

# CO<sub>2</sub> Sequestration effect on Outburst in Coal Mining

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## Abstract

Coal mass has the potential to store substantial amounts of CO<sub>2</sub> in the coal matrix and that CO<sub>2</sub> has the ability to move through the coal seam pore and fracture systems, which influences the release of gases during coal mining and the CO<sub>2</sub> sequestration process. In addition, the reduction of coal mass strength due to CO<sub>2</sub> adsorption greatly affects the outburst process. The sudden and violent failure of coal seam with releasing large amount of gas is called outburst in coal mining. Up to date only few have been conducted to investigate the effect of CO<sub>2</sub> adsorption induces strength reduction on the outburst process. The main objective of this study is to investigate the effect of CO<sub>2</sub> injection on outburst in coal mining. Uniaxial Compressive Strength (UCS) experiments were therefore conducted on black coal samples, which have been saturated with CO<sub>2</sub> and N<sub>2</sub> at various pressures at 33 °C. According to the results CO<sub>2</sub> adsorption causes the UCS strength of coal to be reduced by up to 53 % and this higher strength reduction is due to the CO<sub>2</sub> adsorption induce coal matrix swelling. However, N<sub>2</sub> saturation causes the coal strength to be slightly increased. According to these observations, there is a high risk associated with CO<sub>2</sub> sequestration process in coal seam as it significantly reduces the coal seam strength, which has direct influence on outburst process in coal.

**Keywords:** CO<sub>2</sub> sequestration, UCS test, strength reduction, outburst in coal mining

# 1. Introduction

Global warming is of utmost important challenge for 21<sup>st</sup> century scientists and as a result, numerous greenhouse gas mitigation and global warming control programs have been initiated throughout the world during the last few decades. Basically four main techniques have been identified to minimize the atmospheric CO<sub>2</sub> level, less carbon intensive fuels, more-energy-efficient methods, increased conservation, and carbon sequestration.

After conducting many researches on these techniques, CO<sub>2</sub> sequestration has been identified as the most economical and environmental attractive method. According to scientist's pre-estimations, it is necessary to sequester trillion tons of CO<sub>2</sub> by the end of this century to maintain a safe CO<sub>2</sub> level in the atmosphere. Therefore, various CO<sub>2</sub> sequestration means are being tested 1) in depleted oil and gas reservoirs, 2) in saline aquifers, 3) in deep ocean beds, 4) in deep un-mineable coal beds and 5) as mineral carbonates. Compared with all the described CO<sub>2</sub> sequestration methods, long term storage of CO<sub>2</sub> in deep un-mineable coal seams has been identified as a safer, practical and economically attractive method. Because, adsorption is the main gas storing mechanism in coal and this causes the injected CO<sub>2</sub> to be at more stable form in the coal seam. However, adsorption of the CO<sub>2</sub> into coal matrix causes to induce a strain in-between the adsorbing gas layer and the coal matrix (coal matrix swelling), which causes the coal mass strength to be reduced (Perera et al., 2011a).

Coal mass has a potential to store substantial amount of CO<sub>2</sub> inside the coal matrix and that CO<sub>2</sub> has ability to move through the coal seam pore and fracture systems, which influence the release of gases during coal mining and CO<sub>2</sub> sequestration process, which is commonly known as outburst in coal mining. The strength reduction of coal mass due to CO<sub>2</sub> adsorption highly affects this outburst process. There is a high risk associated with the coal CO<sub>2</sub> sequestration process in the NSW coal seams as outburst in coal mining has been frequently occurred in some areas of coal seams (Lama and Saghafi, 2002; Lama and Bodzinoy, 1996). For instance, many CO<sub>2</sub> outburst incidences occurred at Tahmoor, Metropolitan and West cliff collieries in Illawarra coalfield, basically due to the reasons of structural failure of the coal mass and accumulation of CO<sub>2</sub> inside the coal seams. These outbursts caused to have about 11 deaths of mining workers. In the case of the Appin coal mine (samples location for this study) there were about 24 reported outbursts. Structure failure (presence of rock faults or dikes) of the coal seam caused to have many of them and 2-3 of them occurred due to the stress developed in the coal seam by the accumulated gases (Lama and Bodzinoy, 1996). According to Lama (1995), the overall strength reduction of the coal mass by the CO<sub>2</sub> adsorption induced swelling process plays very important role in any kind of outburst in the Bulli coal seam. Although, many studies have been initiated to investigate the effect of the gas accumulation induced stress development and coal structural failure on the outburst process (Lama and Bodzinoy, 1996; Saghafi and Williams, 1998; Saghafi et al., 1995), up to date no much consideration has been given into the CO<sub>2</sub> adsorption induced strength reduction effect, especially under super critical CO<sub>2</sub> adsorption condition, which is the highly expectable condition of CO<sub>2</sub> in deep coal seams.

## 2. Experimental Procedure

Bituminous type black coal samples used for the study were obtained from the Southern Sydney Basin. The coring machine, the diamond cutter and the rock grinding machine available in the Civil Engineering Department of Monash University were used to obtain the required standard size coal samples (38 mm diameter by 76 mm height) from the collected large coal block.

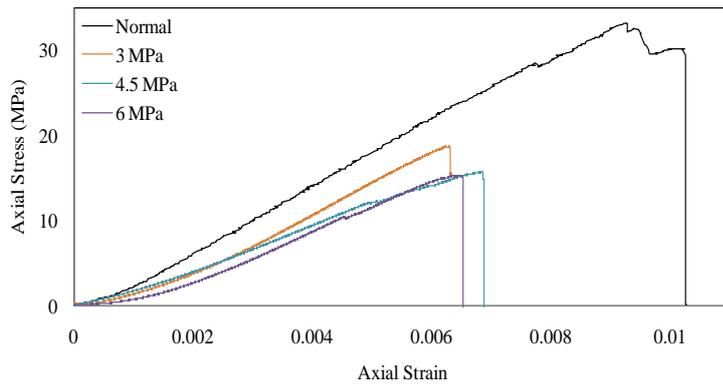
Then, at the next stage of the study samples were saturated under different conditions at 33 °C temperature to identify the CO<sub>2</sub> (3, 4.5 and 6 MPa) and N<sub>2</sub> (6 MPa) saturations effects on coal samples strength. Here, N<sub>2</sub> saturated samples were used on the purpose of comparing the CO<sub>2</sub> saturation effect with a non-reactive gas saturating effect on black coal strength. The pressure cell available in the Ranjith and Perera (2011) was used to saturate the samples.

Then, the effect of CO<sub>2</sub> adsorption on coal mass strength was first investigated using the coal samples saturated at 3 to 6 MPa saturation pressure conditions. After the saturation in the pressure cell of the triaxial set-up an axial load was applied at 0.1 mm/min loading rate, until the sample fail. Therefore, basically the test was done as a uniaxial compressive stress (UCS). After finishing the first test, another sample was saturated under the same 4.5 MPa CO<sub>2</sub> gas confinement at constant 33 °C temperature and UCS test was conducted similarly. The same procedure was followed to check the effect of CO<sub>2</sub> adsorption on coal mass strength at the other saturation pressure condition (6 MPa).

After completing the strength tests for CO<sub>2</sub> saturations, another two samples were saturated from N<sub>2</sub>. In this case the saturating pressure was selected as the maximum saturating pressure used for the CO<sub>2</sub> saturation (6 MPa) at 33 °C constant temperature.

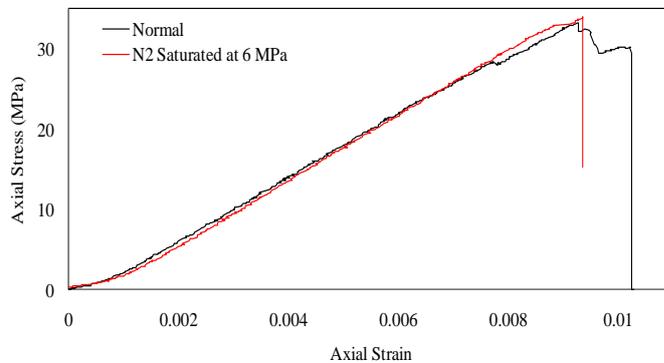
## 3. Results and Discussion

Fig.1 shows how the CO<sub>2</sub> saturation causes the coal strength to be reduced. According to the figure, CO<sub>2</sub> saturation causes the UCS strength of black coal to be significantly reduced, where that reduction is up to 53% from the normal condition. Reduction of coal mass strength due to CO<sub>2</sub> adsorption is associated with the process of coal matrix swelling. The strain induce in-between the coal matrix and the adsorbing CO<sub>2</sub> layer (swelling) during the adsorption process causes the coal mass strength to be reduced along these swelled areas. According to Fig.1, the UCS strength reduction due to CO<sub>2</sub> adsorption reaches to a steady state after about 4.5 MPa saturation pressure condition, which implies that the 4.5 MPa saturation pressure at 33 °C temperature is enough to saturate the used 38 mm diameter by 76 mm black coal samples.



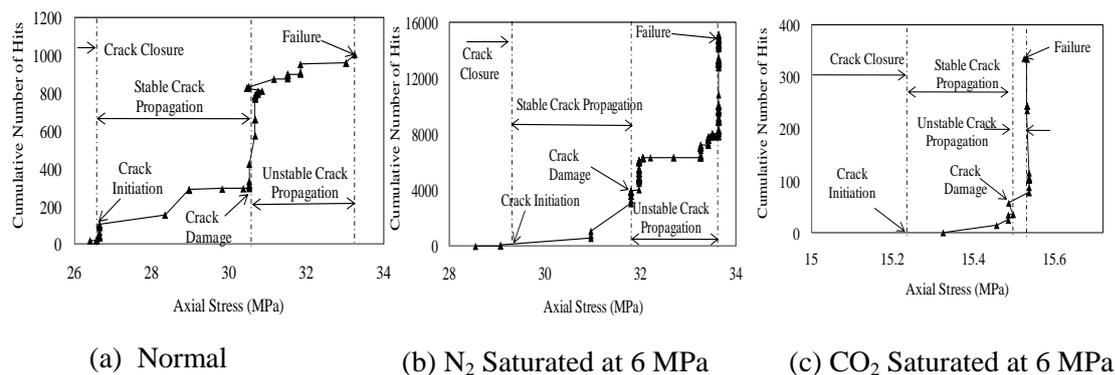
**Figure 2. Stress-strain curves for normal and CO<sub>2</sub> saturated coal samples.**

Fig.2 shows how the N<sub>2</sub> saturation causes the coal strength to be reduced. According to the figure, N<sub>2</sub> saturation at any pressure does not cause either the sample UCS strength or the Young's modulus to be noticeably changed, except the slight increment in UCS strength. It is well known fact that N<sub>2</sub> is a non-reactive gas and therefore, it does not adsorb into the coal matrix, resulting in no any swelling effect due to N<sub>2</sub> saturation. Therefore, this implies that the previous black coal strength reductions observed for the CO<sub>2</sub> saturated samples were purely related with the chemical reactions occurred during the CO<sub>2</sub> adsorption process.



**Figure 9. Stress-strain curves for normal and N<sub>2</sub> saturated coal samples.**

At the end of this study, AE system available in the Civil Engineering Department of Monash University was used to identify the fracture propagation pattern of black coal under the different saturation conditions.



**Figure 11. Variation of cumulative number of hits with axial stress for different saturation conditions**

According to the figure,  $N_2$  saturated sample and normal sample show almost similar fracture propagation patterns. This was expected as  $N_2$  saturation does not much affect black coal strength. However,  $N_2$  saturated samples show significant delays in crack initiation (29.2 MPa) and damage (32 MPa) compared to natural coal samples, where crack initiation is at around 26.2 MPa and damage is at around 30.3 MPa. According to Perera et al. (2011b),  $N_2$  has ability to reverse the  $CO_2$  adsorption induced swelling areas for some extent, which should increase the strength of the coal sample.  $CO_2$  causes the coal strength to be reduced and therefore removal of these two should increase the sample strength. If the  $CO_2$  saturated sample is considered, it causes to have a quite short fracture propagation period (0.2 MPa) compared to normal black coal (11.2 MPa). This is due to the fact that  $CO_2$  saturated samples have already formed fractures during the saturation period as reaching of  $CO_2$  into the cleats and the associated swelling cause the cleats to be expand, resulting in fracture formation.

## 4. Conclusions

Based on the current study, the following conclusions were drawn,

1.  $CO_2$  saturation causes the UCS strength of coal to be significantly reduced, where that reduction is up to 53% for black coal. This strength reduction is associated with the coal matrix swelling created by the adsorbing  $CO_2$  molecules. Therefore, the process of  $CO_2$  injection into natural coal seams has high influence on outburst in coal mining.
2.  $N_2$  saturation does not reduce coal mechanical properties (UCS strength and Young's modulus), which implies that the coal strength reduction observed under  $CO_2$  saturation is purely related with the chemical reactions occurred during the  $CO_2$  adsorption process.
3. However,  $N_2$  causes to have significant delays in crack initiation and damage compared to natural coal samples, which may due to the fact that natural coal has significant amount of in-built  $CO_2$ , which may has already slightly swelled the coal sample This swelled areas can be

reversed by N<sub>2</sub> for some extend. Therefore, injection of N<sub>2</sub> after the CO<sub>2</sub> sequestration process has ability reduce the CO<sub>2</sub> induced strength reduction for some extend.

## 5. Acknowledgement

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