International Journal of Mining Science and Technology 27 (2017) 825–829

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Directivity effect of unloading bedding coal induced fracture evolution and its application

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ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form 16 March 2017
Accepted 10 April 2017
Available online 30 August 2017

Keywords:
Unloading direction
Bedding structure
Gas permeability
Fracture evolution

ABSTRACT

In the coal mining process, the gas contained in the coalbed is one source of the most serious accident hazards. Stress releasing from the coal deposit is the main controlling factor that leads to such accidents. Based on the bedding of coal samples, the gas permeability well describes the evolution of fracture, so the paper carries out research on the permeability properties of coal under different unloading directions. The research obtains that when the stress unloading direction is perpendicular to bedding, more penetrating fractures and bedding fractures occur, and the permeability significantly increases. Although the axial stress reduced, the confining pressure makes the permeability of the bedding plane fracture exist under constant. The permeability obtained when the unloading direction was perpendicular to the bedding is 52 times larger than that when it is parallel to the bedding. The results show that the efficiency of gas drainage is impacted by the relative direction of gas drainage drilling in relation to the bedding orientations. The maximum amount of gas extraction when drilling is perpendicular to the bedding is 1.3 times than that when drilling is oblique to the bedding, and 1.75 times than that when drilling is parallel to the bedding.

1. Introduction

Bedding is the one of the major characteristic of a coal seam, and it can be divided morphologically into horizontal, wavy and oblique ones. Coal seams show significant heterogeneity due to the differences in the lithotype ingredients or the inorganic mineral components that run perpendicular to the bedding [1–3]. Such differences directly affect the mechanical properties of the coal and surrounding rock, which influences coal mining. Beddings may exhibit the appearance of deformation and contain fractures [4]. These properties ultimately affect gas migration in coal and the effectiveness of gas extraction. In the present coal mining process, in order to reduce and control the threat of coal seam gas, gas drainage is a commonly used method to prevent gas disaster accidents [5,6].

Pressure relief through the method of gas drainage is an important technology used for Chinese coalbed methane management. It is also an important measure to reduce the amount of gas emission during the mining process, prevent the accumulation of gas, and reduce gas explosions and coal and gas outburst risks [7–9]. The relief gas migrates through coal seam fractures to the extraction hole under negative pressure drainage. Different unloading directions and structures make the process of coal gas seepage extremely complex. Laubach et al. noted the existence of bedding and the jointed structure of coal destroyed the continuity and integrity of the coal seam, and changed the intensity of the coal seam stress distribution [10]. According to tests on the strength of coal and surrounding rock, Wu et al. indicated that the tensile strength of coal with different bedding directions has a significant anisotropy [11]. The compressive strength for coal with vertical bedding is 10%–15% larger than that of parallel bedding. Liu et al. considered the effect of bedding plane uniaxial compression tests on coal and indicated that the directions both vertical and parallel to the bedding plane uniaxial compression have discrete features [12]. On the basis of rock specimen unloading tests, Shen et al. noted that rock deformation had a strong capacity for expansion along the unloading direction under an unloaded state [13]. According to a test based on the unloading process, Ranjith et al. noted that rock deformation rebounded more strongly in the unloading direction, expanded significantly and exhibited significant brittle failure

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http://dx.doi.org/10.1016/j.ijmst.2017.07.022
2095-2686/

characteristics [14,15]. Meanwhile, Min has studied fracture development with different forces applied to the x and y directions. It was found that the direction of fracture evolution is different with different combinations of forced in the x and y directions [16]. This difference ultimately affected the gas flow direction. In summary, the mechanical properties and permeability of coal are related to the bedding direction.

Thus, permeability can be affected by the strength and deformation characteristics of coal. These characteristics are not only affected by the stress and size but also closely related to the direction of force and the structure of coal. However, the impact of unloading direction and the bedding structure on permeability cannot be ignored. This research will ultimately help to maximize the amount of pressure relief through gas drainage, reduce the amount of gas emissions, and eliminate gas risks. The focuses of this research have great significance for coal mine disaster prevention.

2. A coal seam stress characteristics analysis

From the perspective of mechanics, coal mining is a loading and unloading process. The typical underground loading and unloading features are mainly distributed on the front side and the protective layer. These locations are often in a complex stress environment. The main variation of the force is shown in Fig. 1. It shows that the force characteristics of a coal body undergo stress changes from loading and then unloading. The force changes from the original stress, with stress rising (loading) and stress dropping (unloading) according to the process of coal mining. The coal deformation zone created due to coal mining can be divided into elastic deformation, plastic deformation and fracture deformation. The coal penetration rate of the three deformation zones exhibits dynamic evolution characteristics [17].

When the coal bedding is under loading, it will not damage immediately. With loading increases, micro-fractures appear inside the coal body. These fractures continue to spread and penetrate the coal. The coal body shows damage phenomena until it reaches the maximum strength of the coal. The existence of the bedding fracture has an important impact on coal deformation and permeability.

3. Laboratory experiments

3.1. Coal samples preparation

A large block of coal was collected that displayed a distinct bedding structure. Standard cylinders of 50 mm in diameter and 100 mm in length were cut from this block. The coal samples and the structure of bedding are shown in Fig. 2. Before the experiment, the weight, diameter and length of the samples were measured and recorded.

3.2. Experimental method

The experiments were performed by using the coupling characteristic determinator of adsorption-permeation-mechanics. The transient pulse technique is used in this experiment. The testing principle is to balance the pressure on both ends of the sample for a period of time and then increase the pressure on one end. This approach gives the coal sample a transient pulse pressure difference, and forms a one-dimensional percolation inside the sample. As time passes, the upstream pressure gradually decreases, and the downstream pressure gradually increases until the sample reaches a new pressure equilibrium state [18]. The formula of the pressure gradient upstream over time is as follows [19,20].

$$\delta P(t) = \delta P(t0)e^{-\alpha t} \tag{1}$$

where $\delta P(t)$ is the pressure difference between the upstream and downstream at time t; $\delta P(t_0)$ the initial pressure difference between the upstream and downstream; t time; and α defined as below:

$$\alpha = \frac{kA}{\mu L}\left(\frac{1}{Su} + \frac{1}{Sd}\right) \tag{2}$$

where k is permeability; A the sample cross-sectional area; μ the viscosity of the fluid; L the sample length; and S_u and S_d the storage coefficients of the upstream and downstream, respectively. The permeability is obtained from Eq. (2).

3.3. Experimental conditions

Two sets of experiments were conducted. One is with constant confining stress and reducing the axial pressure and pore pressure in the unloading process; the other one is with constant axial stress, but reducing the confining stress and pore pressure in the unloading process. The detailed experimental scheme is shown in Table 1.

4. Results and discussion

Combined with the testing methods and the principles of penetration previously described, the analysis fits both ends of the pressure difference of the sample to the decay exponent and obtained

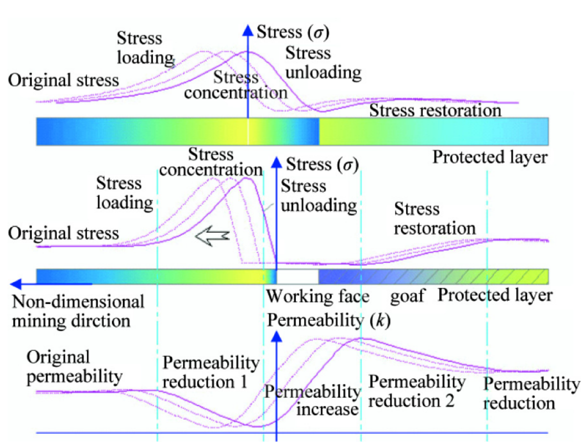

Fig. 1. Schematic diagram of coal stress variation in a mining coal seam.

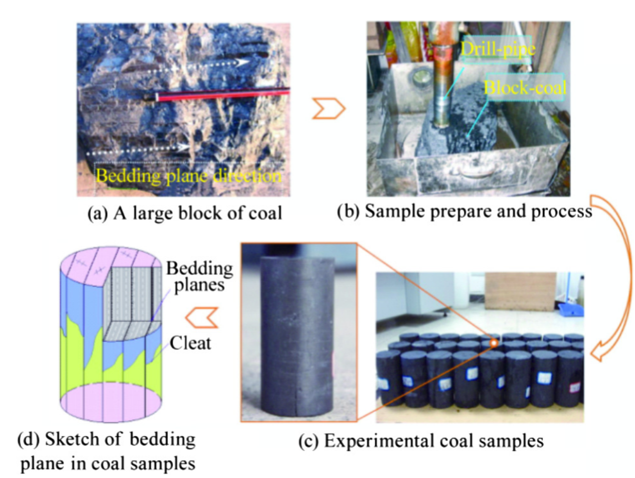

Fig. 2. Coal sample preparing process and its bedding direction.