EGU2020-14434
https://doi.org/10.5194/egusphere-egu2020-14434
EGU General Assembly 2020

Fluid-driven tensile fracture and fracture toughness in Nash Point Shale at elevated pressure.

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Fluid-driven fracturing is a key process in enhancing production in both the hydrocarbon and geothermal energy extraction industries. However, whilst a large number of studies have now developed laboratory methods to simulate the process in a range of settings, and across a number of different rock types, data relating the fundamental material parameters (such as fracture toughness) to the overall rock mechanics response as a function of parameters such as confining and pore pressure remain limited. Here we report a new analysis to recover fracture toughness across a range of effective pressures from hydraulic fracturing experiments that use a modified thick-walled cylinder sample mounted in a conventional triaxial deformation apparatus. We use samples that are 90mm in length and 40mm diameter, with a central, axially drilled borehole 12.6 mm in diameter. An array of 16 ports in the engineered, nitrile, sample jacket allows us to record radial strain (4 channels), acoustic emission output (11 channels) and borehole fluid pressure (1 channel) continuously throughout each test. The sample material was Nash Point shale (NPS) from the south coast of Wales, UK, with samples cored both normal and parallel to bedding in order to investigate the effect of anisotropy. Earlier, ambient pressure fracture toughness tests using the Semi-Circular Bend sample geometry had indicated significant anisotropy, values of 0.24 – 0.30 $MPa.m^{1/2}$ in the Short-Transverse (ST) orientation, and 0.71 - 0.73 $MPa.m^{1/2}$ in the Divider (DIV) orientation.

Here, we present results from a suite of 9 experiments, 6 with samples cored parallel to bedding (ST fracture orientation) and 3 with samples cored normal to bedding (DIV fracture orientation). We find that the fluid injection pressure required to fracture our annular shell samples is significantly higher for DIV samples than for ST samples, and increases significantly with increasing confining pressure in both orientations; ranging from 10 to 36 MPa for ST samples and 30 to 58 MPa for DIV samples as confining pressure is increased from 2.2 to 20.5 MPa. We note that the fluid injection pressure undergoes a number of oscillations between fracture nucleation and the fracture reaching the sample boundary. Such oscillations are more common in ST samples than in DIV samples, and in experiments at lower confining pressures. We use the magnitude of each pressure oscillation to estimate the associated increment of fracture extension via the proportion

of AE energy generated relative to the total energy accumulated when the fracture reaches the sample boundary. This analysis produces fracture toughness values ranging from 0.36 to 2.76 MPa.m$^{1/2}$ (ST orientation) and 2.98 to 4.05 MPa.m$^{1/2}$ (DIV orientation) as confining pressure was increased from 2.2 to 20.5 MPa. We further find that the increase in fracture toughness increases essentially linearly with increasing effective pressure, and this trend appears to be independent of orientation and the material anisotropy.