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Investigation of fault damage zones from direct shear tests and implications for hydraulic fracturing process

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Hydraulic fracturing is an important stimulation technique for extracting resources from low-permeable formations. Apart from hydraulic fracturing (where pore pressure exceeds the minimum principal stress), hydraulic shearing (where pore pressure does not exceed the minimum principal stress) is an essential mechanism in forming the stimulated reservoir volume and controlling the ultimate stimulation results, especially for shale formations with layered beddings (Li et al., 2019). Shear failure in rocks will not only generate primary fractures but also cause stress alteration in the neighboring region around the primary fracture. Such stress alteration affects the rocks' stability and possibly induces more secondary fractures. This phenomenon is also known as fault damage zones, commonly observed in rock masses at different scales (Kim et al., 2004; Sui et al., 2019). In reality, it is almost impossible to directly observe the shear failure process in the subsurface. Therefore, in this work, we adopted an advanced dynamic direct shear testing device to break rocks (Qi et al., 2020) and a micrometer CT to observe the fault damage zones after the shear failure. Quantitative descriptions of the damage zone, such as fracture intensity, roughness, and connectivity, are summarized.
In this research, an independently designed dynamic direct shear testing device (Qi et al., 2020) was utilized to conduct in-house direct shear tests on layered shale specimens with various layer angles (0°, 30°, 45°, and 60°). Subsequently, the sheared shale specimens were scanned with a micrometer CT, and 3D digital cores were reconstructed. Fine segmentation of micron-scale fractures in inhomogeneous shale was achieved using multiple processing algorithms. Considering different bedding structural surfaces, the physical properties and geometrical features of 3D micrometer-scale fractures in shale were quantitatively evaluated. Parameters such as fracture density, 3D shape factor, roughness, Euler number, and morphological filtering were employed to subdivide the damage zones along the main fracture surface.
From the preliminary results, we divided the generated fractures into three categories based on their spatial distribution: the primary induced fracture, fractures in the connected damage zone, and isolated fractures. The range of damage zones varies significantly with different bedding angles. With the increase in bedding inclination, the density of fine fractures distributed along the primary shear fractures initially increases and then decreases, reaching the maximum in samples with 30°inclined layers. The roughness of primary fracture surfaces and secondary fractures in shale samples with different bedding angles displays significant anisotropy and asymmetry, with greater roughness observed at the microfractures and fractures in connected damaged zones. Morphological patterns of the three types of fractures are further discussed. An in-depth understanding of the fault damage zone provides valuable insights to evaluate and optimize the hydraulic fracturing process.

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