

HYDRAULIC FRACTURE PROPAGATION THROUGH GEOLOGICAL DISCONTINUITIES

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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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TABLE OF CONTENTS

ABSTRACT	III
ACKNOWLEDGEMENTS.....	V
DECLARATION	IX
LIST OF FIGURES	XV
LIST OF TABLES	XIX
SELECTED NOMENCLATURE	XXI
CHAPTER 1	1
INTRODUCTION	1
1.1. Preamble.....	1
1.2. Motivation.....	1
1.3. Background.....	7
1.4. Literature Review.....	9
1.5. Statement of the Problem Investigated in this Thesis	20
1.6. Summary.....	29
CHAPTER 2	31
LABORATORY METHOD	31
2.1 Sample Preparation	32
2.1.1 Rock and Fluid Properties	32
2.1.2 Surface Curvature	33
2.1.3 Sample Dimensions.....	34
2.1.4 Borehole Details	35
2.2 Test Preparation.....	37
2.2.1 Laboratory Setup	37
2.2.2 Injection Tool	38
2.2.3 Uniaxial Load Frame	39
2.2.4 Polyaxial Load Frame.....	39
2.2.5 Pressure and Temperature Monitoring	40
2.3 Test Procedure.....	41
2.4 Summary.....	43
CHAPTER 3	45
LABORATORY RESULTS AND DISCUSSION	45
3.1. Summary of Experimental Results.....	45
3.2. Applied Loading Stress Effect.....	48
3.2.1. Contact Stress and Surface Curvature.....	48
3.2.2. Frictional Discontinuity Conditions.....	49

3.2.3.	Interface Hydraulic Conductivity and Effective Normal Stress	49
3.3.	Fluid Viscosity Effect	50
3.3.1.	Viscous- vs. Toughness-Dominated Fracture Growth Regimes	50
3.3.2.	Penetration Effects	52
3.4.	Hydraulic Fracture Geometry	57
3.5.	Crossing Criteria Comparison	62
3.5.1.	Uniaxial Tests Results vs. Crossing Criteria	62
3.5.2.	Biaxial Tests Results vs. Crossing Criteria	65
3.6.	Summary	67
	CHAPTER 4	71
	MATHEMATICAL MODEL AND SCALING	71
4.1	Scaling	74
4.1.1.	Problem Definition	74
4.1.2.	Objective	76
4.2	Analytical Solution Method	77
4.2.1.	Problem Definition	77
4.2.2.	Failure Criterion and Solution Method	78
4.3	Numerical Solution Method	79
4.4	Summary	80
	CHAPTER 5	81
	MODELLING RESULTS AND DISCUSSION	81
5.1	Numerical Results	81
5.2	Analytical Results	83
5.3	Comparison between Numerical and Analytical Results	85
5.4	Universal Curves	86
5.5	Summary	88
	CHAPTER 6	89
	COMPARISON OF EXPERIMENTAL DATA TO MODELLING CALCULATIONS	
	89
6.1.	Propagation Stages	89
6.1.1	Geometry of the Problem	89
6.1.2	Hydraulic Fracture Approaching a Discontinuity	90
6.1.3	Hydraulic Fracture Contacting a Discontinuity	91
6.1.3	Hydraulic Fracture Infiltrating a Discontinuity	93
6.2.	Application	94
6.3.	Summary	95
	CHAPTER 7	97

CONCLUSIONS AND RECOMMENDATIONS97
APPENDIX A: ROCK PROPERTIES101
APPENDIX B: FLUID PROPERTIES109
APPENDIX C: SCRIPT FOR MATHEMATICA SOFTWARE.....111
APPENDIX D: DISPLACEMENT DISCONTINUITY ELEMENT SIZE113
APPENDIX E: UNIVERSAL CURVES.....115
REFERENCES117

LIST OF FIGURES

Figure 1. In situ stresses for vertical (left) and horizontal (right) grow of hydraulic fractures	7
Figure 2. Possible interactions between a hydraulic and a natural fracture: a) Crossing, b) Opening and c) Arresting.....	8
Figure 3. Cubic specimen under: a) uniaxial stress, b) triaxial stress, c) true-triaxial stress. After Jaeger et al., (2007)	10
Figure 4. Hydraulic fracture offsetting along a natural fracture. This photo was taken after mining of an access decline at Northparkes E26 mine. The hydraulic fracture growth was defined by using a red plastic proppant. The injected water contained fluorescein to serve as a fracture fluid marker. After van As and Jeffrey (2002).....	15
Figure 5. Hydraulic fracture that consists of two parallel branches. This photo was taken after mining of an access decline at Northparkes E26 mine. The hydraulic fracture growth was defined by using a red plastic proppant. The injected water contained fluorescein to serve as a fracture fluid marker. After van As and Jeffrey (2002)	15
Figure 6. Schematic diagram of Renshaw and Pollard's (1995) compressional crossing experiment. After Renshaw and Pollard (1995).....	21
Figure 7. Schematic diagram of Blanton's (1986) test configuration. After Blanton (1986).....	22
Figure 8. Plan of site after tunnels were extended through the area of hydraulic fractures. After van As and Jeffrey (2002)	25
Figure 9. Geometry of OpenT by Chuprakov et al. (2013a, 2013b).	27
Figure 10. Surface curvature profile obtained for block 6 side a – Before and After Grinding (solid and dashed lines respectively)	34
Figure 11. Borehole for biaxial setup.....	35
Figure 12. Borehole for uniaxial setup.....	36
Figure 13. Laboratory setup	37
Figure 14. Fracturing fluid injection tool.....	38
Figure 15. Uniaxial experimental setup	39
Figure 16. Biaxial experimental setup	40
Figure 17. Crossing case – lateral view.....	42
Figure 18. Non crossing case – lateral view.....	42
Figure 19. Fracture growth through discontinuities	43
Figure 20. Possible interface crossing observed.....	47
Figure 21. Injection pressure vs time behaviour.....	48
Figure 22. x-z Plane view of the biaxial setup.	53

Figure 23. Fluid leakoff: Experiments D11 (top) and D12 (bottom)	54
Figure 24. Lag zone extension with no fluid penetration: Experiments D13 (top) and D14 (bottom)	54
Figure 25. Convex surface curvature (looking in negative y direction) : Experiments D13 (top) and D14 (bottom).....	55
Figure 26. Convex surface curvature (looking in negative y direction) : Experiment D14 (bottom)	56
Figure 27. Effect of stress on hydraulic fracture geometry.	58
Figure 28. Fracture circular geometry vs. measured elliptical shape in central plate and two boundaries	58
Figure 29. Experiment D11: 1 Pa.s 12 Mpa.....	60
Figure 30. Experiment D12: 1 Pa.s 8 Mpa.....	60
Figure 31. Experiment D13: 100 Pa.s 4 Mpa. Ultimate extent of fracture without and with fluid lag (black and red lines respectively).....	61
Figure 32 Experiment D14: 100 Pa.s 8 Mpa. Ultimate extent of fracture without and with fluid lag (black and red lines respectively).....	61
Figure 33. Uniaxial tests results for fluid with 1Pa·s viscosity compared to Renshaw and Pollard (1995) and Gu and Weng (2010) crossing criteria.....	63
Figure 34. Uniaxial tests results for fluid with 100 Pa·s viscosity compared to Renshaw and Pollard (1995) and Gu and Weng (2010) crossing criteria.....	63
Figure 35. Uniaxial tests results for fluid with 1Pa·s viscosity compared to Blanton's (1986) crossing criterion.....	64
Figure 36. Uniaxial tests results for fluid with 100 Pa·s viscosity compared to Blanton's (1986) crossing criterion.....	64
Figure 37. Biaxial tests results presented after Renshaw and Pollard (1995) and Gu and Weng (2010).....	66
Figure 38. Biaxial tests results presented after Blanton (1986)	66
Figure 39. Geometry for the scaling problem definition	74
Figure 40. Geometry of the problem for the analytical calculation of h_p	77
Figure 41. Evolution of h_p with respect to m for different values of S – numerical results.	82
Figure 42. Evolution of h_p with respect to S for different values of m – numerical results	83
Figure 43. Evolution of h_p with respect to m for different values of S – analytical results	84
Figure 44. Evolution of h_p with respect to S for different values of m – analytical results	84

Figure 45. Evolution of h_p with respect to S for different values of m – Comparison between analytical and numerical results	85
Figure 46. Evolution of h_p with respect to m for different values of S – Comparison between analytical and numerical results	85
Figure 47. Behaviour of fitting coefficients (a,b) with respect to m	87
Figure 48. Behaviour of fitting coefficients (c,d) with respect to m	87
Figure 49. Behaviour of fitting coefficients (e,f) with respect to m	88
Figure 50. Geometry of the problem by Chuprakov et al. (2010).	90
Figure 51. OpenT results as function of intersection angle and dimensionless stress difference (from Chuprakov et al., 2013b).....	92
Figure 52. OpenT results as function of dimensionless stress difference and coefficient of friction (from Chuprakov et al., 2013b).....	93
Figure 53. Cross plot of minimum principal stress and maximum injection pressure (from Kaiser et al., 2013).....	95
Figure 54. Autonomous triaxial cell results – shear vs normal stress.....	103
Figure 55. Triaxial testing results – Poisson’s ratio	104
Figure 56. Triaxial testing results – Young’s modulus	105
Figure 57. Shear rate vs. shear stress results for honey and blue food dye, at 15 °C, 20 °C and 25 °C (Report 4 - Job Ref.: CSI012-04, 2004).....	110
Figure 58. Element size sensitivity analysis – normal and shear stresses profile	113
Figure 59. Universal curve, h_p as a function of S for m = 0.05	115
Figure 60. Universal curve, h_p as a function of S for m = 0.1	115
Figure 61. Universal curves, h_p as a function of S for m = 0.2 and m = 0.3	116
Figure 62. Universal curve, h_p as a function of S for m = 0.9	116

LIST OF TABLES

Table 1. Physical properties of the Donnybrook Sandstone and of the fracturing fluid	33
Table 2. Summary of experimental data: uniaxial tests for fluid with 1 Pa.s viscosity	46
Table 3. Summary of experimental data: uniaxial tests for fluid with 100 Pa.s viscosity	46
Table 4. Summary of experimental data: biaxial tests.....	46
Table 5. Parameters for calculating values of K for a time of 100 seconds.....	51
Table 6. Values of h for different values of L with regard to H.....	82
Table 7. Values of fitting coefficients for given values of m.....	86
Table 8. Values of fitting parameters.....	88
Table 9. UCS measurements	101
Table 10. Porosity measurements.....	101
Table 11. Permeability measurements.....	102
Table 12. Discontinuity friction coefficient measurements.....	103
Table 13. Poisson's ratio measurements.....	104
Table 14. Young's modulus measurements.....	105
Table 15. Brazilian tests parameters.....	106
Table 16. Semi-circular beam tests parameters.....	107

SELECTED NOMENCLATURE

m : coefficient of friction of the discontinuity

T_0 : 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 [$^{\circ}$ C]

k : permeability of the natural fracture

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/cm³]

μ : Viscosity [Pa·s]

ω : residual opening of a closed natural fracture

Σ^* : characteristic stress