Understanding the Variation in Drilling Rate Index with Fracture Toughness and Tensile Strength of Intact Rocks – Some Laboratory Scale Studies and Their Implications in Drilling*

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Abstract

Fracture toughness is an intrinsic material property expressing a material's resistance to crack propagation, and it is a measure of the energy required to create a new surface in a material. Considering the complicated laboratory test of fracture toughness, this study is an attempt at finding a satisfactory relationship between fracture toughness with acoustic and other rock mechanical properties, which can estimated with available techniques. Variety of sandstone rock samples were collected, grain size ranging from fine to coarse grain. They were then subjected to different laboratory scale tests, both destructive and non-destructive. Laboratory tests involved determination of compressional slowness, density, unconfined compressive strength (UCS), tensile strength, brittleness, Sievers' J-value and drilling rate index (DRI). The DRI is assessed based on two laboratory tests, the Brittleness Value S20 and Sievers' J-value SJ. Brittleness Test gives a good measure for the ability of the rock to resist crushing by repeated impacts and Sievers' Miniature Drill Test gives a measure for the surface hardness (resistance to indentation) of the rock. The purpose was to understand and obtain an empirical relationship of fracture toughness with different rock properties.

Samples tested had a compressional slowness values ranging from 65us/ft to 110us/ft. Experiments on the same samples revealed fracture toughness values vary from 0.3 to 2 MPa-m$^{1/2}$. Out of all the laboratory parameters determined, fracture toughness exhibited decent relationship with tensile strength (R^2=0.97), compressional slowness (R^2=0.49), UCS (R^2=0.54) and DRI (R^2=0.46). All of these correlations obtained are non-linear. Lowest uncertainty relationship is obtained with tensile strength with coefficient of determination of 0.97. Analysis proved that fast and stronger rock has larger fracture toughness.

This study will be helpful to estimation of fracture toughness of sandstones based on their sonic and rock mechanical parameters, which in turn can be utilized for classifying rocks into different categories, understand and model fracture propagation, drill energy requirements, drilling rate prediction, wear rate etc. The correlations developed here are confined to sandstone rock with similar rock properties.

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Understanding the variation in drilling rate index with fracture toughness and tensile strength of intact rocks – Some laboratory scale studies and their implications in drilling

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Outline

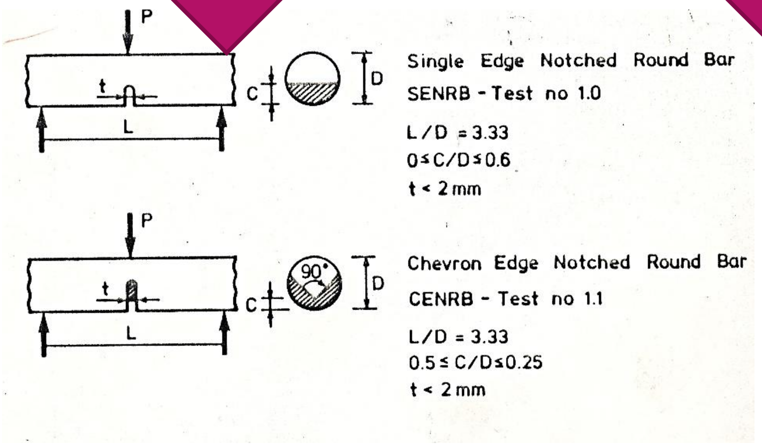
- Objective & Scope of Study
- Methodology
- Fracture toughness and its experimental setup
- Other Laboratory tests -Sievers' J Miniature Drill test, Brittleness Tests and Drilling rate index
- Findings
- Results and Discussions
- Remarks
- References

Objectives and Scope of Study

- To determine and study the variation of K_{IC} , compressional slowness, tensile strength, uniaxial compressive strength, Cerchar Hardness Index, Sievers-J value, Brittleness index and Drilling Rate Index
- To establish empirical correlations for determination of KIC
- Understand how drillability is affected by hardness and fracture toughness

Methodology

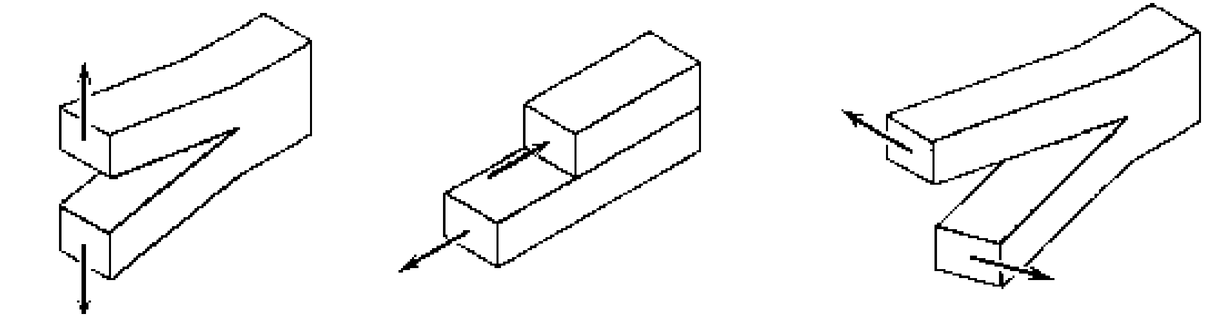
Sample preparation → Testing for fracture toughness → Non Destructive test (Sonic and CHI → 1st part used for UCS test & 2nd Part used for Tensile strength and Sievers -J Value → Brittleness value test → Correlation of FT with S-J and DRI



Fracture Toughness

- a material's resistance to brittle fracture when a crack is present
- the *Stress Intensity factor*
- units : MPa ($m^{1/2}$)

- *Mode I (tensile, opening),*
- *Mode II (shear, in-plane sliding),*
- *Mode III (tearing, out-of-plane) respectively*



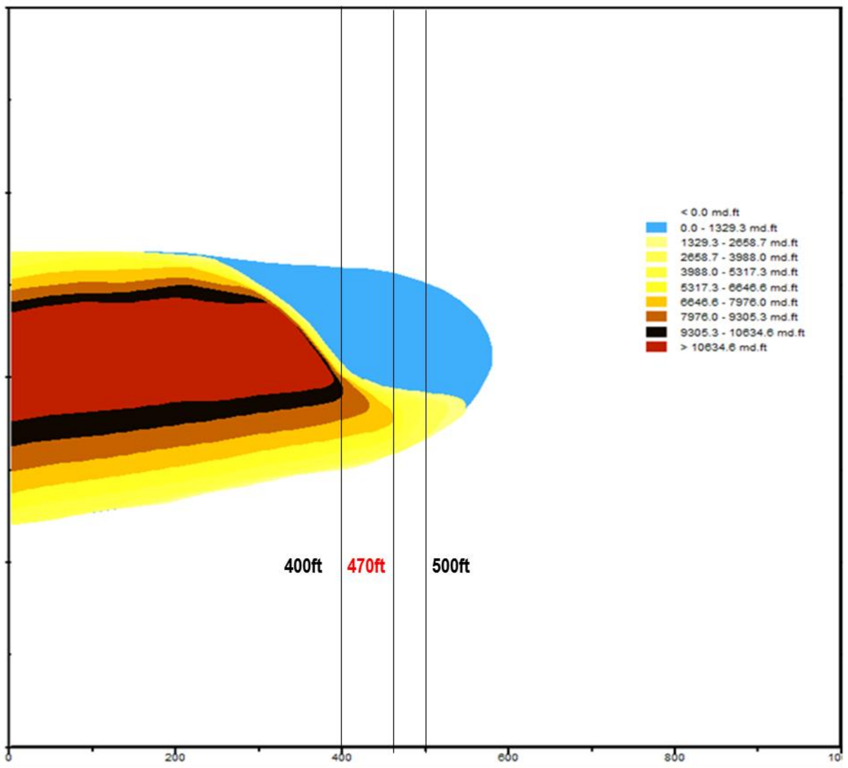
Mode I Fracture Mode II Fracture Mode III Fracture

Uses:

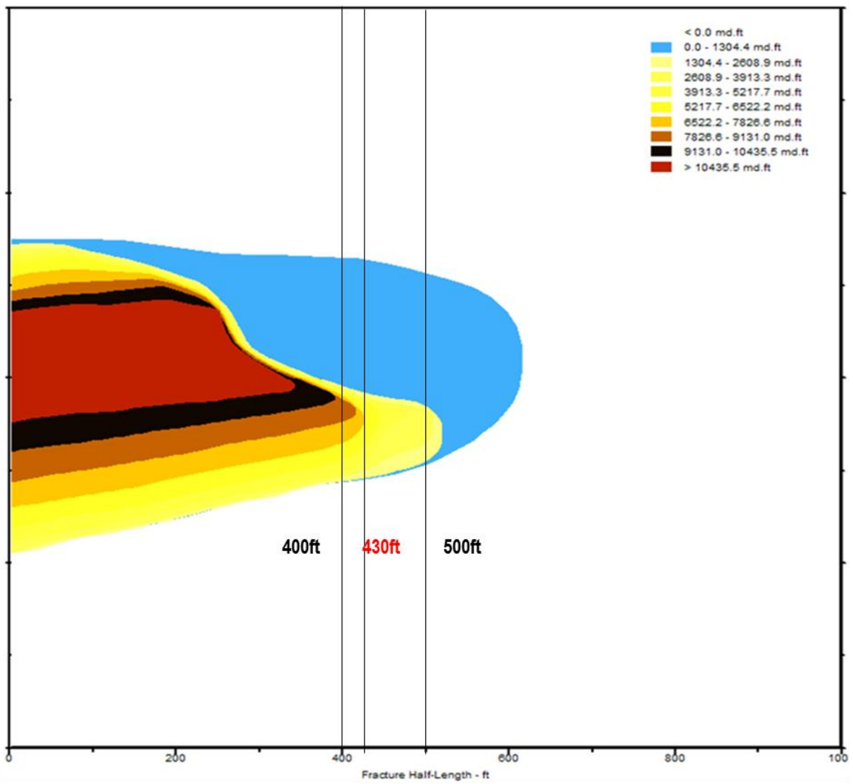
- As an index for rock fragmentation processes such as tunnel boring and scale model blasting
- Frac Design
- Modelling rock cutting
- Stability analysis of rock structure.

Fracture Toughness-Impact on HF

Fracture half-length of hydraulic fracture increases from 430ft to 470ft with decrease in fracture toughness from 2500 psi.in$^{0.5}$ to 800 psi.in$^{0.5}$.



(a)-Fracture Toughness-800 psi.in$^{0.5}$

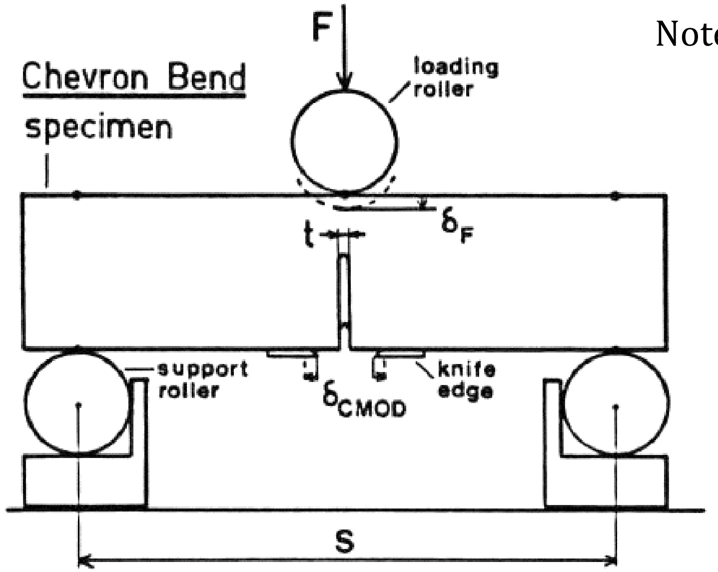


(b)-Fracture Toughness-2500 psi.in$^{0.5}$

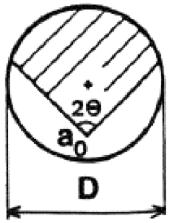
Experimental Setup For FT:

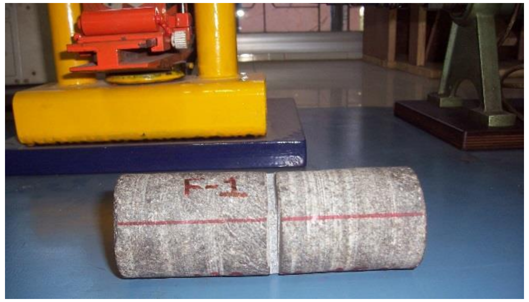
Fracture Toughness

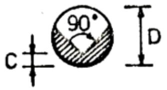
$$K_{IC} = 0.8325\left(7.2984 + 540.26\frac{C}{D} - 122.34\left(\frac{C}{D}\right)^2 + 374.67\left(\frac{C}{D}\right)^3\right) P/D^{1.5}$$



Note that the units of K_{IC} is force /length3/2 and SI unit is N/m 3/2







Chevron Edge Notched Round Bar

CENRB - Test no 1.1

L/D = 3.33

$0.5 \leq C/D \leq 0.25$

t < 2 mm

Post-Fracture Toughness Tests

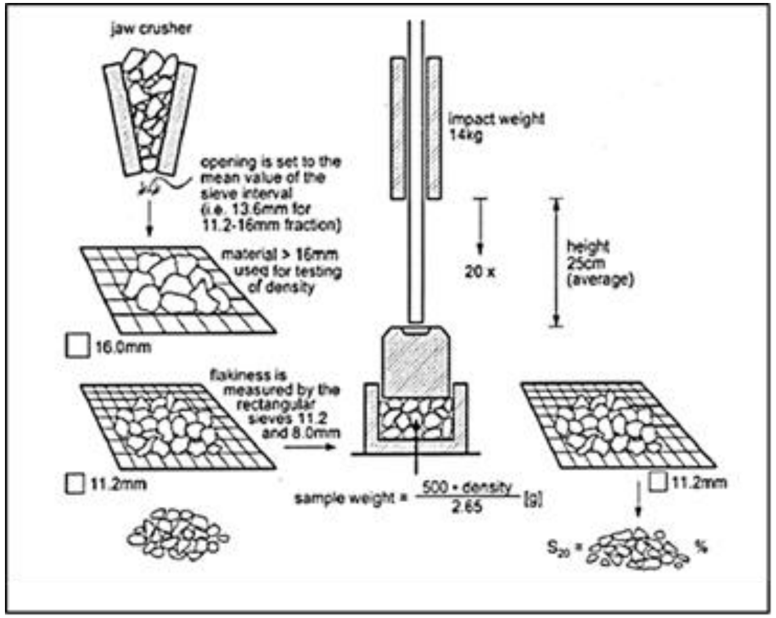
Long samples once got broken in two parts during the fracture toughness test, were individually subjected to non-destructive tests. These mainly included sonic, density and Cerchar Hardness Index (CHI).

Destructive laboratory scale tests-

- UCS
- Tensile Strength
- Brittleness Tests
- Sievers' J Miniature Drill

Brittleness Test

- The brittleness test gives a good measure for the ability of the rock to resist crushing by repeated impacts.
- Brittleness value S20 equals the percentage of material that passes the 11.2 mm mesh after the aggregate has been crushed by 20 impacts in the mortar.

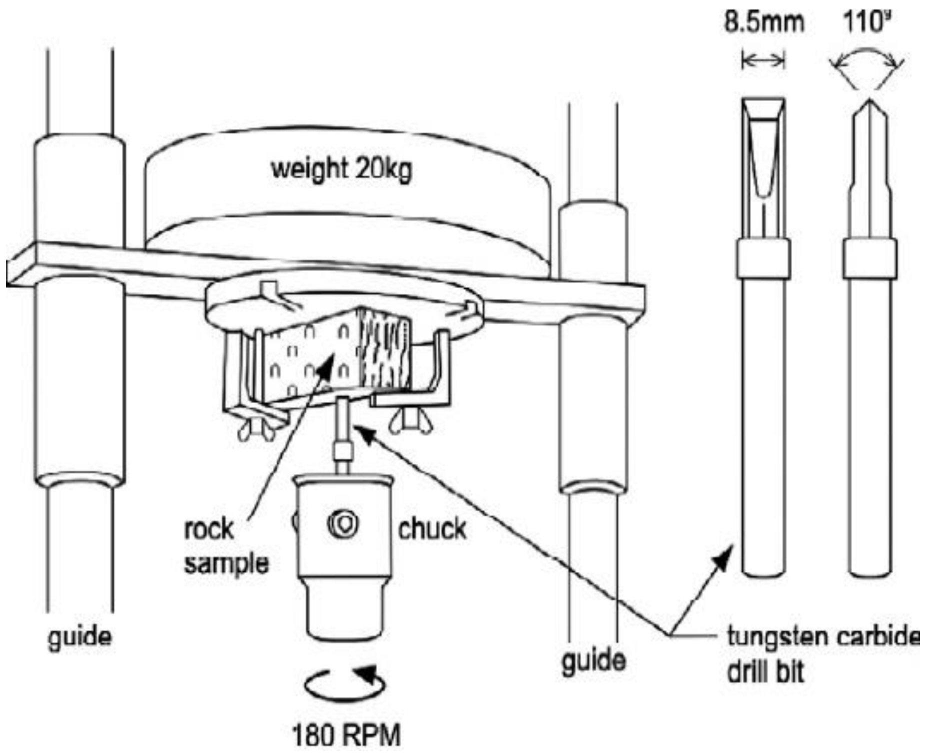


(a) Brittleness test procedure

(b) Brittleness test equipment

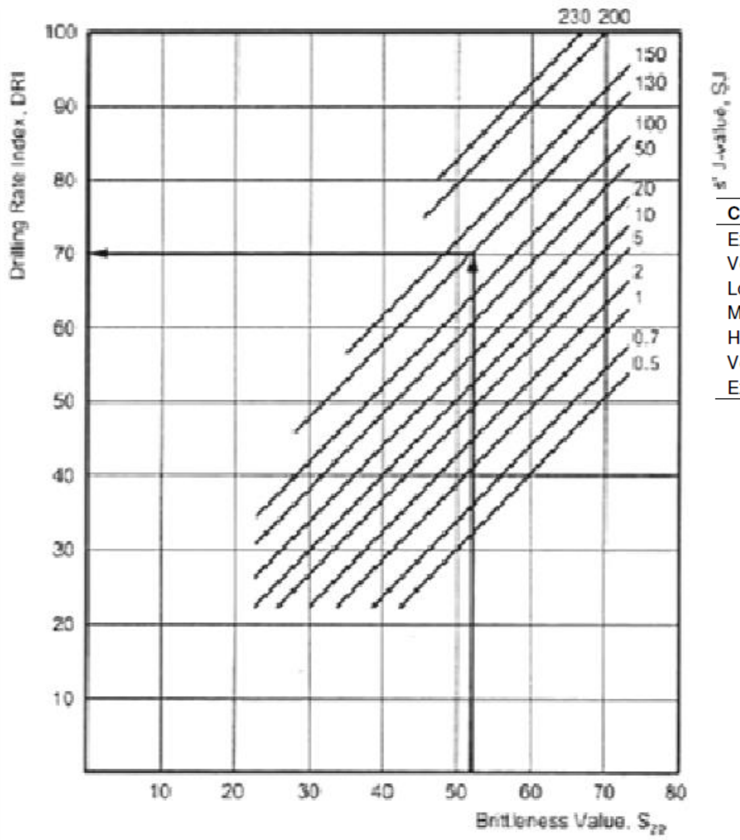
S-J and DRI

Outline of the Sievers'J miniature drill test



S-J test
Bit Angle:90 degree
Bit Diameter : 8.5mm
Tungsten Carbide
RPM:200
Load on bit: 20kg

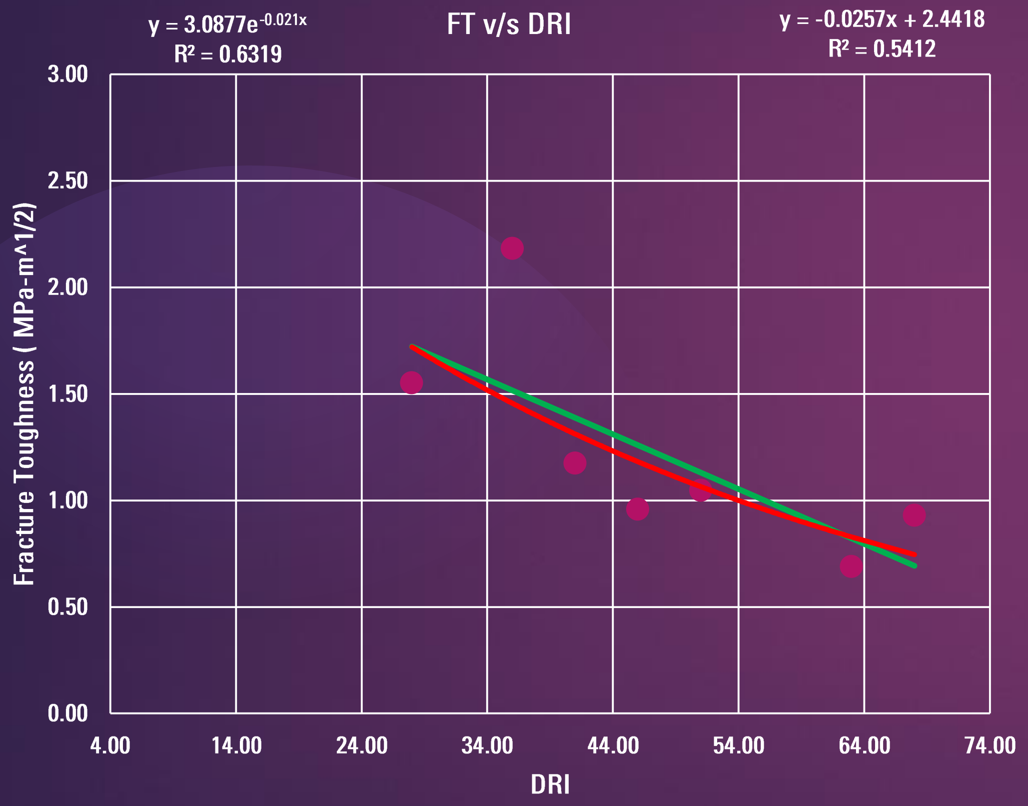
Assessment of drilling rate index(DRI)

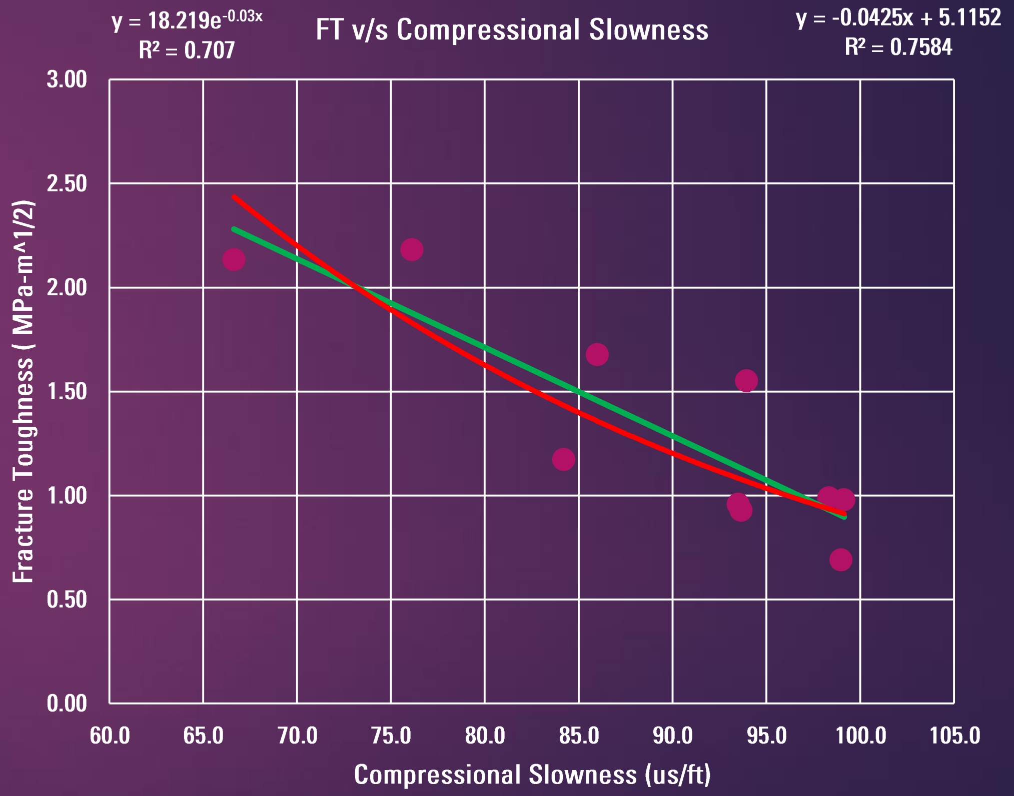


Category	DRI
Extremely low	≤ 25
Very low	26 -32
Low	33 - 42
Medium	43 - 57
High	58 - 69
Very high	70 - 82
Extremely high	≥ 93

(Dahl, 2003)

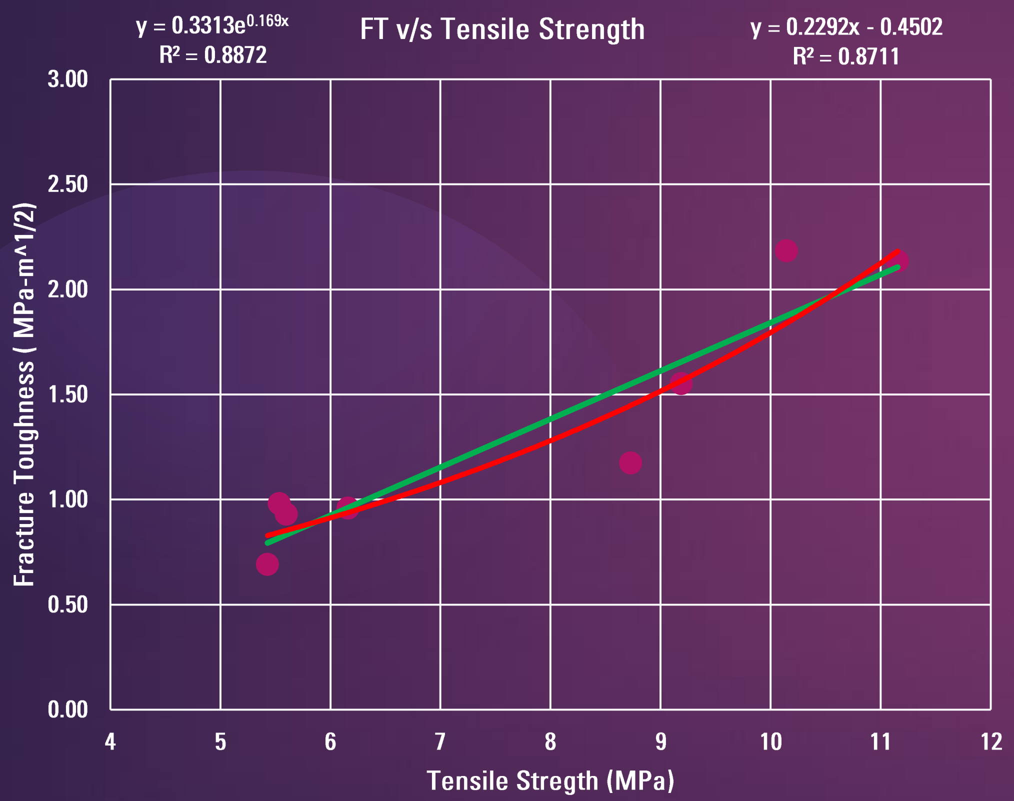
Findings

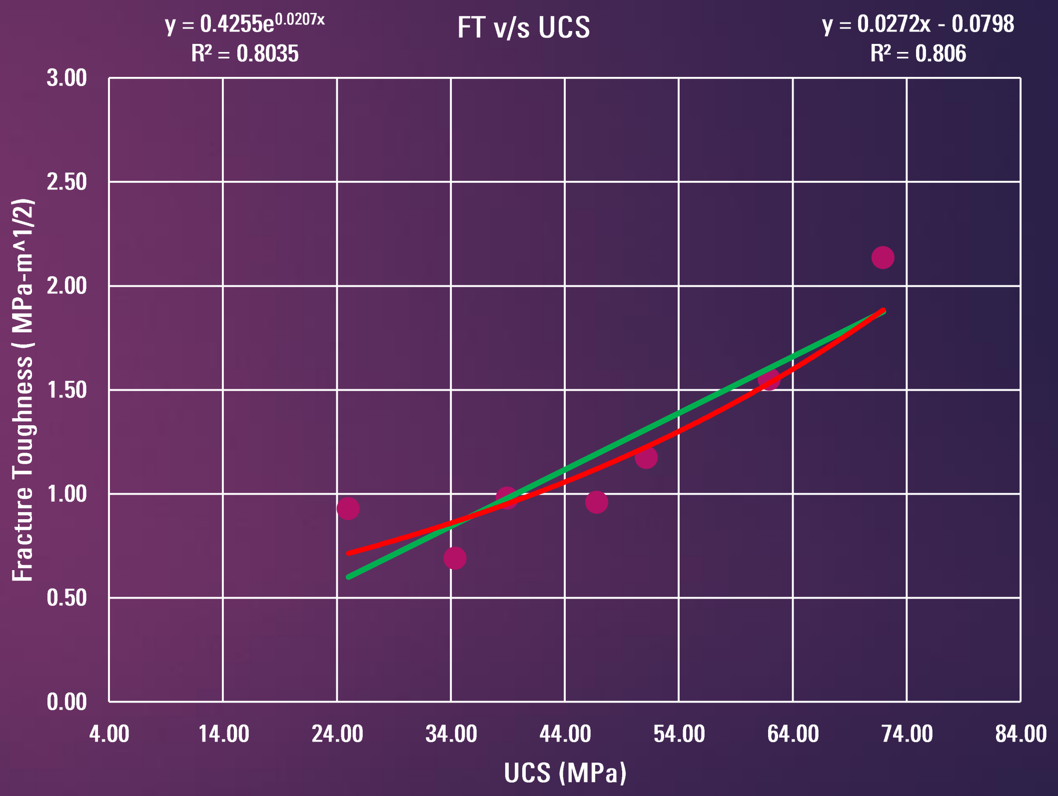




Correlation of Fracture Toughness values with DRI and Compressional Slowness

Findings





Correlation of Fracture Toughness values with Tensile Strength and UCS

Results and Discussions

- Fracture toughness exhibited a very good relationship with tensile strength (R^2=0.87), UCS (R^2=0.80), compressional slowness (R^2=0.76), and DRI (R^2=0.63) both linear and non-linear trends are fitted in the crossplot.
- Linear trends show very decent correlation accuracy. The lowest uncertainty relationship is obtained with tensile strength with coefficient of determination of 0.87.
- Analysis shows that acoustically fast and stronger rock has larger fracture toughness.
- Analysis also shows that fracture toughness doesn’t have a good correlation with S-J value, brittleness value and Cerchar Hardness Index directly.

Remarks

- Specimen preparation for fracture toughness laboratory test is complicated. This study is going to be helpful to estimate fracture toughness of sandstones based on their tensile strength or UCS or compressional slowness or DRI values which in turn can be utilized for classifying rocks into different categories, drill energy requirements, drilling rate prediction, wear rate etc.
- The correlations developed here are confined to clastics with similar rock properties. These correlations will need local calibration, if applied in a different field or environment.

Acknowledgements / Thank You / Questions

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Thank You