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Experimental Determination of the Fracture Toughness and Brittleness of the Mancos Shale, Utah.

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The hydraulic fracturing of Gas-Shales has become a topic of interest since the US Shale Gas Revolution, and is increasingly being investigated across Europe. A significant issue during hydraulic fracturing is the risk of fractures propagating further than desired into aquifers or faults. This occured at Preese Hall, UK in April and May 2011 when hydraulic fractures propagated into an adjacent fault causing $2.3M_L$ and $1.7M_L$ earthquakes [1].

A rigorous understanding of how hydraulic fractures propagate under in-situ conditions is therefore important for treatment design, both to maximise gas accessed, and to minimise risks due to fracture overextension. Fractures will always propagate along the path of least resistance, but the direction and extent of this path is a complex relationship between the in-situ stress-field, the anisotropic mechanical properties of the rock, and the pore and fracturing pressures [2]. It is possible to estimate the anisotropic in-situ stress field using an isolated-section hydraulic fracture test, and the pore-pressure using well logs. However, the anisotropic mechanical properties of gas-shales remain poorly constrained, with a wide range of reported values. In particular, there is an extreme paucity of published data on the Fracture Toughness of soft sediments such as shales.

Mode-I Fracture Toughness is a measure of a material's resistance to dynamic tensile fracture propagation. Defects such as pre-existing microcracks and pores in a material can induce high local stress concentrations, causing fracture propagation and material failure under substantially lower stress than its bulk strength. The mode-I stress intensity factor, K_I, quantifies the concentration of stress at the crack tip. For linear elastic materials the Fracture Toughness is defined by the critical value of this stress intensity factor; K_{Ic}, beyond which rapid catastrophic crack growth occurs. However, rocks such as shales are relatively ductile and display significant non-linearity. This produces hysteresis during cyclic loading, allowing for the calculation of a brittleness coefficient using the residual displacement after successive loading cycles. This can then be used to define a brittleness corrected Fracture Toughness, K_{Ic}^c.

We report anisotropic K_{Ic}^c values and a variety of supporting measurements made on the Mancos Shale in the three principle Mode-I crack orientations (*Arrester, Divider and Short-Transverse*) using a modified Short-Rod sample geometry. The Mancos is an Upper Cretaceous shale from western Colorado and eastern Utah with a relatively high siliclastic content for a gas target formation. The Short-Rod methodology involves the propagation of a crack through a triangular ligament in a chevron-notched cylindrical sample [3]. A very substantial anisotropy is observed in the loading curves and K_{Ic}^c values for the three crack orientations, with the Divider orientation having K_{Ic}^c values 25% higher than the other orientations. The measured brittleness for these Mancos shales is in the range 1.5-2.1; higher than for any other rocks we have found in the literature. This implies that the material is extremely non-linear. Increases in K_{Ic}^c with increasing confining pressure are also investigated, as Shale Gas reservoirs occur at depths where confining pressure may be as high as $35MPa$ and temperature as high as 100^oC.

References

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