HYDRAULIC FRACTURE PROPAGATION THROUGH GEOLOGICAL DISCONTINUITIES

By

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ABSTRACT

Hydraulic fracturing is a stimulation technique widely used to enhance hydrocarbon production and geothermal energy extraction. Other applications include waste disposal and cave inducement and preconditioning of ore for mining. Rocks are naturally fractured and therefore the little-understood problem of hydraulic fracture growth through these pre-existing discontinuities is a key area of research.

Mathematical criteria for predicting whether an induced fracture will cross a discontinuity have been published by several authors. Some used parameters that are difficult to quantify, neglected the stress induced by the hydraulic fracture itself and ignored fluid viscosity effects on crossing behaviour. Others ignored the presence of fluid in the hydraulic fracture, the possibility of fracture re-initiation after slippage and the effect of surface features on crossing. Numerical studies have shown that viscosity-dominated hydraulic fractures would induce slip on the discontinuity more easily than toughness-dominated hydraulic fractures. This implies that crossing should be more difficult for viscosity-dominated hydraulic fractures. To investigate the interaction between hydraulic and natural fractures, laboratory experiments are combined with numerical and analytical work in this thesis to extend two previously published criteria.

This thesis shows the effect of viscosity on the crossing interaction is complex and cannot be predicted based only on whether slip occurs on the discontinuity before the hydraulic fracture intersects it. The laboratory work can also be applied to improved understanding of the effect of the stress field on crossing as it relates to hydraulic fracture height growth. Prediction of the effect of weak bedding planes on height growth has recently gained importance as the risk of vertical growth of fractures into aquifers has emerged as a concern in shale gas and coal seam gas operations. The findings herein can be applied to this problem if the frictional interfaces are considered to represent weak bedding planes. Complete treatment of the height growth problem requires considering fracture growth through elastic layers with contrasts in physical properties.

The experiments show hydraulic fractures may grow to become elliptical because they extend more quickly and further in the direction of maximum stress or in the direction with fewer discontinuities. The preparation of the samples underlined the effect of local imperfections on discontinuities. Small areas of higher or lower contact stress can aid or inhibit fracture initiation. Rock plates must be smooth and flat in order to control this parameter and obtain valid experimental comparisons for contact stress and the other parameters controlling crossing.

Numerical and analytical results are presented as a mathematical expression with universal curves for the locations of slip starting points, providing an important aid for designing industrial hydraulic fractures. One difference between the approach used here and that used by others is their use of the fracture-tip singular stress solution, meaning they do not consider the effect of the non-singular stresses existing around a pressurised fracture. This thesis therefore improves their work.

Experimental and theoretical outcomes herein suggest that hydraulic fracture growth through an orthogonal discontinuity does not depend primarily on the interface friction coefficient. This finding contradicts several models.

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Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, Ella María Llanos Rodríguez, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Ella María Llanos Rodríguez
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SELECTED NOMENCLATURE

m: coefficient of friction of the discontinuity
T_o: tensile strength [MPa]
E: Young’s Modulus [GPa]
K: Permeability of the rock [mD]
K_{IC}: Fracture toughness [MPa $\sqrt{m}$]
Q: Injection rate [ml/s]
T: Fluid temperature [˚C]
k: permeability of the natural fracture
$\mathcal{K}$: dimensionless fracture toughness
t: time (s)
t_{mk}: characteristic time (s)
H: distance between closest tip of the hydraulic fracture and the discontinuity
L: distance between furthest tip of the hydraulic fracture and the discontinuity
P_f: internal pressure
Y_s: slip front location
L_*: characteristic length
h: evolving non-dimensional parameter
σ_x: horizontal compressive stress acting perpendicular to the interface [MPa]
σ_z: horizontal compressive stress acting parallel to the interface [MPa]
σ_y: vertical compressive stress [MPa]
τ: shear stress
σ_n: normal stress
ϕ: Porosity
ν: Poisson’s ratio
ρ: Density [gm/cm^3]
μ: Viscosity [Pa·s]
ϖ: residual opening of a closed natural fracture
Σ_*: characteristic stress