Hydraulic fracturing in pre-fractured media

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Introduction

Hydraulic fracturing in structured rocks is controlled by the orientation of layers and preexisting fracture sets in relation to the in-situ stress field. The opening of pre-existing fractures is favored over the initiation of new hydraulic fractures through the rock matrix in many injection operations. Applications include waste disposal, grouting, enhanced hydrocarbon recovery from unconventional reservoirs, CO_2 sequestration, and deep geothermal systems. This experimental study investigates the competing influences of stress and fabric on the propagation of fractures in pre-fractured media.

Devices and test procedure

True triaxial load frame and injection system

A large-scale true triaxial testing frame houses a 50cmx50cmx50cm prefractured rock specimen and subjects it to independant boundary stresses of up to 3 MPa. Each loading direction is controlled by a pair of hydraulic flatjacks (50cmx50cmx0.4cm). Each pair of flatjacks connects to a computer-controlled syringe pump; this allows for independent control of the three principal stresses. An additional syringe pump is used to inject viscous silicone into the center of the specimen through an injection tube embedded at the center of the cubic specimen (flow rate of q=1 mL/min). We place a 3 mm rubber layer between the specimen and the flatjack to mitigate boundary effects. Each face is instrumented with piezoelectric transducers for P-wave measurements; the sources connect to a function generator and power amplifier while the receivers connect to a filter/amplifier and a digital oscilloscope (Figure 1-a. Details in Garcia et al., 2018).

Specimen Preparation

The hand-assembled pre-fractured rock specimen comprises 4000 precut limestone blocks (2.5cm×2.5cm×5cm). The blocks are arranged to construct packing geometries that mimic natural fractured rock systems: (1) layers of quasi randomly oriented blocks with one continuous plane, (2) a horizontal geometry with two continuous planes and (3) vertically stacked blocks with three continuous planes. Figure 1 highlights the experimental device and fabric geometries (Figure 1-b).

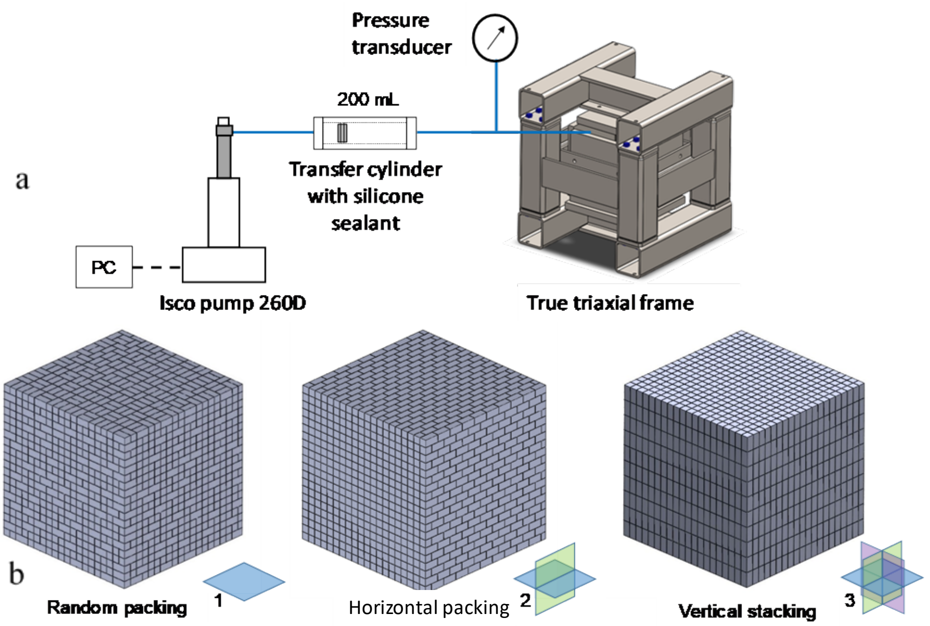

Figure 1: (a) True triaxial device and injection system. (b) Three different fabric geometries

Test procedure

Different confining stresses are applied to the three packing geometries in order to investigate the competing effects of stress and fabric anisotropy (Table 1). The injection pressures are recorded at the pump and along the injection line to estimate the pressure at the tip. We conduct P-wave measurements before, during and following the injection process. The silicone caulking hardens within three days, then the triaxial frame is disassembled and the blocks are individually removed. In particular, the volume affected by the injected silicone is carefully disassembled in order to acquire the fracture imprint.

Table 1: Coda Wave Stretching Factors and Principal Stresses

Specimen Geometry	**Stress [kPa] (X,Y,Z)**	**X**	**Y**	**Z**
Random Packing	(100,100,100)	1.012	1.011	1.052
Horizontal packing	(1000,1000,50)	1.020	1.012	1.041
Vertical Stacking	(200,600,400)	1.035	1.024	1.014

Results

Injection Pressure Curves

The pressure signature for the random packing and the horizontal packing are not steady and pressure peaks point to sequential breakthroughs taking place within the pre-fractured medium. On the other hand, the pressure signature obtained under extreme stress anisotropy (20:1) is quite steady in agreement with continuous fluid invasion perpendicular to the minimum principal stress.

P-wave Propagation

P-wave measurements in all three directions were conducted on each specimen before and after the silicone injection. The signal obtained after the injection was compared with the original signal using coda wave analysis; Table 1 summarizes the stretching factors computed for all three directions. Higher factors correlate with directions transverse to higher silicone invasion. These factors confirm the relative importance of stress and fabric anisotropy on the flow invasion path.

Fracture imprint

Images of the hydraulic fracture imprints were obtained by suspending the extracted imprints in salt water to match density (Figure 2). A detailed analysis of the fracture imprint shows that hydraulic fracturing in fractured rock masses involves the opening of pre-existing discontinuities. The fracture imprint has a characteristic three-dimensional branching geometry with sheet invasion along pre-existing planes near the injection point, and preferential invasion along the block edges away from the injection point (i.e., block rotation and dilational distortion). Results from this limited set of fabric-stress combinations reveal that fabric is more important than stress anisotropy on invasion topology: flow in all fracture sets occurs despite large stress anisotropy.

Figure 2: Photographs of the silicone fracture imprint

Reference

Garcia, A. Rached, R. and Santamarina, J.C. (2018). Large-scale True Triaxial Apparatus for Geophysical Studies in Fractured Rock, ASTM Geotechnical Testing Journal, in print