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Response of pores in coal to repeated strong impulse waves

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A B S T R A C T

Repeated-strong-impulse-wave (RSIW) is a new development technique to enhance coalbed methane recovery. The objective of this paper is to investigate the response of pores to impacts using this device. Bituminous coals and anthracites were impacted, and their pores were analysed by mercury porosimetry, a scanning electron microscope and an optical microscope. The results show that pores of anthracite have limited sensitivity to impacts, and their evolution trend is inconspicuous with increasing the number of impacts. Pores of bituminous coal are remarkably sensitive to impacts. The pore evolution of bituminous coal presents two stages during impacts, sharply increasing and then decreasing slowly. Impacts at higher energy levels shorten the process of pore evolution. The distribution of pores seems to be a reason that smaller pores in size are more sensitive to impacts than the larger ones. The mechanical property results in the differences in responses to impacts between bituminous coal and anthracite. Therefore, it is determined that pre-existing crack propagation is the primary fracturing mode of anthracite. Pore initiation and propagation contribute markedly to the fracture of bituminous coal during impacts. However, their contribution is gradually weakened in the second stage of impact evolution.

1. Introduction

There is an abundance of coalbed methane (CBM) resources in China. However, the low recovery of coalbed methane is an urgent problem that has not been solved in recent years. Therefore, researchers put forward various new technical theories to effectively enhance CBM recovery (Bustin et al., 2008; Huang et al., 2011; Zou et al., 2014; Yan et al., 2015), such as high-pressure pulsed water jets (Liu et al., 2011), water jet slotting (Shen et al., 2015), CO_2-ECBM (Busch and Gensterblum, 2011; Gensterblum et al., 2014), acoustic shocks (Jiang et al., 2015), and microwave vibration (Kumar et al., 2011).

The dynamic load technique such as pre-splitting blasting has a better effect on improving the permeability of coal than a static load (Zhu et al., 2007, 2013). A rapid loading rate can improve the elastic modulus of coal, which results in hardening of the coal temporarily and reaching its ultimate strength quickly (Li et al., 2012). Qiu et al. presented that repeated strong impulse waves (RSIW) could be well applied in CBM production (Qiu et al., 2012). This technology repeatedly emits strong shock waves to impact on coals in drill hole, and this proposal has verified the effectiveness in engineering practice.

Many dynamic load technologies have been studied previously. Pre-splitting blasting can break coal under the load of stress waves and quasi-static detonation gas (Liu et al., 2015). It induces a crushed zone, severely fractured zone and an incipient cracked zone in the coal (Chu et al., 2012), which improves the permeability of the coal and gas drainage quantity (Zhu et al., 2007, 2013). Based on traditional hydraulic fracturing, a pulse hydraulic fracturing technology was designed by Li in an experiment where water with a certain frequency is injected into borehole in coal could greatly improve the effect of fracturing (Li et al., 2013). Moreover, the crack density is also increased after impacting by hydraulic slotting which produces strong shock waves (Li et al., 2008, 2014). Pulsed water jets produce many single and continual high-pressure liquid columns as water hammers, and it creates shear cracks and tensile cracks (Dehkhoda and Hood, 2013). The super-macropore density is improved through adjusting the length and frequency of the liquid columns (Dehkhoda and Hood, 2014). Until now, research on dynamic load mainly concentrated on crack initiation and

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propagation. However, the porosity development under dynamic load is absent.

In this paper, we investigate the pore responses of coal to the repeated strong impulse waves (RSIW) under different impact conditions. The differences in pore sensitivity to the RSIW between bituminous coal and anthracite were compared, and the pore evolution with RSIW impacts was analysed.

The pores are so abundant that a large internal surface area exists, which reflects the methane holding capacity in coal. The pores in coal also determine the diffuse rate and partial permeability of methane based on the pore system of triple porosity/dual permeability model. Therefore, the study of pore response analyses and sensitivity is important to evaluate the effect of the increasing methane recovery on RSIW. As a flaw in coal, pore responses are also vital to investigate the crack initiation and evolution with the RSIW impact. The conclusions will provide a theoretical basis for improving the RSIW technology.

2. Experiment and methods

2.1. Technique

The structure of the experimental device is shown in Fig. 1c. It consists of impulse wave generator, pressure sensor (PS), water tank and casing pipe with round holes. The impulse wave generator is composed of the electrical control box (ECB), transformer (TR), energy storage capacitor (ESC), energy controller (EC) and energy transducer (ET), which is made up of energetic materials and molybdenum wires. The pressure sensor is used to monitor the impulse wave generated from the generator. The casing pipe is first placed in the water tank, and then, the coal sample with metal net is placed close to the round holes. The impulse wave generator is placed in casing pipe and the energy transducer (ET) is placed at the same level of the coal.

An alternating current (AC) is converted into a high voltage direct current (DC) by the electrical control box and transformer. The energy storage capacitor is then charged by the high voltage direct current. The electrode releases 18–20 kV voltage and 20–30 kA current until the electrical energy stored in the capacitor reaches the work threshold of the energy controller. The current melts the molybdenum wire which can detonate energetic materials, which are explosive, between the double discharge electrodes. At last, it produces an impulse impact wave, which impacts the coal sample. An attenuation curve of the shock wave is monitored by the pressure sensor, which is shown in Fig. 1b. The device can emit impact waves repeatedly through replacing energetic materials automatically. Fig. 1a shows an ideal effect sketch about the application of the device in the coal seam.

2.2. Sample preparation

Coal samples were collected separately from work face in Ulan colliery (bituminous coals) and Sihe colliery (anthracites) in the Permian. The Ulan colliery is located in the north of Ningxia province, and the Sihe colliery is situated in the south of Shanxi province, which is a major CBM production region in China. The coal samples collected are primary, hard coal structures. They are mainly composed of bright coal. There are few pre-existing cracks and always distribute in telocollinite. Table 1 shows the basic characteristics of petrography, mechanical properties and proximate analysis of coal samples used in the experiment.

Coal samples were cut into cubes and each side was approximately 0.3 m. The bedding of coal samples was parallel to the top surfaces of cubic.

The cubic sample was placed into water, as shown in Fig. 1c, and the RSIW were loaded on one of its side surfaces. Two bituminous coals were impacted by 5 g and 10 g of energetic materials, denoted by U1 and U2. One anthracite sample, which is called S1, was impacted by 10 g of energetic materials. The strong impulse wave was loaded repeatedly until there were obvious cracks throughout the cubic sample. Furthermore, some sub-samples were randomly collected from cubic sample for further analysis, and the samples were bright coals. We collected the sub-samples by hand and chose the one that had been loosened as far as possible after impact. The sampling interval of bituminous coal and anthracite is different in consideration of the difficulty of sampling. The details were shown in Table 2.

Coal has heterogeneity in pore distribution, mineral content and macerals (Cai et al., 2015; Zhao et al., 2016), which affect the comparison among sub-samples. To reduce the heterogeneity of coal among the same coal rank cubic samples, the cubic bituminous coal samples were all taken from one large sample that weighed about one ton, and the anthracite samples were collected in the same working face. It is more important to reduce the

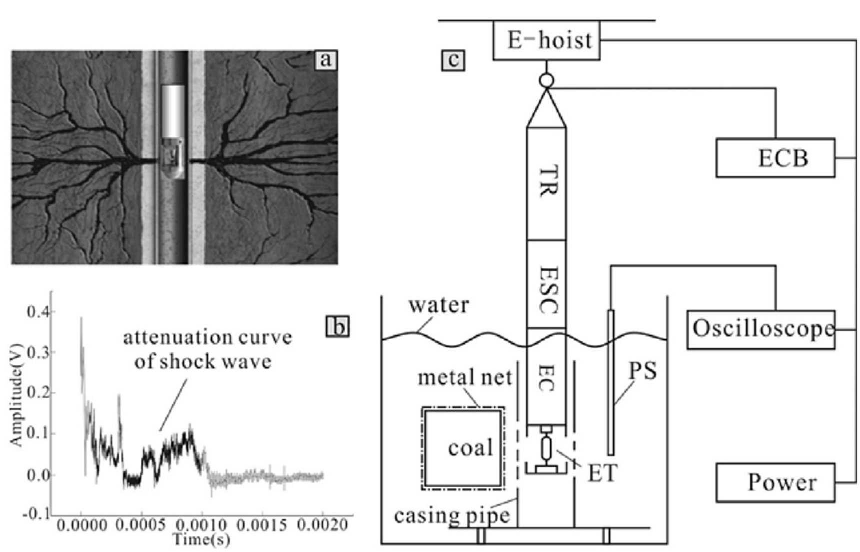

Fig. 1. Structure of experimental device.