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Does the linear hydraulic fracture mechanics predict well the fracture growth in quasi-brittle rocks under laboratory conditions?

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Predicting the growth of fluid-driven fractures in geological systems is essential for the sustainable and efficient engineering of oil and gas reservoirs. The linear elastic hydraulic fracture mechanics (LHFM), which combines the linear elastic fracture mechanics and lubrication theory, has described well the fracture growth in brittle materials. However, the quasi-brittle nature of reservoir rocks may result in deviations of the fracture propagation from LHFM predictions. We have experimentally investigated the propagation of hydraulic fractures in quasi-brittle rocks under true triaxial stress conditions. We have performed HF injections in 250x250x250 millimeters Zimbabwe gabbro samples in the toughness-dominated growth regime. We use active acoustic monitoring to measure the evolution of fracture radius from diffracted waves and estimate fracture width from transmitted waves (Liu et al., 2020). Assuming a radial and uniformly pressurized crack, we find that LHFM predictions overestimate fracture radius inverted from diffracted acoustic waves but underestimate the measured injection fluid pressure. Using the same radial uniformly pressurized linear elastic fracture model, we also estimate an apparent toughness from the measured fracture radius and pressure. This estimated apparent toughness is not constant and tends to increase with fracture extent in some cases up to a constant value. We also obtain another estimate of fracture toughness from fracture width back-calculated from transmitted waves for a few snapshots of the fracture evolution. These two estimates of the fracture apparent toughness are mostly consistent, although higher values are obtained when the estimation is based on pressure measurement. We also observe an attenuation of transmitted waves across the fracture plane prior to the arrival of the fracture front obtained from diffracted waves. This allows us to estimate a process zone size in the range of two to six centimeters (depending on experiments). In addition, post-test micro-CT images reveal the presence of a microscale fracture path with some 3D crack branches and bridges. The thickness of such a crack band is a few millimeters on par with both grain size and the roughness of the fracture surface measured after the test. These experiments document an increase of the process zone size at the early stage, which stabilizes afterward in some of the experiments. It is important to note that complete separation of scales between fracture radius, process zone, and sample size is hardly achieved in these experiments. A non-negligible influence of the process zone may thus explain the reported deviation from LHFM predictions in gabbro. No effect of the minimum confining stress was visible in the range investigated here (0 to 10 MPa). The applied minimum stresses were

always smaller than the reported peak tensile strength for this rock, a domain where the effect of the quasi-brittle nature of rocks is not anticipated to be significant based on recent theoretical results (Garagash, 2019; Liu & Lecampion 2021).