

Effect of Parallel Stresses on Deformation Characteristics of Hydraulic Fracture Tips Postprint

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Abstract

To investigate the influence of parallel fracture stress on hydraulic fracture propagation, this study pre-fabricated penny-shaped fractures in 30-cm cubic artificial cement specimens, with 4 FBG optical fibers containing 20 strain measurement points placed ahead of the fracture front. By varying the intermediate principal stress ($\sigma_H = 12, 21, 30$ MPa), hydraulic fracturing experiments were conducted to analyze fiber deformation, breakdown pressure, and fracture surface characteristics during fracture initiation and propagation. Simultaneously, analytical solutions for strain at the tip of penny-shaped hydraulic fractures were employed for analysis. The following conclusions were obtained: (1) Parallel fracture stress exerts a compaction effect, causing the material to exhibit plastic hardening, which increases the effective fracture toughness and raises both the breakdown pressure and propagation pressure. (2) As σ_H increases, mixed-mode fracture occurs more readily, with fracture surfaces exhibiting curved surfaces, step-like features, etc., and the roughness of fracture surfaces increases accordingly. (3) The hydraulic fracture tip comprises a sub-critical fracture zone, nonlinear zone, unloading damage zone, and elastic zone; the nonlinear zone at the fracture tip displays elastoplastic characteristics, manifesting as “heart-shaped” or “rabbit-ear-shaped” configurations. The fundamental reason for the increase in breakdown pressure is that parallel fracture stress enlarges the area and deformation magnitude of the nonlinear zone at the fracture tip. This research holds significant importance for understanding deformation characteristics at hydraulic fracture tips and can be used to correct criteria for hydraulic fracture initiation and propagation. It also provides mechanistic insights for interpreting fracture propagation modes and fracturing impacts from field DAS and DSS data.

Full Text

Preamble

Investigation of Hydraulic Fracture Propagation Subjected to Crack-Parallel Compressive Stress

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Abstract

To investigate the influence of crack-parallel stress on hydraulic fracture propagation, this study conducted hydraulic fracturing experiments on 30 cm cubic artificial cement specimens with pre-existing penny-shaped cracks. Four fiber Bragg grating (FBG) optical fibers comprising 20 strain measurement points were placed ahead of the crack tip. By varying the intermediate principal stress ($\sigma_H = 12, 21, 30$ MPa), we analyzed fiber deformation, breakdown pressure, and fracture surface characteristics during crack initiation and propagation. Analytical solutions for strain at the tip of a penny-shaped hydraulic fracture were also employed for comparative analysis.

The results reveal that: (1) Crack-parallel stress exerts a compaction effect, causing the material to exhibit plastic hardening behavior, which increases the effective fracture toughness and raises both breakdown and propagation pressures. (2) As σ_H increases, mixed-mode fracture becomes more likely, with fracture surfaces displaying curvature, step-like features, and increased roughness. (3) The hydraulic fracture tip can be divided into a subcritical crack region, nonlinear zone, unloading damage zone, and elastic zone. The nonlinear zone at the crack tip exhibits elastoplastic characteristics, manifesting as a “heart-shaped” or “rabbit-ear” configuration. The fundamental reason for the increased breakdown pressure is that crack-parallel stress enlarges the area and deformation magnitude of the nonlinear zone at the crack tip. This research provides important insights into deformation characteristics at hydraulic fracture tips, can be used to correct criteria for hydraulic fracture initiation and propagation, and also offers mechanistic understanding for interpreting fracture propagation patterns and fracturing hits through distributed acoustic sensing (DAS) and distributed strain sensing (DSS) in field applications.

Keywords: crack-parallel stress; crack-tip deformation; optical fiber; nonlinear deformation; fracture process zone

Figure 1 [Figure 1: see original paper] Representative results showing artificial specimen with FBG optical fibers and post-fracturing crack morphology: (a) Schematic diagram of artificial specimen with optical fibers; (b) Specimen after fracturing.

Figure 2 [Figure 2: see original paper] (a) Optical fiber variation during fracturing and (b) measured values of hydraulic fracture tip deformation versus analytical solution for penny-shaped hydraulic fracture tip deformation.

Note: Figure translations are in progress. See original paper for figures.

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