UQ Gas & Energy Transition Research Centre

Experimental Study of Coal Directional Sorption-induced Strain Under Different Temperatures

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Introduction

Australian coal is highly cleated, exhibiting pronounced anisotropic flow behaviour. Accurate predictions of reservoir behaviour for CSG/CBM or CO_2-ECBM recovery require reliable data on directional mechanical and petrophysical properties.

However, such data are scarce in the literature. When volumetric strain data are unavailable, they are often sourced from studies on different coal seams, which can compromise the reliability and confidence of the results.

This project aims to quantify the sorption capacity of Australian coal and the resulting directional strain under various temperatures. Additionally, this work also seeks to explore the feasibility of estimating sorption-induced strain directly from isotherm curves.

Methodology

Two rectangular coal samples (20 mm× 22 mm ×35 mm), taken from Goonyella middle seam named S1 and German Creek seam named S2, respectively, were prepared for this study.

Anisotropic deformation of the sample was determined by attaching three strain gauges in the directions perpendicular to face cleats, butt cleats and the bedding plane (Figure 1 (a)).

The experiments were conducted with the three gases (He, N_2 and CO_2) and three temperatures (35, 40 and 45 °C). The gas injection procedures are as follows:

1. Set up the T= 35°C
2. Helium injection from vacuum to 9 MPa
3. Start gas depletion to 1 MPa then vacuum
4. Repeat the whole process for T= 40°C, and 45°C
5. Once Helium gas measurement is done, then replace it with Nitrogen and CO_2, and repeat the above steps

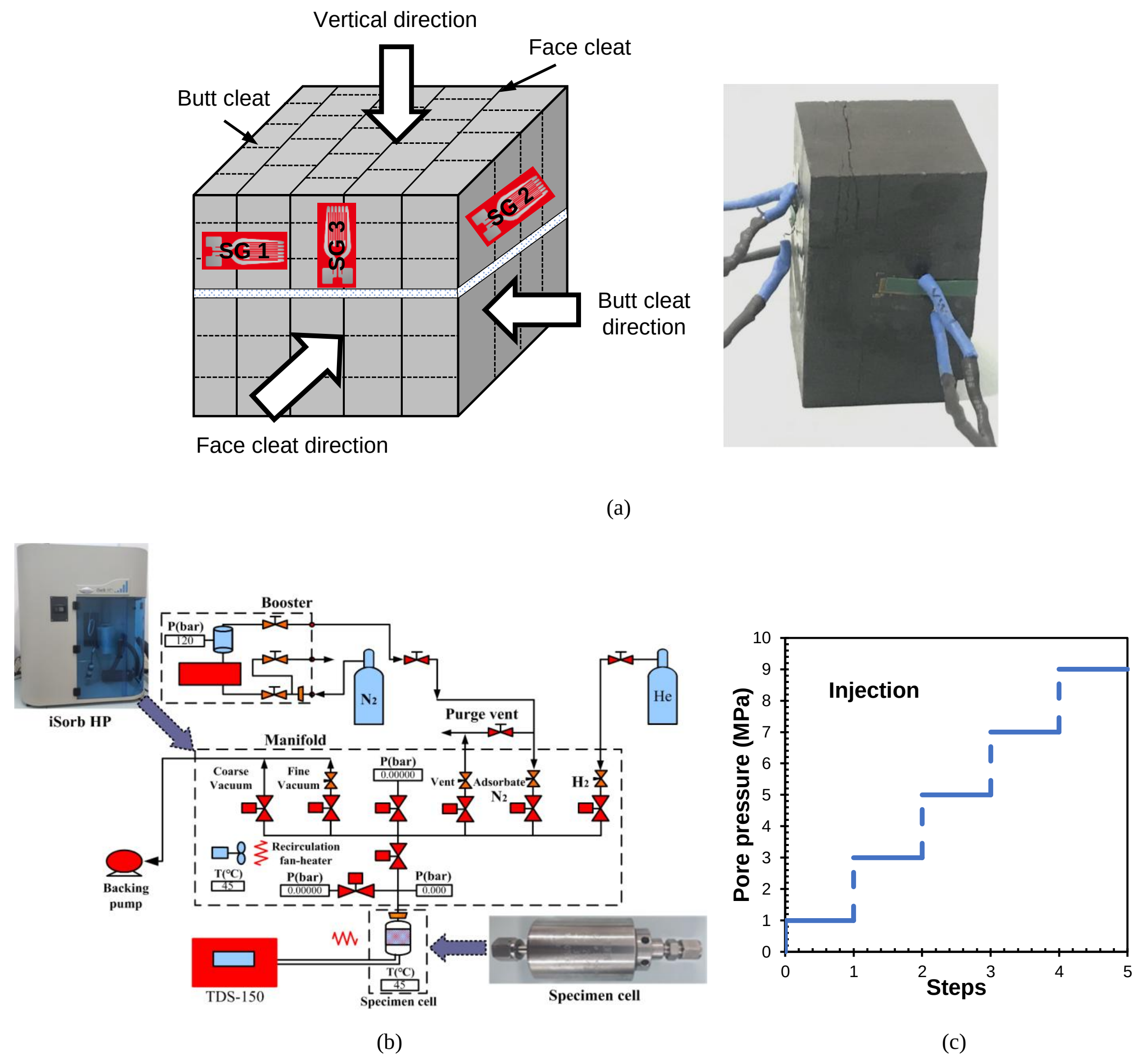
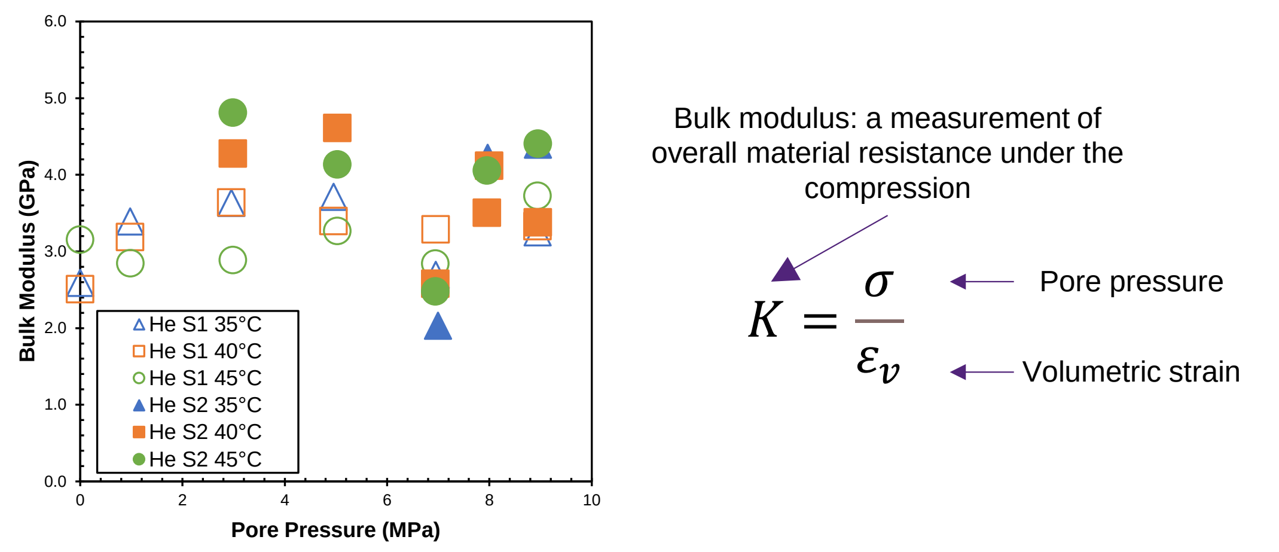


Figure 1: (a) Illustrations of coal sample and strain gauge orientations where SG 1, SG 2, SG 3 represent face cleat direction, butt cleat direction and vertical direction, respectively. (b) Experimental system and setup. (c) Pressure sequence for He , N_2 and CO_2



Bulk modulus: a measurement of overall material resistance under the compression

$$K = \frac{\sigma}{\varepsilon_v}$$

Pore pressure

Volumetric strain

Figure 2. Bulk modulus determined by He for sample S1 and S2

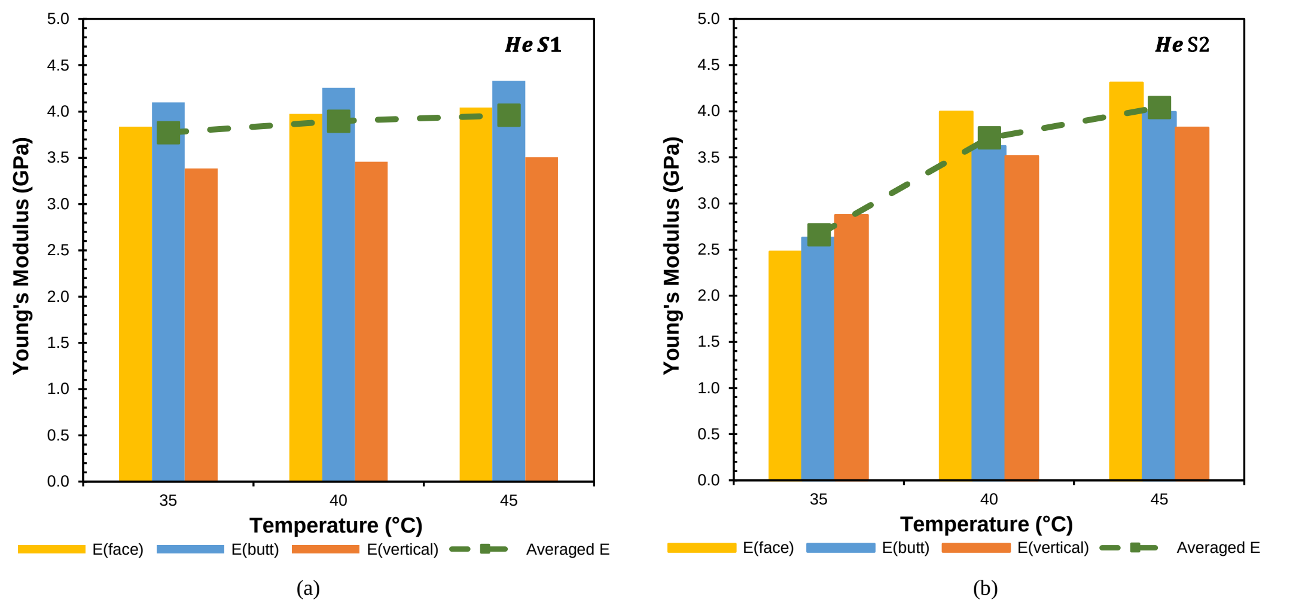


Figure 3. Young's modulus for different directions with various temperatures for (a) sample S1 and (b) S2

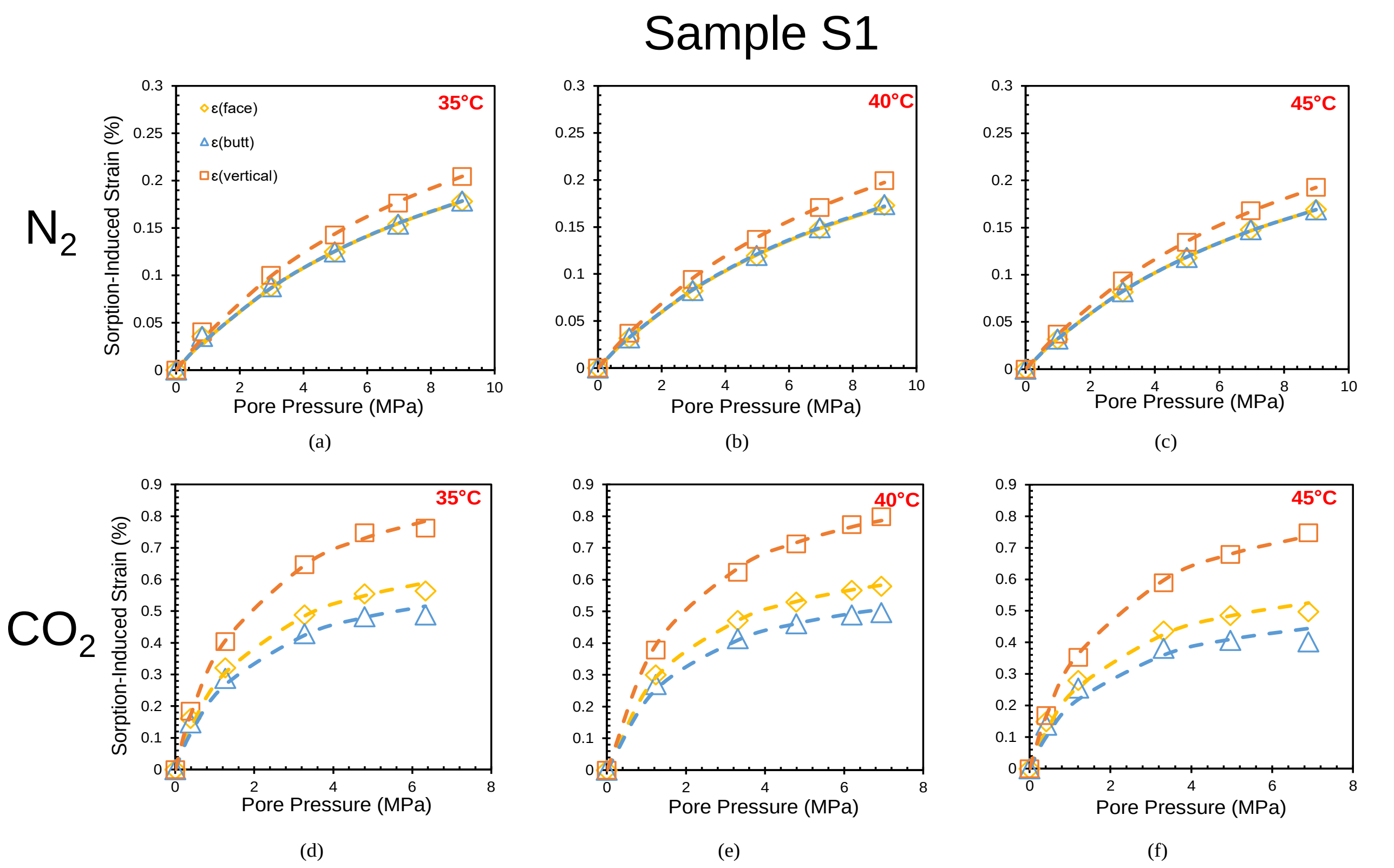


Figure. 4. Relationship between pore pressure and strain of sample S1 during N_2 injection at (a) 35°C; (b) 40°C; and (c) 45°C. Relationship between pore pressure and strain of sample S1 during CO_2 injection at (d) 35°C; (e) 40°C; and (f) 45°C

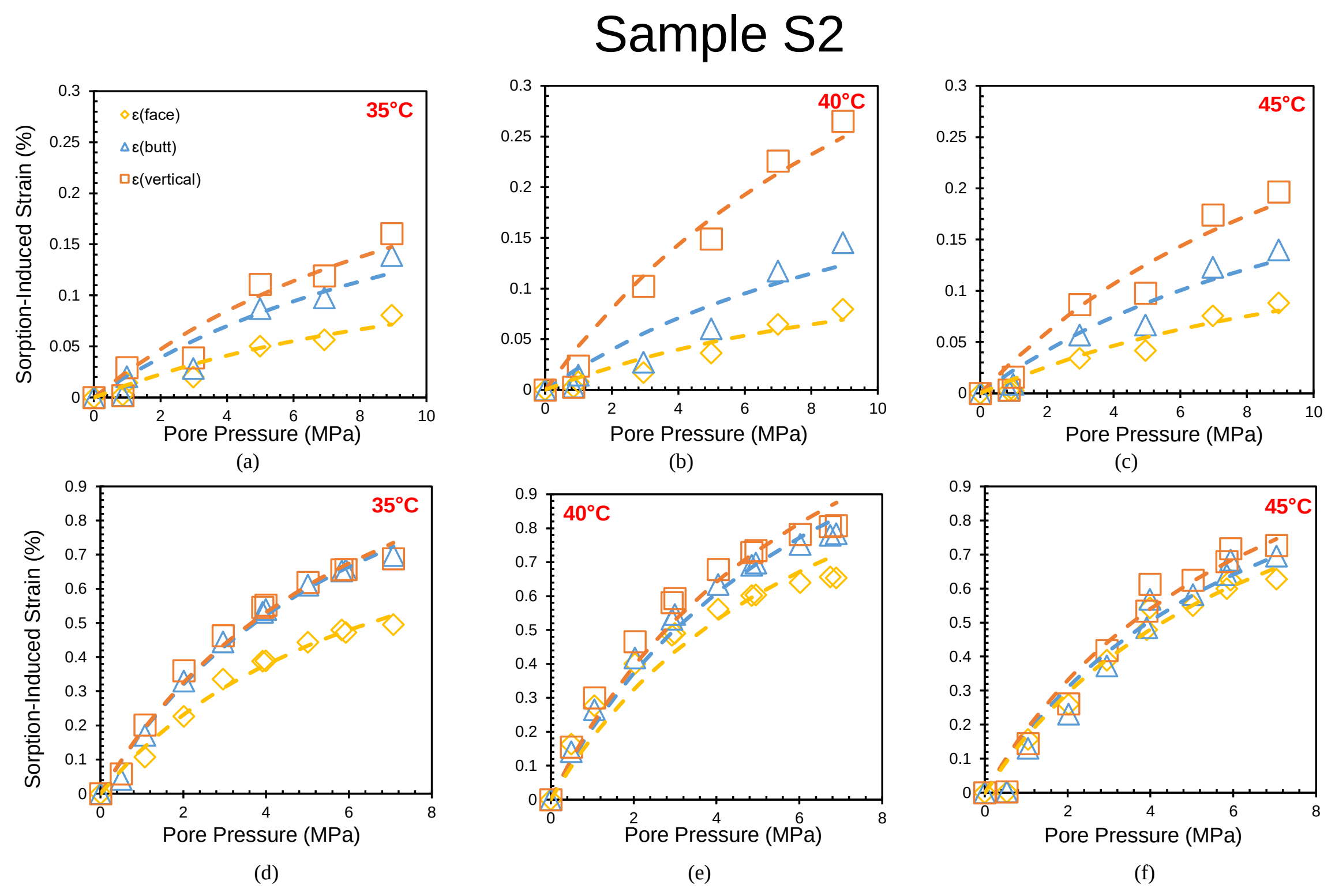


Figure 5. Relationship between pore pressure and strain of sample S2 during N_2 injection at (a) 35°C; (b) 40°C; and (c) 45°C. Relationship between pore pressure and strain of sample S2 during CO_2 injection at (d) 35°C; (e) 40°C; and (f) 45°C

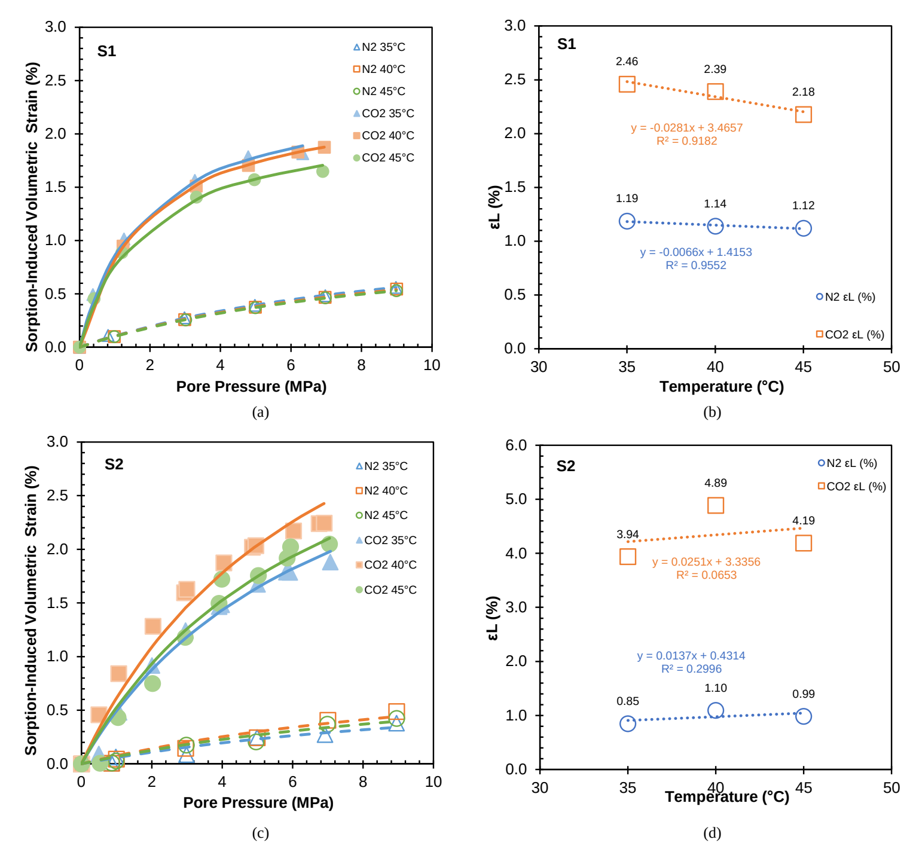


Figure. 6. Adsorption-induced strain as a function of pore pressure for (a) Sample S1 and (c) Sample S2; Langmuir strain constant for (b) Sample S1 and (d) Sample S2

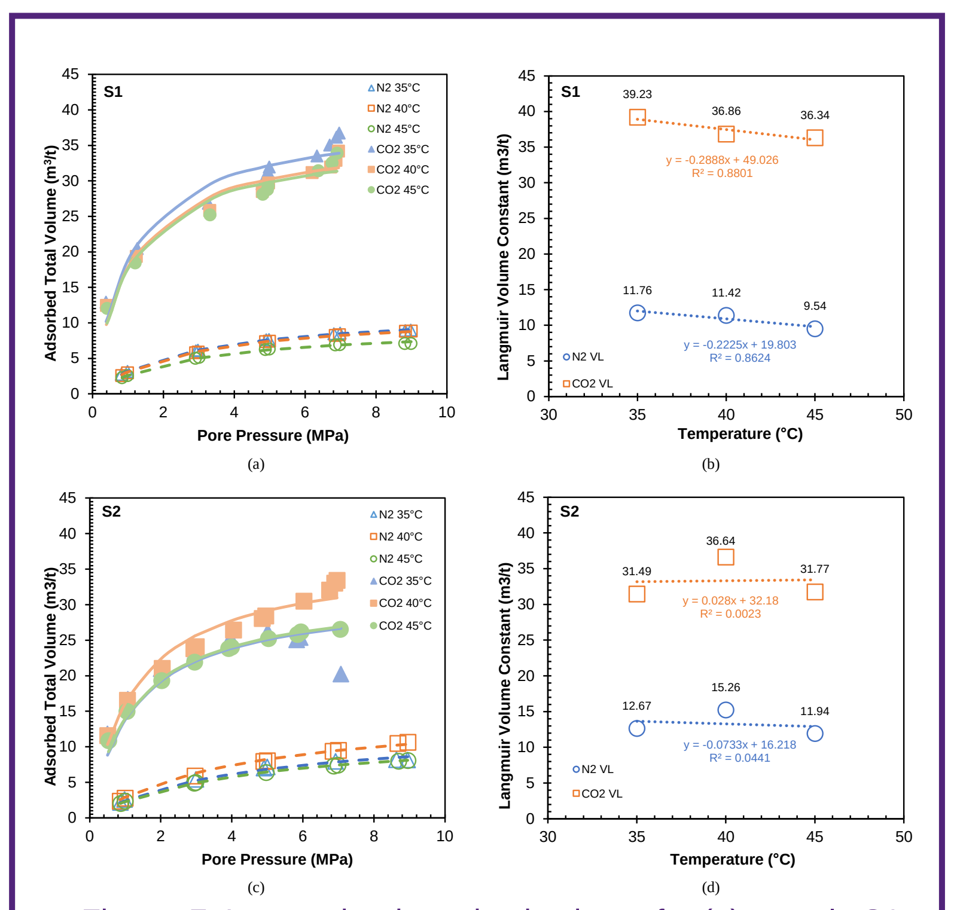
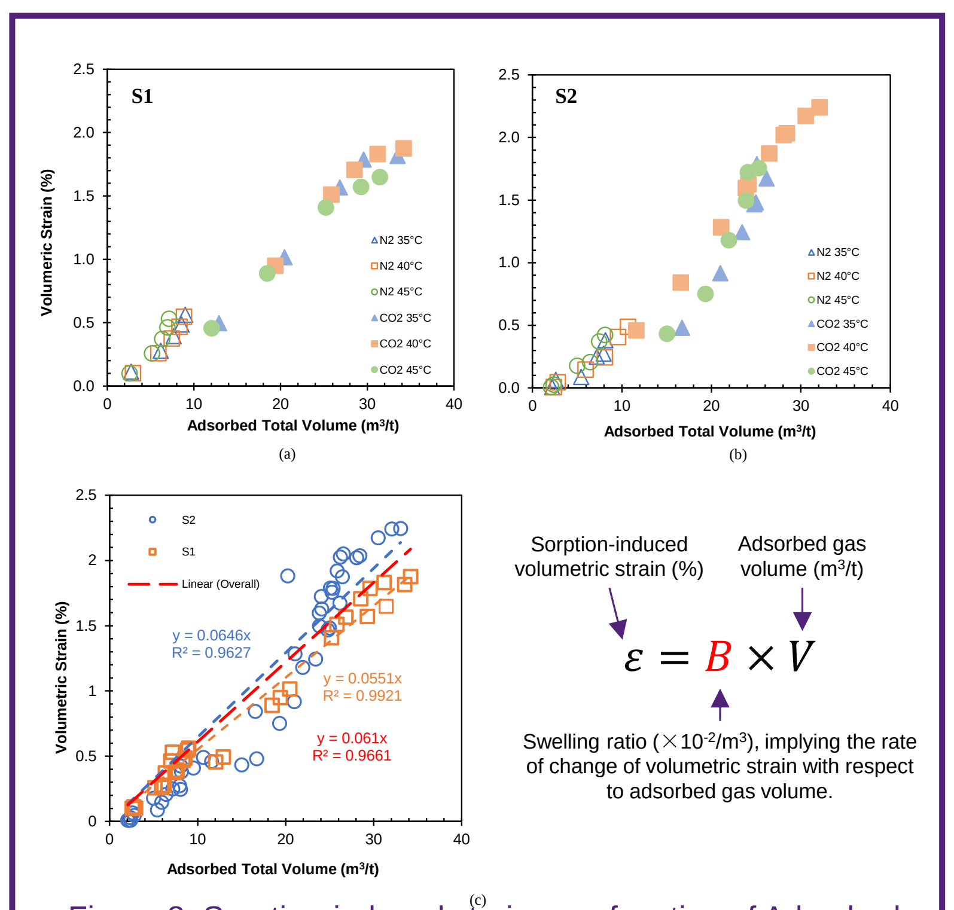


Figure. 7. Langmuir adsorption isotherm for (a) sample S1 and (c) sample S2. Langmuir volume constant V_L for (b) sample S1 and (d) sample S2



Sorption-induced volumetric strain (%)

Adsorbed gas volume (m³/t)

$$\varepsilon = B \times V$$

Swelling ratio ($\times 10^{-2}/m^3$), implying the rate of change of volumetric strain with respect to adsorbed gas volume.

Figure 8. Sorption-induced strain as a function of Adsorbed volume for (a) sample S1, (b) sample S2 and (c) both sample S1 and S2 with linear fitting.

Results

Mechanical properties

Helium was used to test the mechanical properties of the samples.

Bulk modulus: Figure 2 indicates that temperature and pore pressure do not significantly affect bulk moduli for both samples. Overall, sample S2 has a higher Bulk modulus value of 3.81 than S1 of 3.19, which implies a higher compression resistance subjected to the He injection.

Young's modulus: Young's modulus (Figure 3) increased as the temperature rises in all directions for both samples.

The averaged Young's modulus ratio of E_{face}: E_{butt}: $E_{vertical}$ for S1 is 1.15:1.23:1.00 and for S2 is 1.06: 1.00: 1.00. Thus, the minimum Young's modulus occurs along the vertical (bedding) direction.

The average Young's modulus from three directions are 3.77, 3.90 and 3.96 GPa for sample S1 and 2.66, 3.71 and 4.04 GPa for sample S2 at the temperatures of 35°C, 40°C, and 45°C, respectively.

Directional adsorption

When an adsorbing-gas (e.g., N_2 or CO_2) is injected, the measured strain is the sum of the strain induced by pore pressure and the sorption-induced strain. Thus, the sorption-induced strain is computed using the equations below:

$$\varepsilon_{N_2\ swelling} = \varepsilon_{N_2} - \varepsilon_{He}$$

$$\varepsilon_{CO_2\ swelling} = \varepsilon_{CO_2} - \varepsilon_{He}$$

We computed the directional sorption-induced strain for both samples with different temperature and gases using the above equations and present them in Figures 4 and 5.

Directional strain ratio: The averaged strain ratios of ε_{face}: ε_{butt}: $\varepsilon_{vertical}$ for sample S1 using N_2 are 0.87:0.87:1.00, and for sample S1 using CO_2 are 0.71:0.60:1.00.

In contrast, the averaged strain ratios of ε_{face}: ε_{butt}: $\varepsilon_{vertical}$ for sample S2 using N_2 are 0.42:0.71:1.00, and for sample S2 using CO_2 are 0.80:0.98:1.00.

Temperature effect on Langmuir strain constrain: For S1, A higher temperature results in a lower Langmuir strain constant due to gas storage capacity reduction with increasing temperature. For S2, no noticeable correlation between the Langmuir strain constant and the temperature has been identified

Volumetric adsorption

Volumetric strain Vs. pore pressures (Figure 6):

Temperature effect: For sample S1, the Langmuir strain constant and temperature are inversely correlated (shown in Figure 6 (b)). However, the Langmuir strain constants for sample S2 do not show a direct relationship with temperature (shown in Figure 6 (d))

Difference between gases: maximum swelling under the CO_2 injection is approximately double that under N_2 for sample S1, and four times than that under N_2 for sample S2

Adsorption volume Vs. pore pressures (Figure 7):

Temperature effect: For S1, a higher temperature corresponds to a low adsorption volume for the same pressure point. However, S2 does not show a direct relationship between adsorption capacity and temperature.

Difference between gases: The ratio of V_L between using CO_2 and N_2 is 3.44 for sample S1 and 2.51 for sample S2.

Volumetric strain Vs. Adsorption volume (Figure 8):

The obtained swelling ratios for sample S1 and S2 are 0.0551 and 0.0646, respectively.

The overall linear fitting leads to a swelling ratio of 0.061, indicating that every cubic meter of gas sorption would generate 0.061% volumetric swelling strain.

With a known Langmuir isotherm curve for a coal, this universal correlation can be applied to estimate the swelling strain at a given gas pressure.

Conclusions

- The anisotropic behaviour of the tested coal sample has been identified, and the direction perpendicular to the bedding plane shows the largest strain
- N_2 and CO_2 adsorption results show a difference in the directional sorption-induced strains. Compared with N_2, the sorption capacity of CO_2 is two to three times larger.
- Total volumetric strain and adsorption volume are well linearly correlated regardless of the adsorbing gas type and temperature. The mean volumetric swelling per cubic meter of sorption gas for the tested coal samples is 0.061%. The sorption-induced strain can be directly estimated from the Langmuir isothermal curve

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