute to the fracture toughness. Detailed results are presented for fibrin gels, which are the main structural component of blood clots. We find that the contribution of fluid mixing with the fibrin network to the initiation toughness for fibrin gels is significant at moderate critical stretches. We also find that fluid flow around a steadily moving crack leads to a contribution to the toughness that is linear in crack speed and fluid viscosity.

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