Measurement of anisotropic properties of coal under triaxial stress condition

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Project background and objectives

Coal shows highly anisotropic material and flow properties under confined stress conditions. In coal seam gas (CSG) reservoirs these properties play a vital role in altering the permeability that effect the reservoir production.

The objectives of the project are:

1. **Evaluate factors affecting coal permeability**
2. **Measure coal's anisotropic geomechanical properties**
3. **Develop an anisotropic geomechanical permeability model.**

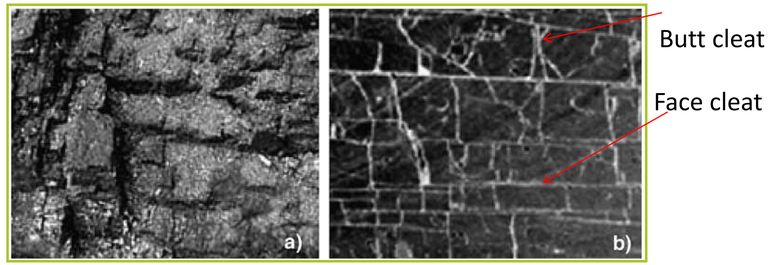
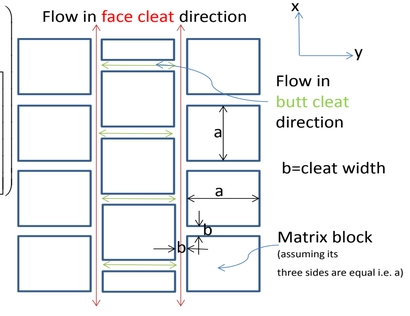


Fig 1. A typical coal petrography a)macro structure b)cleat system[1]

Coal permeability model

$$\frac{\Delta k_{face,x}}{\Delta P} = 3k_{face,x}\frac{1}{\Delta P}\left(-\left(\frac{\Delta P_y}{E_{fy}}-\nu_{f_{yx}}\frac{\Delta P_x}{E_{f_x}}-\nu_{f_{yz}}\frac{\Delta P_z}{E_{f_z}}-\frac{\Delta P_P}{E_{f_y}}\right)+\frac{3}{\phi}\left[\left(\frac{\Delta P_y}{E_{my}}-\nu_{m_{yx}}\frac{\Delta P_x}{E_{m_x}}-\nu_{m_{yz}}\frac{\Delta P_z}{E_{m_z}}-\frac{\Delta P_P}{E_{m_y}}\right)-\frac{S_{s_y}P_{L_y}}{\left(P_{L_y}-P_{P_0}\right)\left(P_{L_y}+P_P\right)}\Delta P_P\right]\right)$$

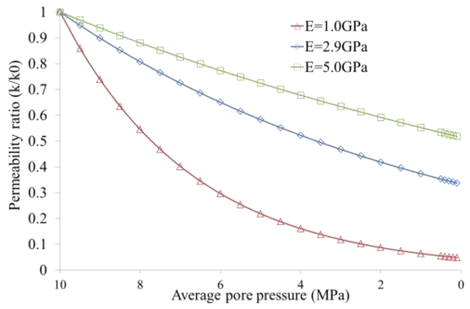


Varying pore pressure but constant overburden and tectonic pressure

In this case $\Delta P = \Delta P_P$ and $\Delta P_x = \Delta P_y = \Delta P_z = 0$

$$\frac{k_{face,x}}{k_{face,x_0}} = e^{3\left(\frac{1}{E_{fy}}\Delta P_P-\frac{3}{\phi_0}\frac{1}{E_{my}}\Delta P_P-\frac{3}{\phi_0}\frac{S_{sy}P_{Ly}}{\left(P_{Ly}+P_{P_0}\right)}\ln\frac{\left(P_{Ly}+P_P\right)}{\left(P_{Ly}+P_{P_0}\right)}\right)}$$

K= permeability (md), P= pressure/stress (MPa), E=Elastic Modulus (GPa), v=Poisson's ratio, Ø=Porosity, Subscript: x, y, z (face, butt and vertical direction), f= fracture, m=matrix, 0=initial, L= Langmuir, p=pore



Experimental setup to measure anisotropic properties of coal

Using a cubic sample (40mm or 60 mm) permits stress-strain measurements in 3 orthogonal directions so that the tensors may be resolved. Directional permeability is also measured. The confining and axial stresses are independently manipulated.

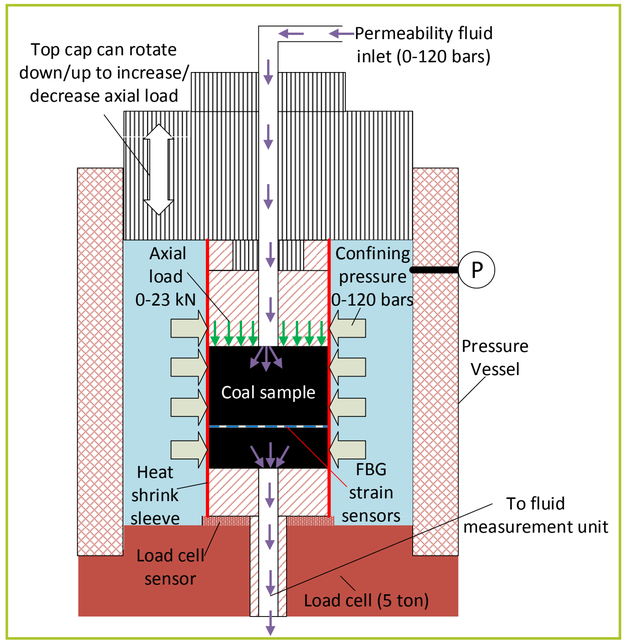
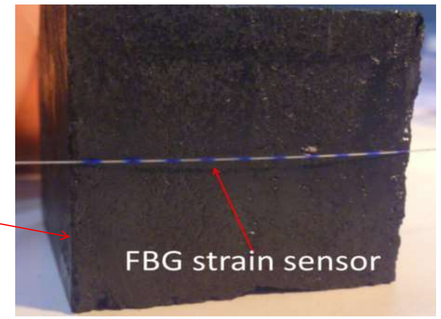


Fig 2. Schematics of Triaxial stress permeameter

Key features of triaxial stress permeameter

1. Mimic CSG reservoir conditions for up to ~1400 m depth (around 135 bar pressure).
2. Independent stress control in longitudinal and transverse directions.
3. Load cell and pressure transducers for accurate stress measurement.
4. Multipoint high precision fibre optics based strain sensor.
5. Simultaneous measurement of permeability and stress-stain data.
6. Cubical sample used to easily reorient in x, y and z directions.

Strain measurement using fibre optics



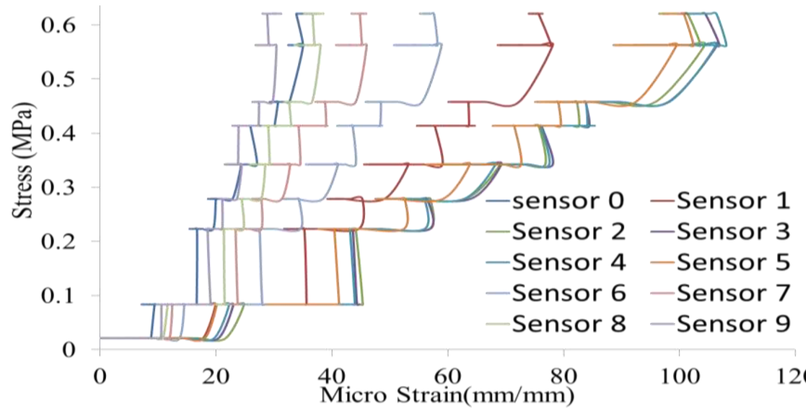


Fig 3. FBG strain sensors results using hand turn vice.

Expected outcomes

1. Direct laboratory capability to measure the directional geomechanical character of coal.
2. Experimental determination of stress-strain tensors and relaxation times.
3. Anisotropic permeability evolution in coal by experiment and simulation.
4. The results will better inform the physics of reservoir models, and provide coal character parameters to be used within them.

Acknowledgement and References

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[1] Wang, G. X., Z. T. Wang, V. Rudolph, P. Massarotto, and R. J. Finley. "An analytical model of the mechanical properties of bulk coal under confined stress." *Fuel* 86, no. 12 (2007): 1873-1884.