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Permeability evolution of induced shear fractures at varying effective pressures using the saturated Punch-Through Shear test

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The permeability of geothermal reservoirs is often low and requires enhancement techniques such as hydraulic stimulation. The fractures generated by hydraulic stimulation have been described as purely tensile for a long time. However, borehole and seismic analysis methods have proven that macroscopic shear fracturing is a common fracture mechanism for the stimulation of geothermal reservoirs, especially in crystalline rock. To properly describe the evolution of fracture permeability during the fracturing process in the laboratory, a flow parallel shear fracture generated under in-situ reservoir conditions is required. Such a configuration is missing in the present literature.

We demonstrate a setup for the generation of a cylindrical shear fracture allowing for fracture parallel flow conditions. Our innovative Punch-Through Shear (PTS) setup, which was previously used to measure the unsaturated mode II fracture toughness, enables permeability and strain measurements under elevated pore and confining pressures. Two notched cylindrical samples of intact Odenwald granite are installed into a MTS tri-axial compression cell. A self-designed end-cap with a cylindrical loading stamp guided by a hollow cylinder, punches down the inner cylinder of the sample, applying a constant displacement. This creates the desired fracture geometry. A constant flow rate is applied through fluid ports from the bottom of the sample towards the top such that permeability is measured for the entire duration of the experiment. An extensometer chain measures the circumferential strain of the sample, from which fracture aperture can be inferred. After the generation of the fracture, the shear displacement is increased. The effective pressure is varied by increasing and decreasing the pore pressure by 5 and 10 MPa at a constant confining pressure of 40 MPa, to simulate injection and production scenarios and to monitor the subsequent evolution of the fracture permeability. The friction coefficient is determined from the stress state during the experiment, measured by the load cell. CT scans were made after the experiment to characterize the fracture geometry.

The increase of flow volume from the bottom during loading demonstrates the shear fracture propagation from bottom to top. Shear fracturing increases the permeability of the granite rock from less than 1 μD to the about 1 mD. After failure, further shear displacement leads to no noticeable increase of permeability, and effective pressure cycling reduces permeability by less than half an order of magnitude. After displacement is stopped, repeated pore pressure changes lead to a sudden stress drop, caused by further slip along the shear plane. Although slip events occur, friction never reaches the critical value of 0.85 as predicted by Byerlee (1978). CT scanning images show that the fracture network is rather complex and deviates from the assumption of a single cylindrical shear fracture.