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Pulverization characteristics of coal from a strong outburst-prone coal seam and their impact on gas desorption and diffusion properties

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ABSTRACT

Coal seams that are prone to strong outbursts have low strength and cause heavy structural damage to the seam. Their outburst risk is highly related to the release of the adsorbed coalbed gas, which is controlled by the gas desorption and diffusion characteristics of coal. In the Haizi Coal Mine, China, an extremely high gas outburst risk was detected, and the coals from this area were found to have an unprecedented high degree of fragmentation and were present in the pulverized state. To explain the pulverization characteristics of the pulverized coal, the related physical parameters were investigated; the gas desorption and diffusion properties of the pulverized coal were analyzed and compared with those of the unpulverized coal. The results indicated that the pulverized coal could easily reach the required degree of fragmentation for a coal and gas outburst to occur. Furthermore, the pore volume and specific surface area of the pulverized coal differed according to the coal particle size. Compared with the unpulverized coal, the gas desorption and diffusion properties of the pulverized coal were largely varied, and the pore structure of the pulverized coal was much simpler. The formation of pulverized coal is believed to be closely related to complex geological conditions.

1. Introduction

Coal mine gas accidents, which are usually caused by gas outbursts, constitute an increasing portion of coal-mine fatalities in China. The fundamental mechanisms causing coal and gas outbursts remain a mystery due to numerous contributing factors (Fisne and Esen, 2014; Shepherd et al., 1981; Singh, 1984; Skoczylas et al., 2014; Wang et al., 2014c; Wierzbicki and Skoczylas, 2014). Many attempts have been made to explain the outburst process, and various hypotheses and theoretical models have been proposed (Barron and Kullmann, 1990; Hodot, 1966; Lunarzewski, 1998; Skoczylas et al., 2014). However, limited progress has been made toward understanding and predicting such catastrophes due to a lack of field data, which attributed to difficulties in observing outburst events.

The original structure of coal can quite easily be destroyed by tectonic movement, which could result in the formation of tectonic coal (Jian et al., 2015). Many scholars have found that coal and gas outbursts are related to geologic tectonism during their investigation of sites where outbursts occurred (Airey, 1968; Cheng et al., 2013; Sachsenhofer et al., 2012; Zhang et al., 2016). Not all tectonic coal will result in coal and gas outbursts; however, tectonic coal was often found in these sites. Therefore, many authors have emphasized that the presence of tectonic coal ought to be treated as a factor that increases the outburst risk (Sachsenhofer et al., 2012; Skoczylas and Wierzbicki, 2014). Previous studies have mainly focused studying coal powder collected from accident sites where coal and gas outbursts occurred, whereas few studies have been conducted on the characterization of the structure of natural pulverized coal and its rules of gas occurrence and migration. The No. 7 coal seam of the Haizi Coal Mine in the Huaibei Coalfield, China, is a typical pulverized coal seam with an incomparably high degree of

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fragmentation, very small coal particle size, and quite low strength (the Protodyakonov coefficient is typically less than 0.15).

In this paper, the drilling cuttings gas desorption index (Δh_2) was introduced to describe the outburst risk of pulverized coal. The index represents the pressure created by the desorbed gas releasing from 50 g of coal cuttings with a 1–3 mm particle size during the 2 min between the third and fifth minute, which reflects the coal gas desorption ability at the initial stage of pressure relief. The larger the value of Δh_2, the higher is the propensity toward outburst. According to experience at sites in China, the threshold values of Δh_2 are 200 Pa and 160 Pa for dry and wet coal, respectively (SACMS, 2009). The field data indicated that, after a long period of gas drainage in the No. 7 coal seam of the Haizi Coal Mine, the gas pressure and content decreased to less than 0.15 MPa and 2 m^3/t, respectively (the values of which are far less than the stated threshold values of 0.74 MPa and 8 m^3/t in China); however, the value of Δh_2 was still greater than 350 Pa, which is much higher than the threshold value.

An examination of the pulverization characteristics of the outburst coal in the Haizi Coal Mine was conducted to reveal the mechanism of this unusual phenomenon. The Protodyakonov coefficient, microstructure and particle size distribution of the coal were measured, and the proximate analysis and pore structure were tested on pulverized coal with different particle sizes. Meanwhile, the gas desorption and diffusion properties of pulverized coal were analyzed and compared with those of unpulverized coal. Furthermore, the causes of formation of pulverized coal was discussed.

2. Pulverized coal and its pulverization characteristics

2.1. Coal samples

Pulverized coal samples were collected from the No. 7 coal seam of the Haizi Coal Mine. As shown in Fig. 1, the degree of fragmentation of pulverized coal is extremely high, which is very similar to the coal powder produced after a coal and gas outburst. The partial enlargement of the image indicates that most of the coal particles present loose flakes and irregular lenticular fragments. The stratification and endogenic fracture of the coal are difficult to identify, and the extended fracture surfaces of the coal fragments are very unstable. Additionally, a pronounced pulverized appearance can be recognized in some cross-sections of the coal particles.

The Protodyakonov coefficient, petrographic composition and adsorption constants were measured. The results are shown in Table 1.

To recognize the microscopic structure characteristics of pulverized coal, the microstructure of the coal samples was analyzed by scanning the selected smooth surfaces of the coal particles. The scanning electron microscope (SEM) images are shown in Fig. 2. As shown in Fig. 2(a) and (d), there are many fractures with irregular shapes on the surfaces of coal particles. Fig. 2(b) and (c) indicate that the fracture surface is very uneven, there are distinctive layered structures, and the surfaces are characterized by having many concave–convex structures. Fig. 2(d) also shows that the surfaces of the coal particles are very rough and there are many sub-micron particles, such as clay particles and tiny coal fragments, which are attached to the coal particle surfaces. Previous studies (Qu, 2010) have indicated that the microscopic layered structure of pulverized coal is very fragile, resulting in the low strength and hardness of the coal and in a the coal mass that is extremely easy to break.

2.2. Particle size distribution of pulverized coal

The coal samples were separated into different size ranges, including <0.01 mm, 0.01–0.074 mm, 0.074–0.1 mm, 0.1–0.2 mm, 0.2–0.25 mm, 0.25–0.5 mm, 0.5–1 mm, 1–3 mm and >3 mm, and the mass of each size range was determined. To ensure replication, a sieve analysis test was conducted in triplicate. The results are shown in Table 2, which indicates that there are no obvious differences between each test; thus, the average value is taken for analysis.

Table 2 indicates that most of the pulverized coal particles are less than 3 mm, and the coal with a particle size greater than 3 mm accounts for only 7.02%. Among the samples, the percentage of coal particles that lie in the hundred micron size range (0.1–1 mm) is the greatest (46.7%), those at the millimeter level (>1 mm) account for 25.7%, the ten micron-sized (0.01–0.1 mm) coal particles account for 18.46%, and the micron-sized (<0.01 mm) coal particles account for 9.14%. Because the samples were directly and quickly tested after collection from the sites in sealed canisters without crushing, this result is considered to be a good representation of the actual coal particle size distribution in the coal seam.

Our research group studied the coal powder samples collected from the accident sites of the Machang, Yangquan and Bailongshan coal mines, China, where coal and gas outbursts occurred, and analyzed their particle size distributions. The results are shown in Table 3.

A comparison of the data between Tables 2 and 3 indicates that pulverized coal and coal powder sampled from coal and gas outburst accident sites are very similar in terms of their particle size

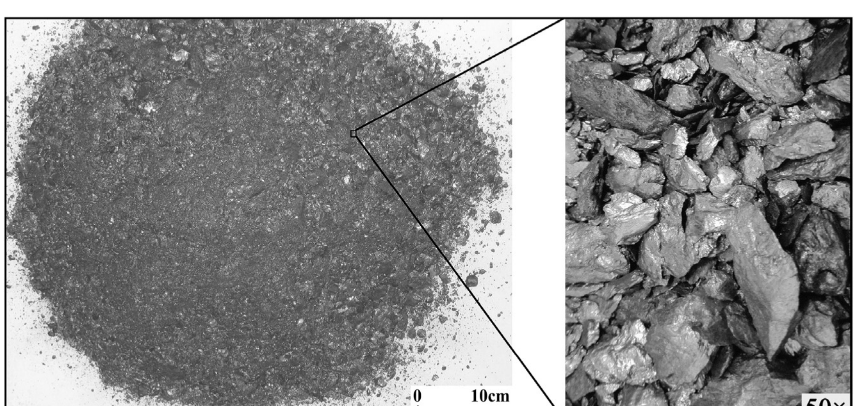

Fig. 1. Image of pulverized coal from the No. 7 coal seam in the Haizi Coal Mine.