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SECTION DE GÉNIE CIVIL

Geometrical control of fluid flow through single carbonate fracture

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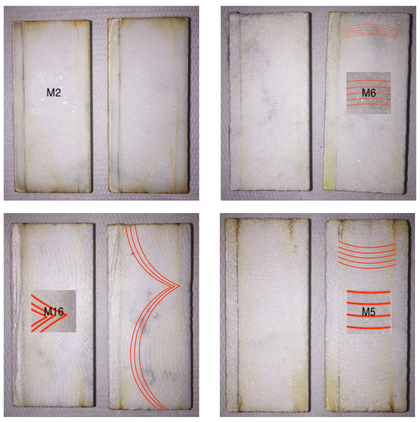
Introduction and motivation

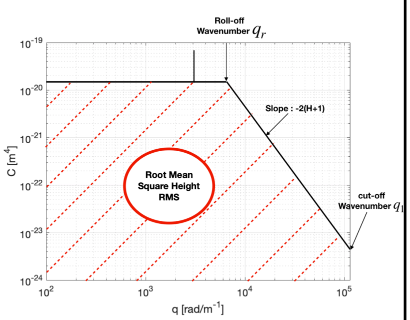
Fluid flow through single rough fracture is critical for many geophysical processes and engineering applications. Earth crust is composed of plenty of fracture sets which govern and control the fluid flow and this is moreover at that place that geothermal and other geophysical applications are realised.
It is thus really important to understand fluid flow in rough natural fractures. Plenty of authors studied flow in single rough fractures since the so called "Cubic law" for fluid flow between two flat plates (Lomize – 1951). Recent experimental and numerical development analysed fracture roughness effects over fluid flow. Here a great innovation is made in the research of the effect of the geometry of rough fractures on fluid flows; indeed four pairs of engineered Carrara marble surfaces with different roughness properties and imposed macro wavelength are created. They are tested with steady-state permeability at effective stresses representative of the upper continental crust in order to study fracture transmissivity.

Such analysis of every surface roughness properties composing a rough single fracture are extremely important for plenty of engineering applications. As an example, such results can make understanding some relative extremely low fluid flow during fluid recovery in natural reservoirs for petroleum engineering. This results can also helps in CO2 or nuclear waste storage in permeable layer between two cap rocks whose fractures should be judged to have a low transport capacity according to their geometric properties. This project can also helps for geothermal applications in extensional area composed of marble such as in the Larderello geothermal system because one can choose and optimize the injection orientation in the fracture that will bring the most energy gains. Thus, that is why the results of this master project are hugely important in order to gain time and money for reservoir engineers and other participants in geothermal operations.

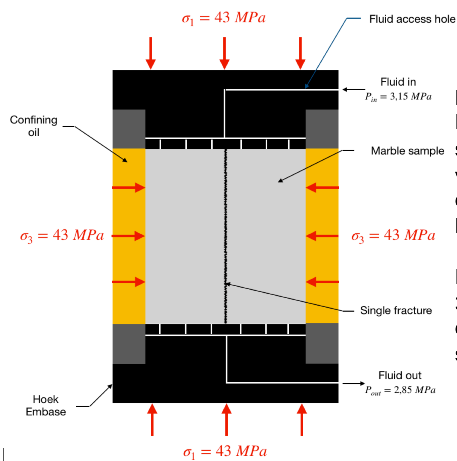
Experimental Methods

Creation of Carrara Marble surfaces with smooth #1200 grit disc (M2) and with milling machine to impose macro wavelength. (M5-M6-M16)





Surface roughness properties are analysed thanks to Fourier analysis with Power Spectral Density (PSD) curves. The linear part reflects the fractal dimension of the surface thanks to Hurst exponent H. Integral of such curve relates to the root mean square height of the surface otherwise called standard deviation of the heights around the mean height measured value. Roll-off wavevector q_r represents the wavelength limit between fractal and non-fractal behaviour. Peak in the PSD represent the imposed macro wavelength λ. Those 4 roughness and geometrical parameters are studied in this project.

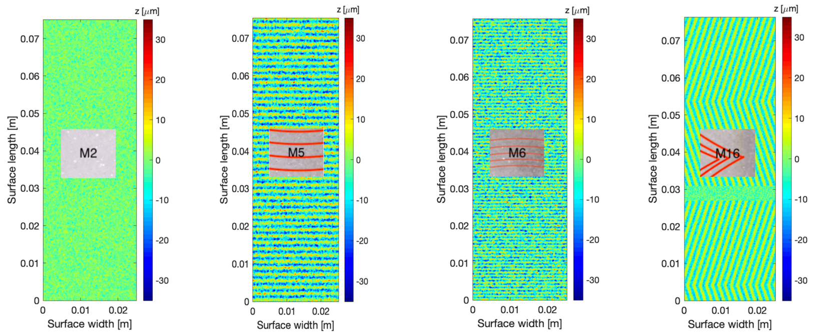


Permeability tests are done on Hoek-cell at 43 MPa of confining stress. Imposed pore pressure varies from 15 to 3 MPa and let to effective pressures of 28 to 40 MPa.

Fluid pressure differential ΔP = 300 kPa is imposed at each effective pressure to do the steady state permeability test.

Numerical Methods

Numerical surfaces with same roughness and geometrical properties as the real ones are created thanks to surface generation methods in the Fourier domain.

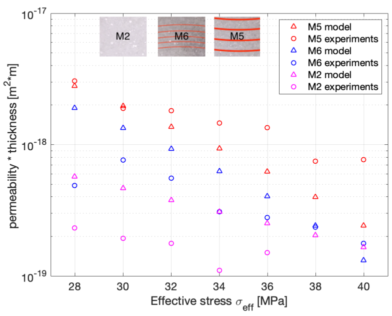


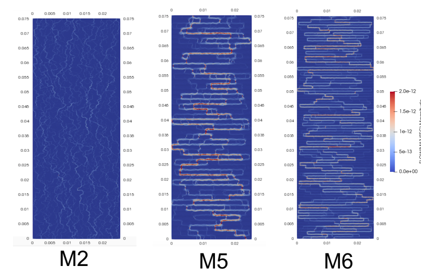
Contact between two surface is modelled using Half-Space based contact model theory in order to represent fracture shape during effective pressure application. Then geometrical aperture distribution e is output for each effective stress and each surface pairs.
After that, this geometrical aperture is used as an input in numerical model using finite volume method to solve so called Reynolds equation which is a simplification of Navier-Stokes equation for laminar flow with viscous dominated forces. Pressure distribution is found and then velocities and global flux are deduced. (μ is the dynamic viscosity and p the fluid pressure)

Reynolds equation : $\frac{\partial}{\partial x}\left(\frac{e^3}{12\mu}\frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{e^3}{12\mu}\frac{\partial p}{\partial y}\right) = 0$

Results

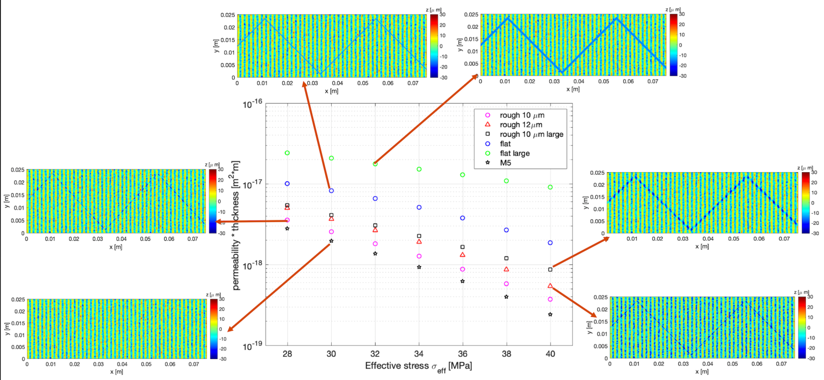
Results in terms of transmissivity (permeability*thickness of the hydraulic aperture (i.e. constant aperture which gives the same global flux as the rough fracture under the same loading and pressures conditions)) are showed.





From those results and from numerical parametric analysis to evaluate effects of the four roughness and geometrical parameters :

- Numerical models fit quite well experimental results
- RMS height and imposed λ have huge influence over fluid flow
- H and q_r have negligible influence over fluid flow
- In general higher flow when PSD curve tends to the right (high flow for high RMS and short imposed λ).
- Great influence of flow path illustrated through numerical analysis below



Future work

- Thermo-Hydro-Mechanical behaviour of fluid flow through fracture (with varying density and fluid viscosity).
- Research of the influence of gouge, wear and abrasion product over fluid flow.
- Test different lithologies
- Test samples during shearing stage