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The mechanical behaviour of coal with respect to CO_2 sequestration in deep coal seams

D.R. Viete [a], P.G. Ranjith [b,*]

[a] Research School of Earth Sciences, Australian National University, ACT 0200, Australia
[b] Department of Civil Engineering, Monash University, Victoria 3800, Australia

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Abstract

Carbon dioxide displays a strong affinity for coal due to its propensity to adsorb to the coal surface. The process of CO_2 adsorption on coal causes lowering of surface energy and, it is hypothesised that an associated decrease in surface film confinement results in a decrease in material tensile resistance. Following the results of work carried out on the mechanical influence of CO_2 on brown coal under *in situ* conditions [Viete DR, Ranjith PG. The effect of CO_2 on the geomechanical and permeability behaviour of brown coal: implications for coal seam CO_2 sequestration. Int J Coal Geol 2006;66(3):204–16], a theoretical explanation is proposed for the perceived lack of a weakening effect with the adsorption of CO_2 to coal at significant confining pressures. We propose that at significant hydrostatic stresses, resistance to failure is otherwise provided (by external confinement) and the effects of adsorptive weakening are concealed. Our model predicts that adsorptive weakening, fracturing under *in situ* stresses, and associated permeability increases are not an issue for coal seam CO_2 sequestration for sufficiently deep target seams. Lowering of the elastic modulus of coal upon introduction of CO_2 may proceed by means other than surface energy lowering and could well occur irrespective of the depth of sequestration. The effect of elastic modulus lowering under *in situ* conditions would be beneficial for the long-term retention of sequestered gases.

Keywords: Coal; CO_2 sequestration; Mechanics; Adsorptive weakening; Confinement effects

1. Introduction

In response to predictions of irreversible global warming under current rates of greenhouse gas emission, governments and private institutions alike are considering options to reduce atmospheric emissions. These options include plans to sequester carbon dioxide (CO_2) in large quantities beneath the Earth's surface. The adsorbing nature of CO_2 on coal affords excellent CO_2 retention capacity, a property that has generated interest in the prospect of CO_2 sequestration in unminable coal seams.

Of vital consideration in plans for the large-scale impoundment of CO_2 is the stability of proposed reservoirs. While geotechnical investigation of potential sites would typically involve geological and mechanical characterisation of the reservoir environment, the manner by which CO_2 sequestration modifies the mechanical character of the geological media must also be considered.

The process of adsorption is thought to affect the physical behaviour of solids, and theorisations of the influence of surface-active adsorbents on the mechanical behaviour of solids are well supported by the results of experimental studies [15,6,7]. Of particular relevance to the mechanical influence of CO_2 in the sequestration process are studies concerning the effect of the introduction of CO_2 on the mechanical behaviour of organic substances [8,4,23,1]. While historically, studies have focussed on adsorptive modifications to the material strength, recent investigations have also suggested that the sorption of CO_2 can cause changes in other mechanical properties of coal, specifically, its elastic modulus [22].

* Corresponding author. Tel.: +61 3 9905 4982; fax: +61 3 9905 4944.
E-mail address: ranjith.pg@eng.monash.edu.au (P.G. Ranjith).

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The sequestration environment is very different from those normally considered in coal engineering. Thus the results of conventional coal tests, conducted by investigators interested in coal behaviour under surface or mining conditions, may not be appropriate for direct application to CO_2 sequestration. The role that *in situ* confining pressures play in modifying the influence of CO_2 adsorption on coal seam behaviour is, however, significant. Recently, the results of Viete and Ranjith [22] showed a decrease in both uniaxial compressive strength and elastic modulus with the adsorption of CO_2 on brown coal under atmospheric confinement but showed no strength or elastic modulus decrease for tests carried out under 10 MPa confinement.

This article discusses theory concerning modifications to the influence of CO_2 adsorption on the mechanical behaviour of coal with significant hydrostatic confinement and discusses the origin and consequences for coal seam CO_2 sequestration of changes in the elastic modulus of coal samples exposed to CO_2.

2. Methodology

The results discussed below were drawn from a number of studies concerning the mechanical effects of sorption on solids. The most pertinent results for the current discussion are those of Viete and Ranjith [22], who studied the mechanics of coal seam CO_2 sequestration. They used a uniaxial and triaxial testing approach to investigate the differing mechanical responses of air- and CO_2-saturated brown coal specimens. Overall, four air-saturated and three CO_2-saturated specimens were tested in the uniaxial testing program and tests on four air-saturated and four CO_2-saturated specimens formed the triaxial program. Triaxial runs were carried out at a confining pressure of 10 MPa and internal gas pressure of 2 MPa. Prior to testing, individual specimens were exposed to the appropriate sorbed phase at a pressure of 1.5 MPa for a period of 72 h and, in the case of triaxial tests, internal gas pressures were applied during testing using the gas phase to which the specimen was exposed prior to testing. Uniaxial and triaxial tests used a constant axial strain rate. Viete and Ranjith [22] provide a more detailed description of the testing procedure.

3. Results and discussion

From their results, Viete and Ranjith [22] found a decrease in the compressive strength and elastic modulus of brown coal of about 13% and 26%, respectively, with the introduction of CO_2 for uniaxial tests (Fig. 1a) and no corresponding strength or elastic modulus decrease for the triaxial tests (Fig. 1b). Uncertain of an explanation for the lack of a mechanical response to CO_2 sorption for the specimens tested at larger confining pressures, they suggested that natural mechanical variability in tested specimens might have masked the real effect. Nevertheless, the results of their study provide evidence to suggest that the

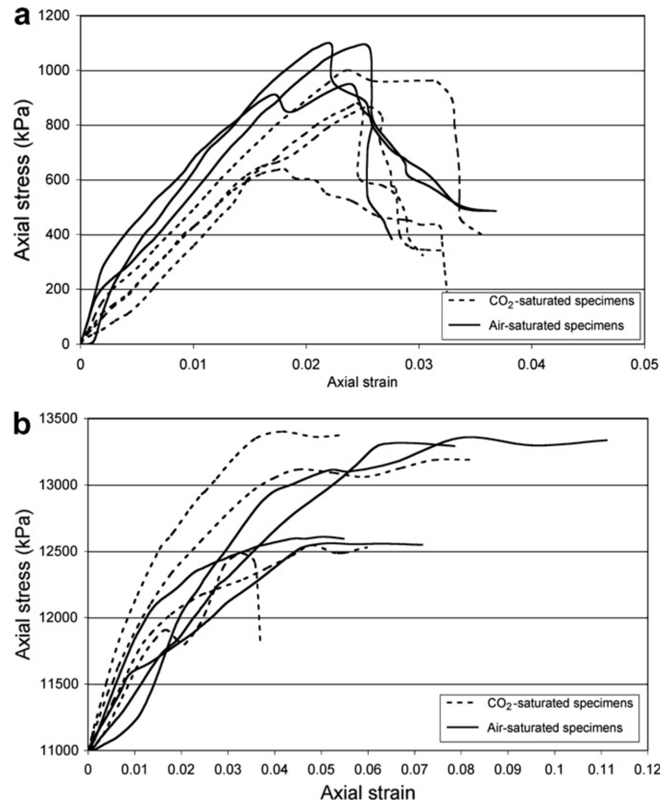

Fig. 1. Stress–strain plots for air- and CO_2-saturated specimens: (a) uniaxial tests, and (b) triaxial tests (from [22]).

adsorption of CO_2 has a negligible effect on the compressive strength and the elastic modulus of coal under significant confining stress.

3.1. The origin of mechanical changes in coal with the introduction of CO_2

The affinity of CO_2 for coal is strongly related to its propensity for adsorption to the coal surface, a process known to influence the mechanical properties of materials (see [19]). However, adsorption is not the only mechanism by which coal can retain CO_2. CO_2 sorption on coal also involves uptake of the sorbent into the coal pore space. Coal is a polymer and the presence of certain functional groups in its polymeric structure allows chemical interaction with solvents (such as CO_2) through electron transfer and a variety of different non-covalent bonds [25,13]. These chemical interactions can cause significant changes to the macromolecular structure of the coal [10,13] and thereby affect its mechanical behaviour [11,25].

An explanation for the apparent lack of strength reduction in the triaxial tests of Viete and Ranjith [22] may be found in adsorption theory. Changes to the coal polymeric structure with the introduction of CO_2 may also play a role in influencing coal strength, though by which mechanisms and to what degree of influence remain unknown. No theoretical explanation for the lack of an elastic modulus decrease under confinement has yet been proposed.