ENAC / PROJET DE MASTER 2019-2020
SECTION DE GÉNIE CIVIL

Transmissivity of rock fractures: Normal loading and shear reactivation

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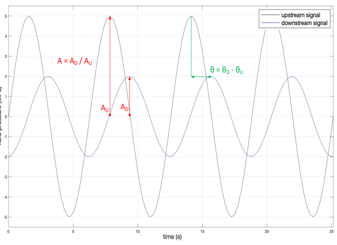
Abstract Enhanced Geothermal Systems represent a major field of study in the context of renewable energy resources. To create extractable energy from those reservoirs, a high enough fluid flow rate for production needs to be achieved. This fluid flow rate is directly related to the permeability of the fracture system in the reservoir. Hence, by increasing the reservoir's permeability the fluid flow increases as well. For this purpose, shear stimulation has proven itself effective but remains a challenging field of study. Many aspects of this mechanism are still unknown and have to be explored further. This study focuses on the fracture transmissivity evolution of low porosity rocks (i.e. granite and marble) with smooth fracture surfaces subjected to progressing shear displacement until several millimetres of offset. The aim of this study was to record fracture transmissivities continuously throughout the experiment without stopping the mechanical loading processes and thereby using the oscillatory pore pressure method.

The results showed that rock fractures behave in different manners according to their lithology and more precisely, to the material's hardness. Rock fractures often form wear products which can either obstruct the flow paths or enhance them as a function of the wear mechanism and wear volume. The granite sample encountered the debris formation mechanism that would transition from mild to severe wear. On the other hand, the marble sample was subjected to a continual asperity smoothing mechanism. Within the frame of EGS, the results of this work can have interesting implications for production rates. Results showed that not only loading conditions can affect the fluid flow through rock fractures. Rock lithologies and ranges of shear displacement also play an important role and should be explored further.

I. Fundamentals



Oscillatory pore pressure method

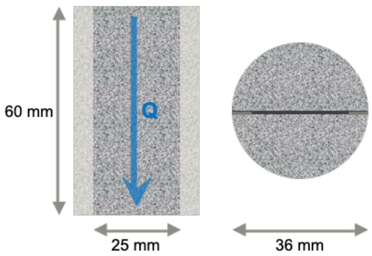
- Sinusoidal upstream pressure through rock fracture
- Measure downstream response
  - Amplitude ratio A
  - Phase shift θ

Transmissivity: $\boldsymbol{T} = kt$

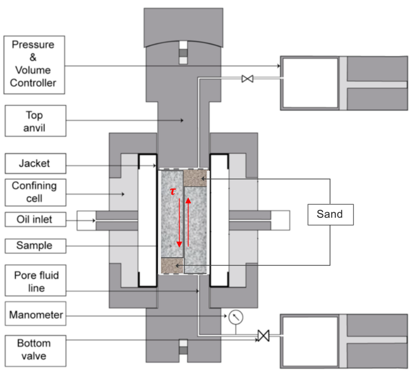
II. Methodology & Concepts

i. Rock samples

The efforts of this thesis were concentrated on two different low porosity rock lithologies being a granite from La Peyratte in France and a marble from Carrara in Italy. The samples are cylindrical with a smooth fracture oriented along the vertical axis of the sample.



ii. Experimental Setup



A standard triaxial apparatus was used in axisymmetric shortening to create a shear displacement between both fracture surfaces. Pure quartz sand was used as a displacement buffer.

- Hydrostatic confinement of $\sigma_3 = 25\,MPa$
- $P_{f,mean} = 5\,MPa$
- $A = 500\,kPa$
- Period of 8 min.
- $\Delta = 10^{-5}\,mm/s$
- $d_{max} = 4\,mm$

➤ Additionally, a sand calibration experiment was performed to evaluate the downstream storativity of the displacement buffer and to monitor the stress-displacement curve during triaxial compression.

iii. Transmissivity Calculations

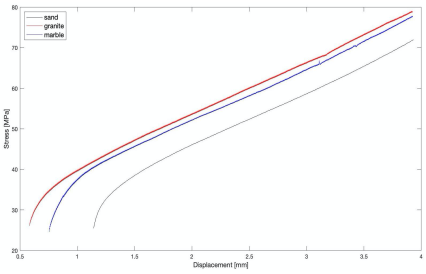
Based on Bernabé et al. (2005) and Rutter and Mecklenburgh (2017) a new transmissivity formula was derived for this particular experimental setup based on an analogy between electric and hydraulic current:

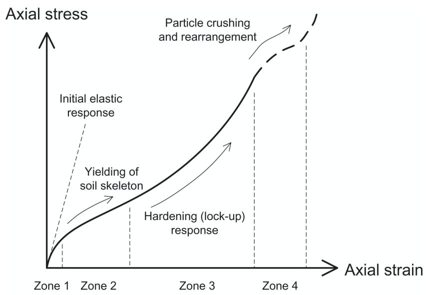
$$\mathrm{T} = kt = \frac{\pi\,\mu\,\beta_D(d)\,2A\,L(d)}{\Gamma\sqrt{1-A^2}\,w} \quad \text{with} \quad \beta_D(d) = V_{d,void}(d) * \beta_{fl}$$

- k : fracture permeability
- t : fracture thickness
- μ : fluid viscosity
- $\beta_D(d)$: downstream storativity
- A : amplitude
- $L(d)$: fracture length
- Γ : oscillation period
- w : fracture width
- $V_{d,void}(d)$: downstream void volume
- β_{fl} : fluid compressibility of water

III. Results

i. Mechanical Data





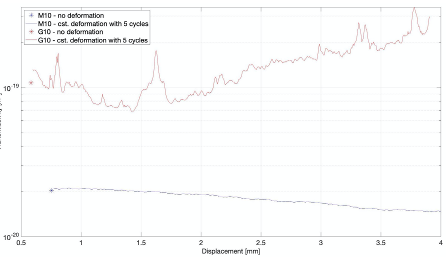
The mechanical data confirmed the successful execution of this novel experimental technique.

The recorded stress-displacement curves of both flow through experiments only reflect the mechanical response of the sand under triaxial compression with constant radial stress and increasing axial stress. Once the imposed axial displacement phase begins, the rock samples have already experienced a small amount of fracture displacement. They have overcome the static frictional stress limit and are in frictional sliding which means that the imposed shear displacement is exclusively irreversible (i.e. the elastic shear limit has already been overstepped). As a result, the measured data does really correspond to the fracture transmissivity while shearing.

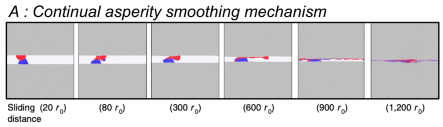
ii. Fracture Transmissivities

The differences in the transmissivity evolutions can be explained by the phenomenon of adhesive wear product formation created by frictional sliding. Aghababaei et al. (2016) investigated adhesive wear mechanisms and identified two distinct types (A and B, right figures). Based on their findings and on the differing mechanical properties (hardness, yield strength), the granite fracture could be categorised as B and the marble fracture as A.

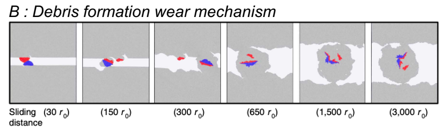
Also, the granite fracture would be subjected to a mild to severe wear volume transition (Aghababaei et al., 2018), responsible for the sudden upwards trend in transmissivity caused by the propagation of subsurface cracks and formation of large debris particles.



A : Continual asperity smoothing mechanism



B : Debris formation wear mechanism



IV. Conclusions

- New experimental technique using the oscillatory pore pressure method for continuous rock fracture transmissivity measuring
- Derivation of corresponding transmissivity formula
- Fracture transmissivity under shear reactivation depends on two factors:
  - ➢ Rock lithology
  - ➢ Final shear offset