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Effects of subcritical and supercritical CO_2 sorption on deformation and failure of high-rank coals

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ABSTRACT

This paper presents the results of an extensive experimental analysis aimed at establishing the effects of sub-critical and supercritical CO_2 sorption on deformation and failure of coals. Two high-rank anthracitic coals from the South Wales coalfield, obtained from different locations and depths of 150 m and 550 m, are employed for that purpose. The investigations include i) determination of unconfined compressive strengths and elastic moduli of the cores both non-saturated and saturated with CO_2 at 2.1 MPa, 4.3 MPa and 8.5 MPa, ii) assessing the dependence of the parameters obtained on CO_2 pressure, iii) analysing the effect of CO_2 saturation on failure patterns of the samples tested and iv) determination of the particle size distribution after the failure of the samples. Based on the results of twenty coal specimens tested, it is demonstrated that CO_2 sorption reduces the uniaxial compressive strengths and elastic moduli by between 29% and 83% for the range of pressures studied. The reductions observed increase gradually up to 4.3 MPa and then reach a plateau. By accommodating the effect of effective stress on compressive strength values, it is shown that chemical weakening of high rank coals is mostly associated with sorption of subcritical CO_2, with negligible impact of supercritical CO_2 on further parameter reduction. Inspection of failure patterns during uniaxial compression suggests that non-saturated coal specimens fail through axial splitting with rapid crack propagation and high outburst of coal pieces while the failure of cores subjected to CO_2 injection occurs through multiple fractures with negligible material outburst. The post-failure analysis demonstrates that CO_2 treated samples disintegrate on smaller particles than non-saturated specimens, as up to 5.6 more CO_2 saturated coal pieces passed through the sieves considered in this study than non-saturated pieces. It is claimed that this study presents novel insights into the geomechanical response of high rank anthracitic coals to high pressure CO_2 injection.

1. Introduction

Geological sequestration in unmined coal seams offers a prospect of delivering greenhouse gas emissions reductions and at the same time offsetting the costs of CO_2 capture, transportation and storage as the injection of CO_2 in the coal beds allows the production of a value-added product such as methane (White et al., 2005). In general, numerous studies have shown that coal can hold at least twice the volume of CO_2 as CH_4 (Jones et al., 2004; White et al., 2005). However, coals are a mixture of inorganic minerals and organic material that may be affected during the gas injection and adsorption process (Karacan, 2007; Gathitu et al., 2009). Hence, understanding the response of coal under applied stress and storage conditions is of importance for the integrity and safety of the coal seams targeted for CO_2 sequestration and the over-laying strata. This paper aims to enhance such understanding by presenting the experimental investigation of the effects of sub-critical and supercritical carbon dioxide saturation on high-rank coal failure and elastic deformation under uniaxial compressive stress conditions.

The most favourable coal seams for sequestration are occurring at depths where pressure and temperature may exceed the critical values of CO_2, i.e. 750 m (White et al., 2005). At such depths, high rank coals offer a great prospect of storing CO_2 as the maximum sorption capacity generally increases with coal rank (Li et al., 2010; Busch and Gensterblum, 2011). This is related to the fact that high rank coals predominantly contain micropores which provide most of the surface area where gas can adsorb (White et al., 2005).

To date, most research efforts were focused in investigating the geomechanical behaviour of lignite and bituminous coals predominantly exposed to CO_2 in the sub-critical state (Viete and Ranjith, 2006; Perera et al., 2011; Ranjith and Perera, 2012; Perera et al., 2013; Hol et al., 2014; Masoudian et al., 2014; Vishal et al., 2015; Ranathunga et al., 2016a, 2016b). Several studies indicated that CO_2 saturation and

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induced swelling cause crack initiation and enhancement of the fracture lines along the coal increasing the total pore volume (Larsen, 2004; Liu et al., 2010; Hol et al., 2012; Liu et al., 2015). However, very little is known about how anthracitic coals respond to compression after being treated with CO_2, in particular in the supercritical state.

Hence, the geomechanical response of high-rank anthracitic coals under a range of both subcritical and supercritical CO_2 injection pressures up to 8.5 MPa is investigated and discussed in this paper. The results of uniaxial compressive tests of two sets of coal samples obtained from different depths and locations in the South Wales Coalfield are presented. In total, eight samples are tested in natural air-dried state without CO_2 saturation. Twelve specimens were exposed to different sub-critical and supercritical CO_2 pressures for two weeks before testing. Based on the stress-strain data obtained, unconfined compressive strengths and elastic moduli are calculated and presented. In addition, the change in the measured parameters with an increase in gas saturation pressure is shown and discussed. The reductions in elastic moduli and unconfined compressive strengths are quantified by applying a fitting curve to the experimentally determined values and obtaining the parameters related to the reduction of deformation properties as a function of gas pressure. Failure patterns of non-saturated and CO_2 saturated specimens of both coals are analysed and discussed, based on the photographs taken before and after the coal failure. The distribution of particle sizes after the failure of the samples is also examined.

2. Methodology

2.1. Samples

Coal blocks were collected from two different coal mines, the East Pit East Opencast Coal Site and the Aberpergwm drift coal mine from depths of 150 m and 550 m, respectively. Both coal mines are located in Wales as a part of the South Wales Coalfield (Fig. 1). Coal extracted from the East Pit East Opencast Coal Site is locally known as Black Diamond while coal from the Aberpergwm mine is from a 9 ft. seam layer and in the future text they will be referred as BD and AB, respectively. The coal blocks obtained on site were wrapped in cling film and put in plastic bags to minimize the oxidation of the coal surfaces and preserve chemical and physical properties. Upon arrival in the laboratory, the sealed blocks were labelled and stored in the constant room temperature environment.

Fig. 2. A typical coal block used for the extraction of coal samples for uniaxial compressive tests.

Coal cores were drilled out of the coal blocks using a coring machine. Water was used as a cooling agent while drilling. Diamond core drilling bit with an internal diameter of 36 mm was used to obtain the coal cores from the Black Diamond and 9 ft. seam blocks (Fig. 2). Preparation of coal samples for the experiments was conducted following the ASTM D2013/D2013M (ASTM Standards, 2012) standard of practice. As the drying of coal at temperatures higher than 70 °C might create new cracks and small fissures leading to alteration of the physical structure of coal (e.g. Gathitu et al., 2009), an air-drying method following the ASTM D3302/D3302M (ASTM Standards, 2015a) was applied.

A total of twenty coal cores were selected for the uniaxial compressive testing. Although a larger number of coal cores has been extracted, only the ones with minimum fractures or small inconsistencies were chosen. The dimensions of the selected samples are shown in Table 1 together with the measured values of mass and density for each core. The average densities of both BD and AB samples are the same, i.e. 1376 kg/m^3.

Crushed samples passed through a sieve size of 0.212 mm were used for the Proximate and Ultimate analyses, and the results are presented

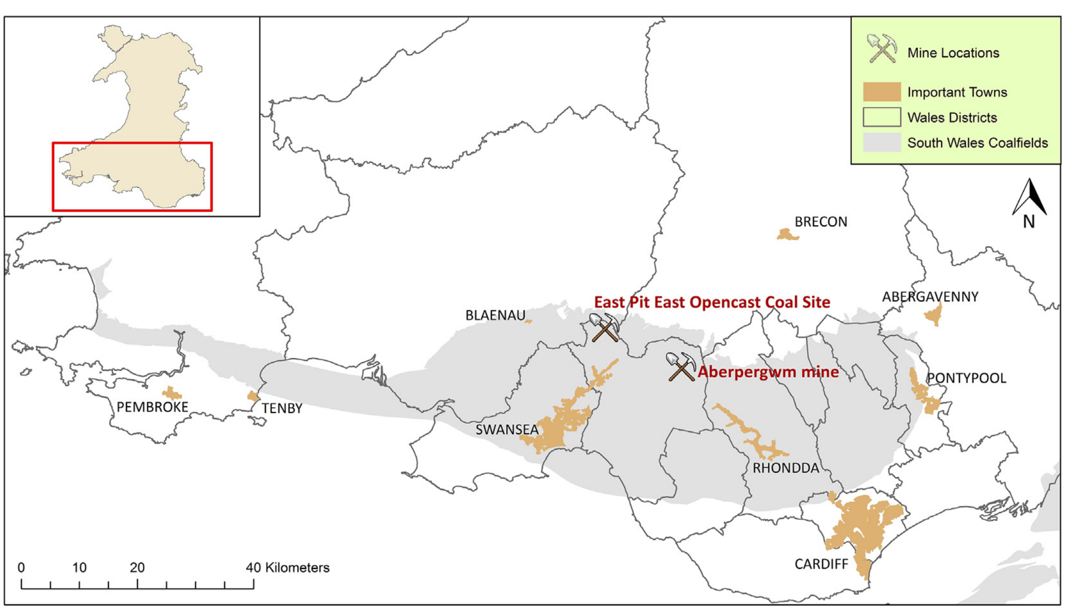

Fig. 1. South Wales Coalfield and locations of the East Pit East Opencast Coal site and the Aberpergwm drift mine.