Dynamics of Hydraulic Fracture in Tough Hydrogels

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15 Second Summary:

We model hydraulic fractures in heavily cross-linked hydrogels in order to study fracking. We are interested in the material properties that govern the scale, extent and morphology of hydraulic fractures in brittle materials. This summer I did experiments to explore if/how hydraulic fractures propagate across boundaries.

Motivation

Fracking is of immense environmental, economic, & political concern today. Our hope is that studying how hydraulic fractures react to interfaces will help address containment issues in fracking operations, where target rock formations are often capped by, or intertwined with, other materials.

Background

A fracking operation involves pumping millions of gallons of water, chemicals & sand deep underground at very high pressures; this forces open fractures in the target rock formation, which releases previously inaccessible oil and natural gas. Although this technique of energy extraction is much disputed, it is poorly understood. Operations cannot be directly observed, because they occur more than a mile below the surface of the earth. Therefore, our lab has developed a system of modeling these fractures using heavily cross-linked hydrogels.

We know these gels are analogous to rock because of work done by the Fineberg group; they established qualitatively and quantitatively that these hydrogels break in the same manner as classically brittle materials, such as PMMA, glass & rock [1]. Based on this research, the Rubenstein & Weitz groups began using tough hydrogels to study fracking. The experimental advantages of our approach are the gels' transparency, chemical manipulability, & slower fracture speed, which allow us to take videos of fracture dynamics using a high-speed camera. We're now capable of altering the gels' chemistry to achieve desired material properties & of getting videos with incredible temporal resolution, as well as getting great post-fracture images of fracture surface details (figure 3). Ultimately, this system should help advance our understanding of fracking & its effects.

[1] Livne et al. "Universal Aspects of Dynamic Fracture in Brittle Materials," Proceedings from the 8th Experimental Chaos Conference, Florence, Italy (2004)

Our System

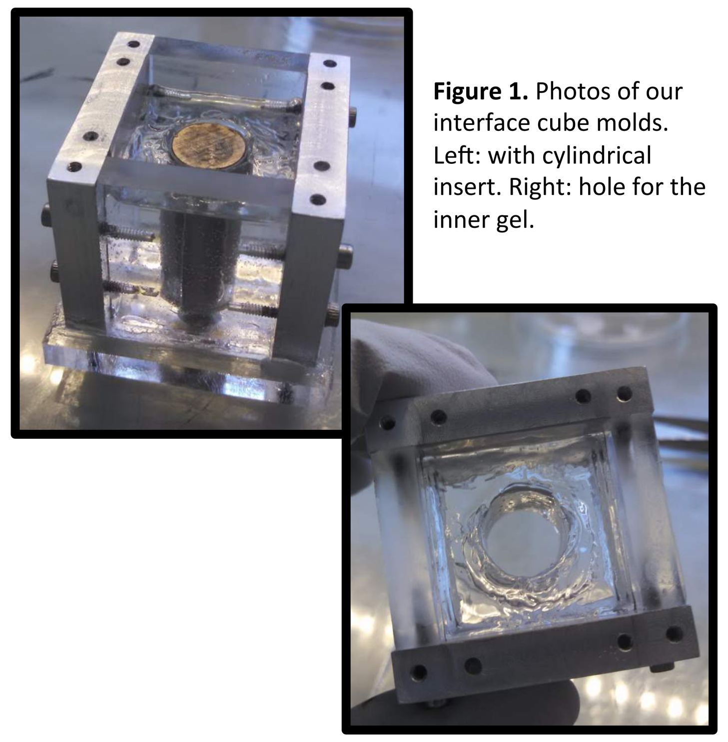


Figure 1. Photos of our interface cube molds. Left: with cylindrical insert. Right: hole for the inner gel.

We make interface cubes of PEG (polyethylene glycol) gel that are 1 cubic inch. We set two distinct gels in the same mold using a multi-step process. We begin by setting an outer gel around a teflon coated aluminum rod (see figure 1). Once the outer gel has polymerized, we remove the rod and set another gel in the cylindrical hole. After the inner gel has set we remove the entire cube & insert a glass capillary into the center of the gel.

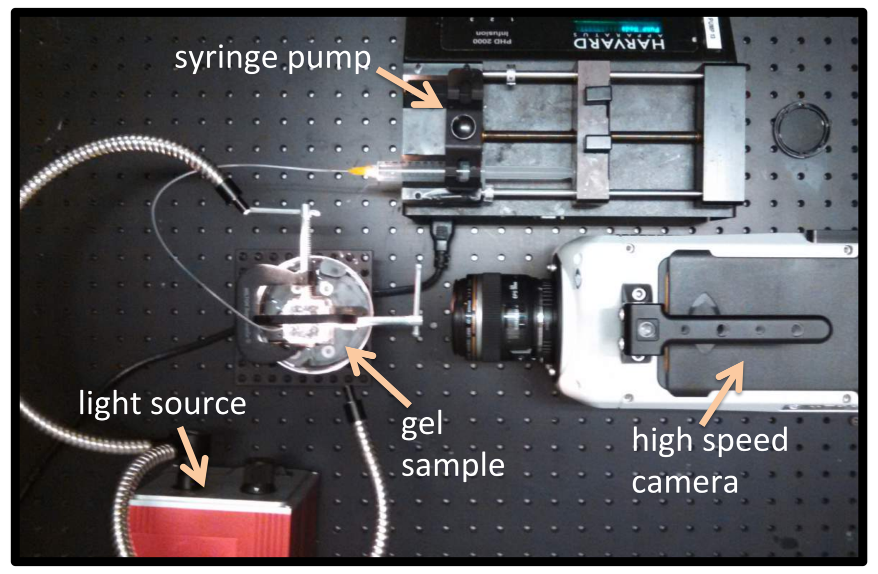


Figure 2. Top view of our fracture filming setup. The syringe pump pumps fluid through the capillary at a constant rate (2 ml/min). The gel cube is compressed by 2 C-clamps (to force it to break in plane), & it sits on top of an angled mirror, so our videos are actually filmed from below.

We fracture the cubes by pumping air or fluid into the gel through the capillary. At some point, the pressure of the fluid exceeds the strength of the gel, & our fracture begins to tear the gel in half. We take high-speed videos of this process at 10,000 frames per second.

We often do microscopy on our gel fracture surfaces afterwards. The cubes generally break in half, & we can then remove the top half of the gel to expose the bottom fracture surface. This allows us to image the detailed fracture features, enabling us to do post-mortem forensic analysis of the hydraulic fractures.

Results

Thus far, our results are almost exclusively qualitative. We have been doing preliminary experiments to optimize our system & determine what areas of interest to pursue.

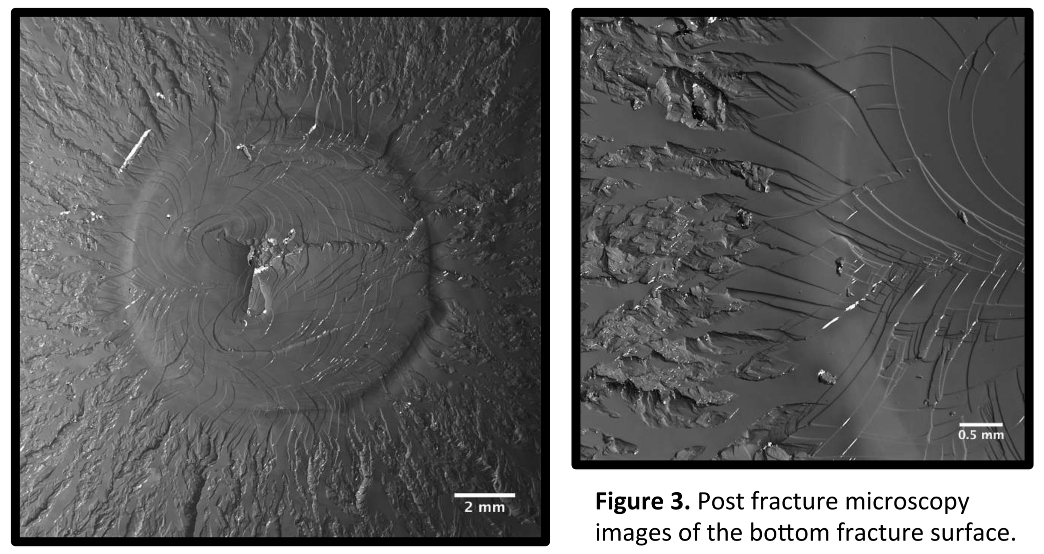


Figure 3. Post fracture microscopy images of the bottom fracture surface.

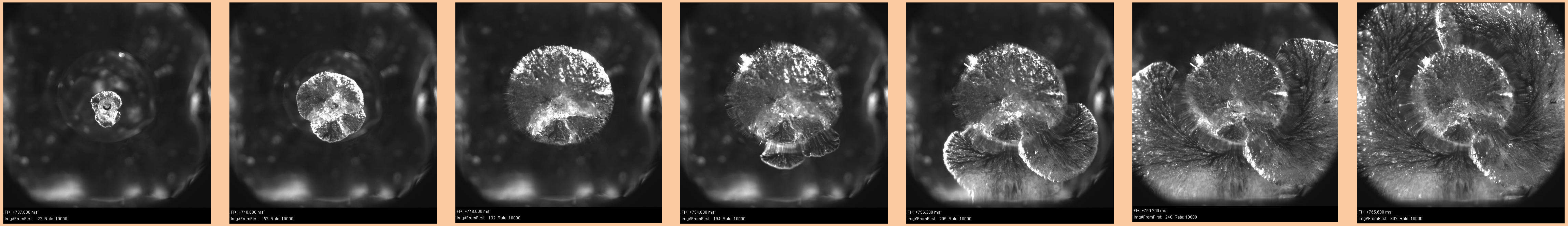
Conclusion

We have successfully devised a system for studying how hydraulic fractures react to interfaces. We are able to set multiple gels in the same mold, creating a clear, discernable interface. We have also been able to get numerous videos of hydraulic fractures in interface gels, with high temporal resolution. However, these fractures are very complex and there are still a lot of open questions.

Future Vision

We are currently working towards embedding index matched tracer particles in our gels, which we would then excite using a laser sheet microscope while simultaneously taking a high speed video of the fracture. This would give us 3D stress and strain maps of the fractures. We want to learn more, in hopes of better understanding fracking operations.

Time Lapse of a Hydraulic Fracture: An interface cube with a soft inner gel surrounded by a tough outer gel



Time from fracture initiation: 2.2 ms, 5.2 ms, 13.2 ms, 19.4 ms, 20.9 ms, 24.8 ms, 30.2 ms

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