Investigation of the fracture mechanics behaviour of the fluid driven mechanical fracture process in a highly anisotropic shale

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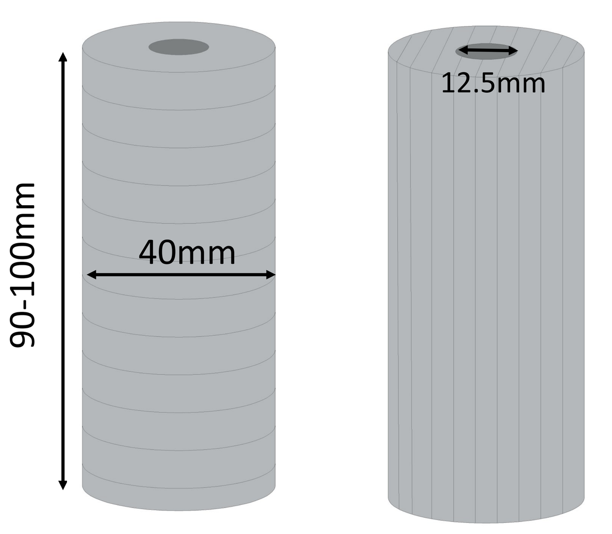
The finding of considerable volumes of hydrocarbon resources within tight sedimentary rock formations in the UK led to focused attention on the fundamental fracture properties of low permeability rock types and hydraulic fracturing. Despite much research in these fields, there remains a scarcity of available experimental data concerning the fracture mechanics of fluid driven fracturing and the fracture properties of anisotropic, low permeability rock types.

In this study, hydraulic fracturing is simulated in a controlled laboratory environment to track fracture nucleation (location) and propagation (velocity) in space and time and assess how environmental factors and rock properties influence the fracture process and the developing fracture network. A new technique has been developed, to allow a fluid-rock contact and to generate micro tensile fractures from the inside of the sample at various pressure conditions (axial pressure ≠ confining pressure). An early Jurassic shale from the Lower Lias, with a very low permeability and a high anisotropy of ≈57% (Vp), has been used for this experimental study.

Bedding orientation



Z-direction	X-direction
Cored normal (90°) to Bedding	Cored parallel (0°) to Bedding

Figure 1: Sample dimensions and orientation of bedding relative to coring axis

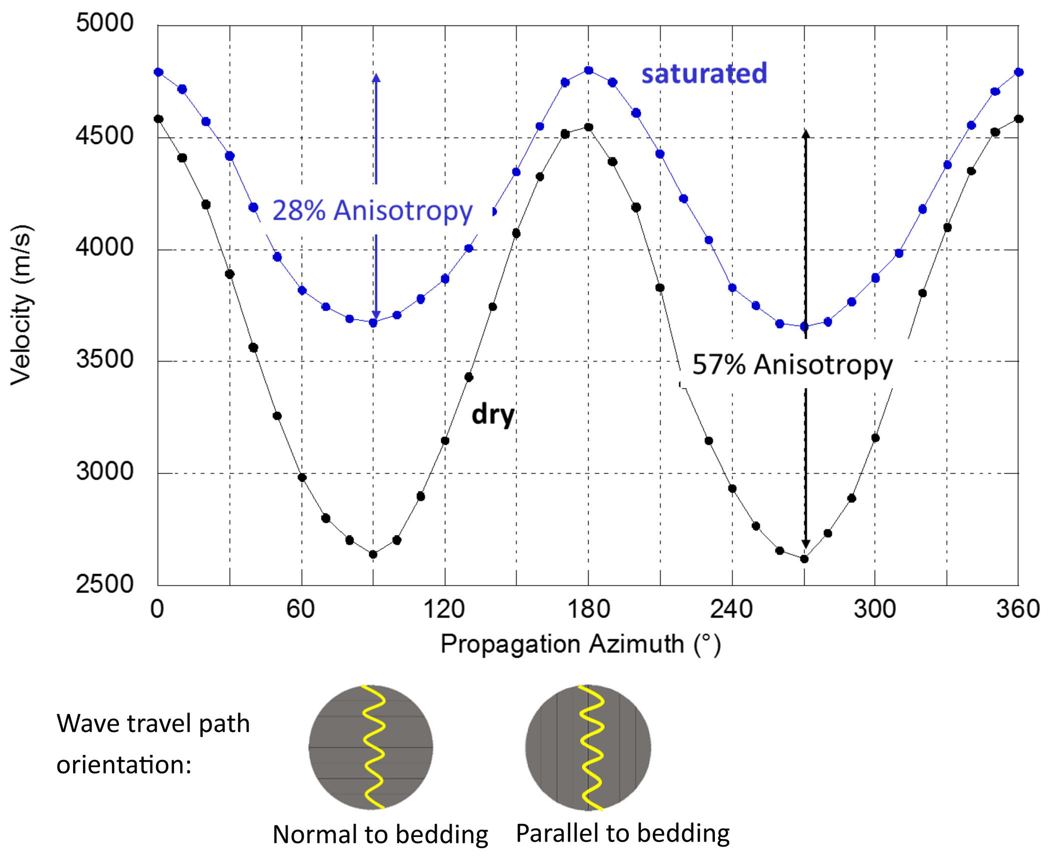


Figure 2: Elastic wave velocity measured parallel and normal to bedding and velocity anisotropy

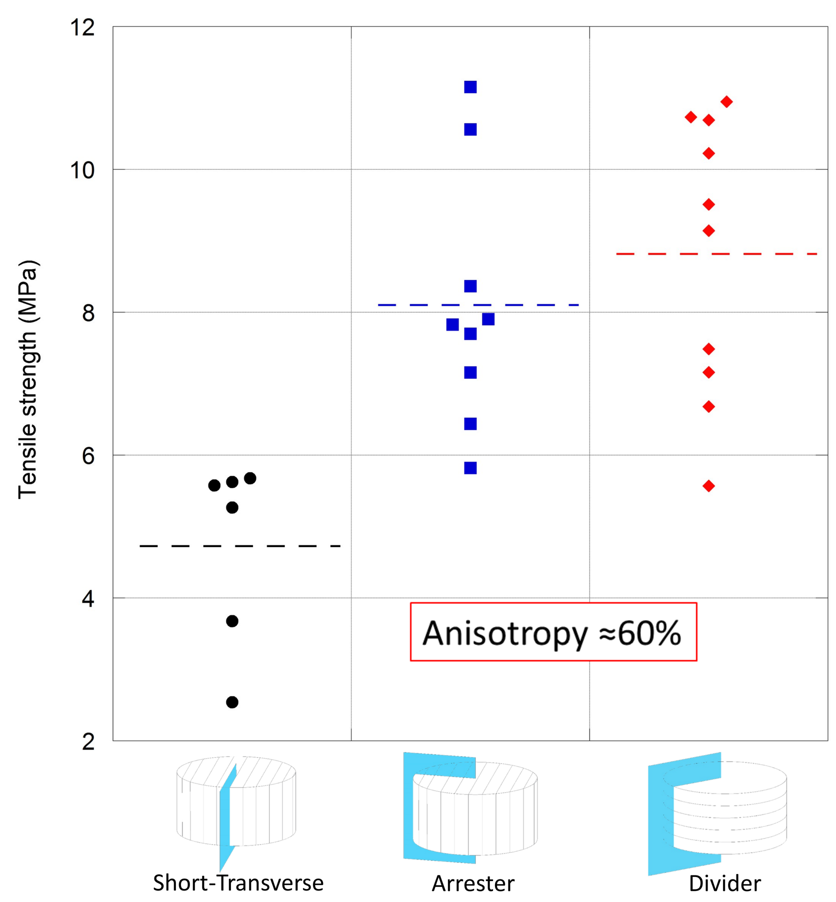


Figure 3: Indirect Tensile Strength measured in the 3 principal fracture directions (tested at ambient pressure conditions)

Fluid driven fracturing experiments

Fracture parallel to bedding — Short-Transverse

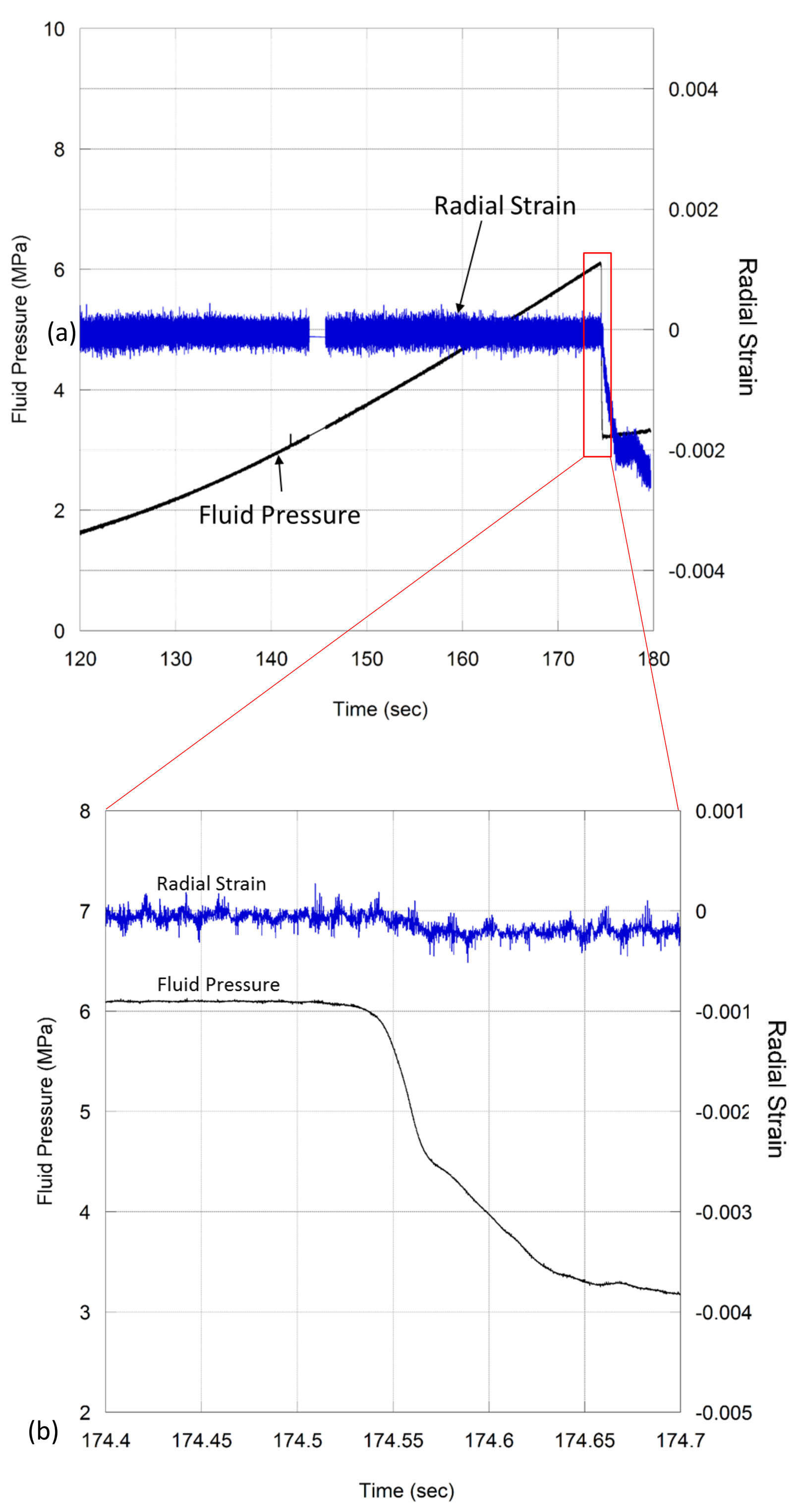


Figure 4: Fluid pressure and strain during fluid driven fracturing experiment (a) Entire experiment (b) Zoom in to time of failure [strain → compression (+) and tension (-)]

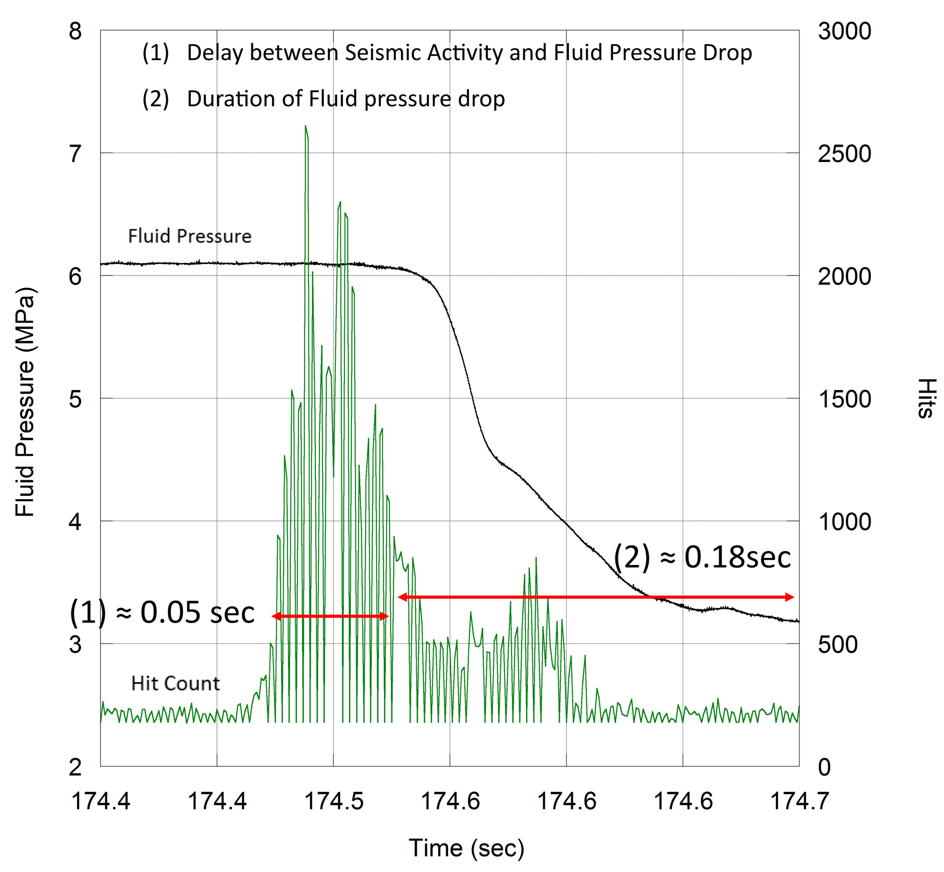


Figure 5: Fluid pressure and seismic activity at time of failure

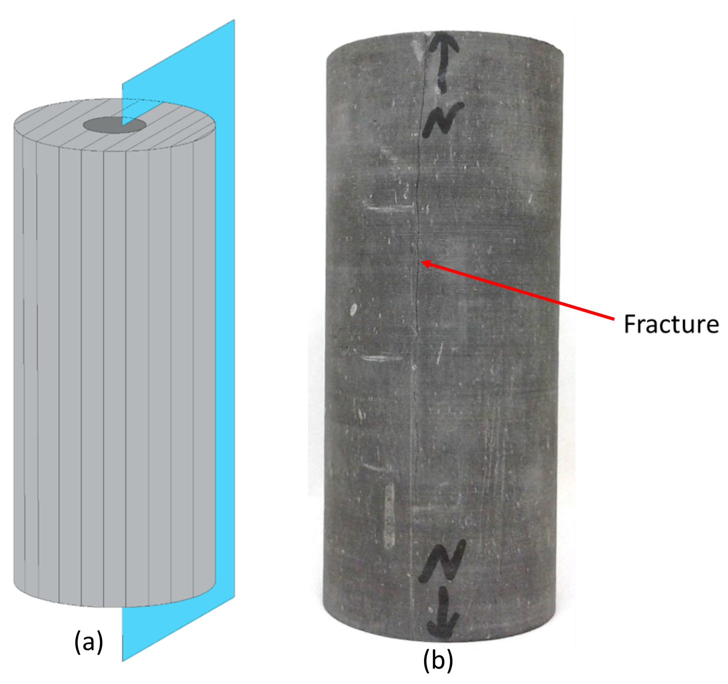


Figure 6: (a) Fracture Plane orientation relative to inherent bedding (b) Sample after fluid driven fracturing— one visible planar fracture along axis → Short-Transverse fracture direction (parallel to bedding)

Fracture normal to bedding — Divider

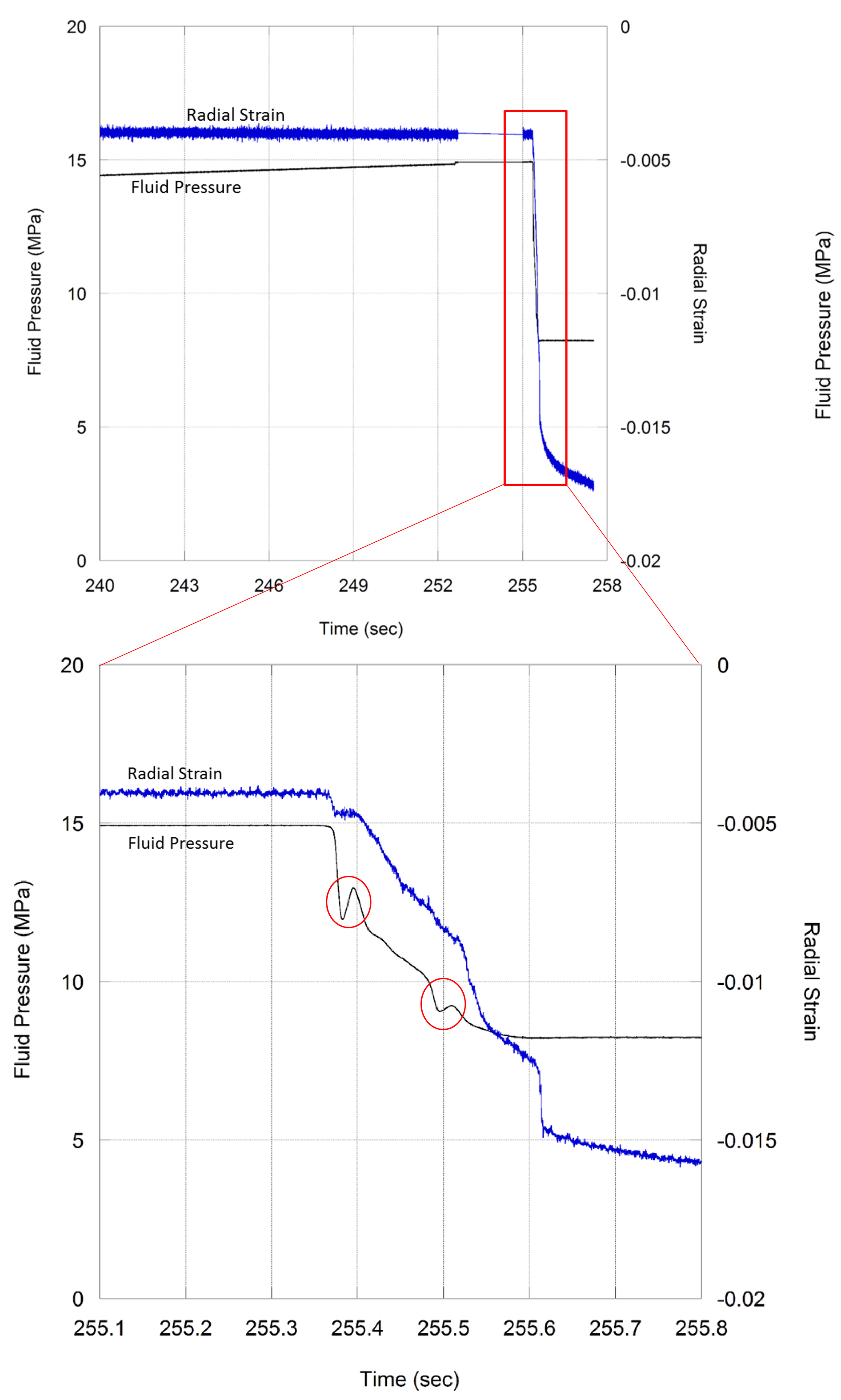


Figure 7: Fluid pressure and strain during fluid driven fracturing experiment (a) Entire experiment (b) Zoom in to time of failure [strain → compression (+) and tension (-)]

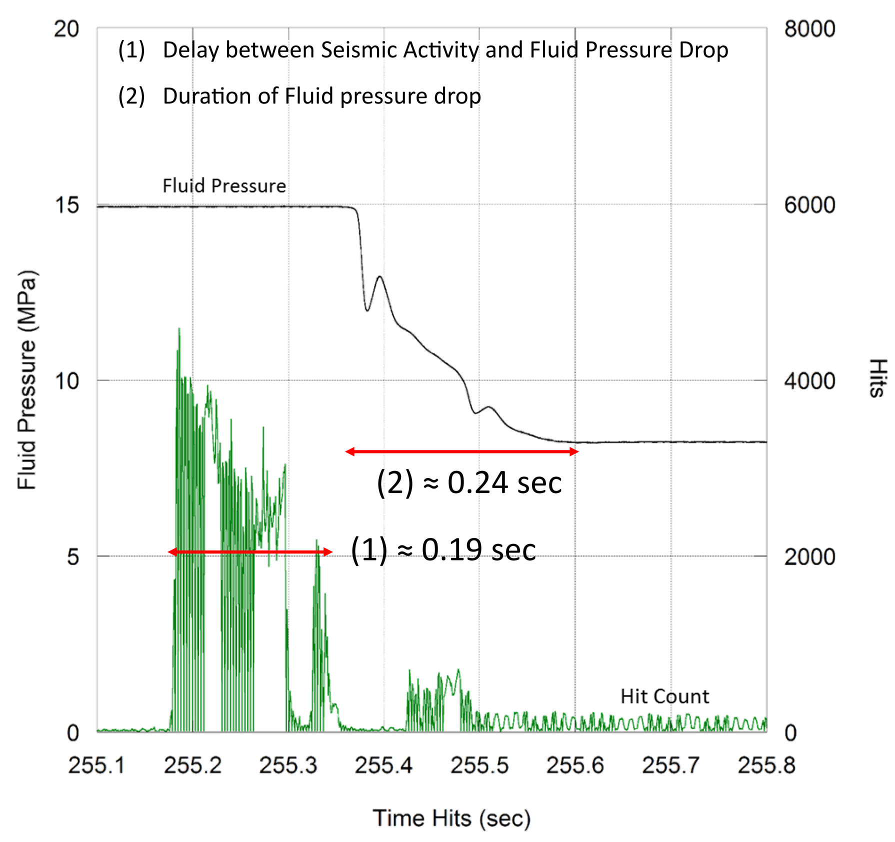


Figure 8: Fluid pressure and seismic activity at time of failure

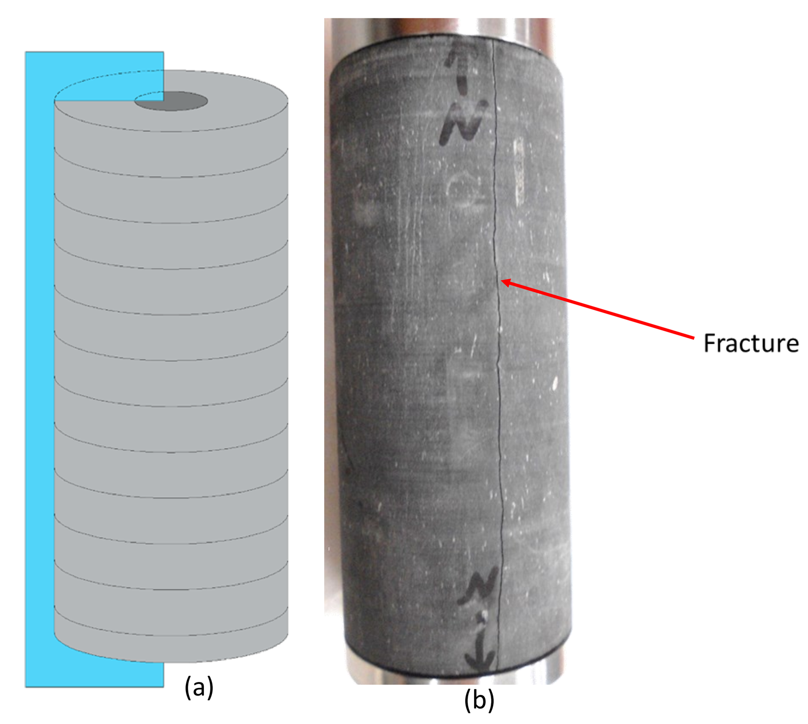


Figure 9: (a) Fracture Plane orientation relative to inherent bedding (b) Sample after fluid driven fracturing— one visible fracture along axis → Divider fracture direction (normal to bedding)

Overview of conducted experiments

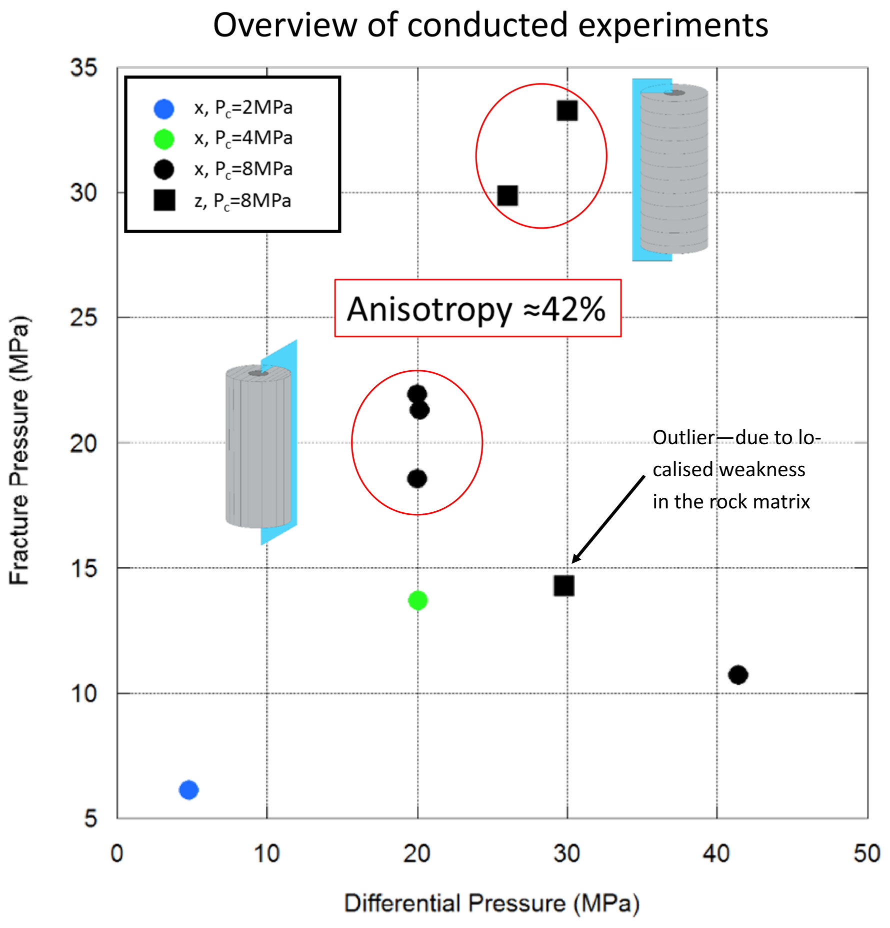


Figure 10: Fracture Pressure for different pressure conditions and bedding orientations — Shape = Bedding orientation; Colour = Pressure conditions

Conclusions

- Inherent Anisotropy within the rock changes significantly the mechanical properties and behaviour of the rock depending on the orientation relative to the anisotropic feature.
- Fracture propagation trajectories and fracturing fluid pressure are predominantly controlled by the interaction between the anisotropic characteristic of the shale and the stress environment
- Strength Anisotropy for hydraulic fracturing (~42%, tested at 8MPa confining pressure) is similar to that of indirect tensile strength (~60%, tested at ambient pressure conditions), suggesting similar fracture process and controls. (Difference are within margin if rock variability.)
- Despite the different fracture orientation relative to bedding planes, Short-Transverse and Divider fracture orientation developed planar axial fractures and show a similar seismic activity pattern.
- Fluid pressure drop and radial deformation occur at the same time, but with a time delay to the onset of seismic activity.
- Seismic activity starts ahead of fluid pressure drop and radial deformation with different delay periods depending on the fracture orientation: ~0.05sec for Short-Transverse (along bedding plane) and ~0.19sec for Divider (normal to bedding planes). → Potential to develop a real-time seismic monitoring system / forecast tool to warn operators and control the fracturing process to avoid uncontrollable fracturing and fracture extent.
- Pressure drop is faster when fractured along bedding planes: ~0.18sec for Short-Transverse compared to ~0.24sec for Divider (normal to bedding). Therefore faster fracturing velocity is recorded when fracturing along bedding planes than normal to bedding. This suggests that fracture speed is effected by the tensile strength of the rock and depends on the fracture propagation direction.