An approach to study hydraulic fracturing using a fully coupled SPH framework

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Abstract

Hydraulic fracturing has been used extensively as a successful stimulation method to improve production from oil and gas reservoirs. It is a very complex process that can be more simply defined as the initiation and the propagation of cracks due to the injection of fluid at high pressure into the formation. It is a multi-physics phenomenon involving fluid-driven fracture propagation, mechanical deformation of the rock, and fluid advection along the fracture and diffusion into the formation.

The paper presents an approach in Smoothed Particle Hydrodynamics (SPH) framework for modeling the initiation and propagation of fluid-driven fractures in brittle rocks. For nonlinear behavior of brittle rock, Drucker-Prager plasticity model is implemented to predict material shear failures due to plastic deformation. For tensile failure, the Grady-Kipp damage model is used. These two types of failure criterion have been coupled together so that both shear and tensile failures can be simulated within the same scheme. In the proposed method, fluid and solid are treated as a single system for the entire domain of interest, and are computed using the same stress representation within a uniform SPH framework. The velocity and stress continuity at the interface is maintained through kernel summation, which allows interactions between particles from different materials when solving the momentum equation. A corrected SPH approximation form of the density continuity equation is implemented to handle the density discontinuity of the two phases at the interface.

The above procedures have been applied to simulate rock deformation in a variety of rock mechanics test cases, including a hydrostatic problem, a penny-shaped crack in the presence of in-situ stresses and a hydraulic fracturing case. Results for elastic deformation obtained using SPH have been compared to analytical solutions (where available) for these test cases. The simulation of fracture initiation and propagation in the hydrofracturing case is also presented in this work. Good results demonstrate that SPH has the potential to accurately simulate the hydraulic-fracturing phenomenon in brittle rocks.

Keywords: SPH, hydraulic fracturing, fluid-solid coupling, fracture mechanics