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AN IMPLICT LEVEL SET ALGTRITHM FOR HYDRAULIC FRACTURES

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ABSTRACT

Fluid-driven fractures are a class of tensile fractures that propagate in compressively prestressed solid media due to internal pressurization by an injected viscous fluid. Hydraulic fractures occur both naturally due to the flow of pressurized magma as well as in engineering applications such as: block caving in mining, remediation projects in contaminated soils, and most commonly for the stimulation of hydrocarbon-bearing rock strata to increase production in oil and gas wells. There has been considerable analytic and experimental effort devoted to characterizing the different physical regimes of propagation for hydraulic fractures. The near-tip asymptotic form of the fracture width w exhibits a different power law behavior depending on the dominant physical process governing the propagation of the fracture. In general, this behavior is even more complex and occurs on multiple length scales. Indeed, as one moves away from the tip, w assumes different functional forms depending on the dominant physical process active locally.

A hitherto open computational problem has been to develop robust numerical algorithms that will be able to simulate planar fractures in three dimensional elastic media that are able to capture these multiple length scales and regimes of propagation with reasonable computational resources. One of the major challenges in this process has been to find a robust algorithm that will locate the unknown boundary of the fracture. In this talk we describe a novel algorithm that is based on an implicit level set method to locate the free boundary. The algorithm exploits the applicable local tip asymptote to locate the unknown fracture front. The algorithm does not rely on the calculation of the normal front velocity from the pressure gradient field, which is typically singular at the tip. In fact, the implicit algorithm is able to provide accurate estimates of the normal velocity of the front by solving an appropriate nonlinear equation within each element of a small set of elements close to the fracture front. The fact that this implicit algorithm does not require the velocity field as an input function is also novel in the level set context.

We provide numerous examples that demonstrate the robustness, efficiency, and accuracy of the algorithm for fractures that propagate in a variety of regimes: toughness dominated, viscosity dominated, and leak-off dominated.