Characterization of local poroelastic swelling near the tip of a propagating crack in a hydrogel

Chenzhuo Li*†[1] and John Kolinski‡[2]

[1]School of Engineering, EPFL – Switzerland
[2]School of Engineering, EPFL – Switzerland

Abstract

Polyacrylamide hydrogels are widely used as model materials in experimental fracture mechanics due to their transparency and low Rayleigh-wave velocity. While traditionally regarded as "brittle" and analyzed using linear elastic fracture mechanics (LEFM), hydrogels can exhibit poroelastic swelling at the crack tip when the experimental timescale is comparable to the poroelastic timescale. This swelling, despite lacking direct measurements, can significantly influence fracture behavior, leading to rate-dependent effects and delayed fracture (1). Here, we employ a particle tracking technique augmented by digital image correlation to capture high-resolution 3D particle trajectories and measure the 3D kinematic fields near the tip of a slowly propagating crack. For the first time, we experimentally quantify the local swelling field by evaluating the determinant of the deformation gradient tensor. The kinematic measurements confirm the complex multi-axial stretching and the substantial geometric nonlinearity near the crack tip, as well as an increasing disagreement with LEFM predictions. Significant poroelastic swelling is resolved spatially near the crack tip, with its magnitude strongly correlated to local stretch values. Our quantification of the near-tip swelling is expected to provide insights for the development of constitutive models in swelling-coupled fracture problems. The experimental method we used can be readily adapted to study complex 3D deformation fields.

References

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*Speaker
†Corresponding author: chenzhuo.li@epfl.ch
‡Corresponding author: john.kolinski@epfl.ch