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Mechanical behavior and permeability evolution of gas infiltrated coals during protective layer mining

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ABSTRACT

This study investigated the stress–strain–permeability relationship of a Chongqing coal under the stress path during the mining process. The abutment stress was first measured at the longwall (LW) face 3211 of Songzao Mine in Chongqing, China. The field monitoring results revealed that the concentration coefficient of the abutment stress was approximately 1.5–2.0 during protective layer mining. Then, triaxial compression tests for the gas-infiltrated coals were conducted under the above stress path and different gas pressures. These tests, with the simultaneous actions of unloading confining stress and loading axial stress, are called SUL tests. The triaxial compression tests revealed that the peak deviatoric stress and the corresponding strain of coal under SUL tests were lower than those under conventional triaxial compression (CTC) tests. Poisson's ratio was higher, but the elastic modulus was lower in SUL tests. The permeability evolution of coal under the SUL tests underwent four distinct stages: the increasing stage in the process of SUL, decreasing stage, slowly increasing stage beyond the yield point, and sharply increasing stage after the peak stress. With the increased gas pressure, the peak deviatoric stress and corresponding axial strain decreased, Poisson's ratio increased, and elastic modulus decreased. Further, the permeability of coal increased with increasing gas pressure in the complete deformation process.

1. Introduction

Coal mining induces different stress zones in front of the working face of coal—a relief stress zone, abutment stress zone, and recovered stress zone—from the initial in-situ stress state.[1] During this coal mining process, the stress path experiences the loading of axial stress and the simultaneous unloading of confining stress. However, current investigations on the coupling mechanism between the mechanical behavior and permeability of coal are almost all based on conventional triaxial compression (CTC) tests. This CTC path may not represent the coal mining process. It is necessary to validate the applicability of the current investigations to the coal mining process.

The stress evolution of coal seams has been widely investigated. A series of three-dimensional numerical models were developed to examine the effect of the mining depth, in-situ stress and stope geometry as well as the orientation on the overbreak of a stope wall.[2] For example, Wang et al. took the cutting face from disaster sites as prototypes to study the effect of the stress distribution on dynamic disasters of coal mines.[3] Guo et al. presented a comprehensive study on the longwall in a deep underground coal mine.[4] They investigated the mining-induced strata movement, stress changes, fracture openings, and gas flows. Their studies included the field monitoring of overburden displacement, changes of stress and water pressure at the LW face. They concluded that the vertical stress increased and the horizontal stress decreased during mining. All of the above investigations revealed that deeper mining faces a higher risk of mining disasters.

Coal seam gas couples with coal deformation to affect mining safety. In China, coal seams are rich in coal seam gas. There is approximately 10 billion m^3 of the recoverable coalbed methane (CBM) in China. The Erlian basin in Inner Mongolia contains 2 billion m^3 of recoverable CBM. The Ordos basin and Qinshui basin contain more than 1 billion m^3 of recoverable CBM. The gas content gradually increases with coal burial depth. The accumulation of coal seam gas during mining may trigger dynamic disasters, such as gas emission, and even the occurrence of coal and gas outburst in front of the working face. The gas accumulation depends on many parameters, of which the permeability evolution of coal is the most important. Therefore, the investigation of the

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permeability distribution within coal and the surrounding rocks is the core work of the simultaneous extraction of coal and gas.

Stress-dependent permeability has been investigated for different rocks and coals.[5–7] An exponential function was proposed to describe the relationship between coal permeability and stress.[8,9] Coal is a type of organic porous rock with a strong sorption capacity for coal seam gas. This desorption of the gas may induce the volumetric shrinkage of coal matrix[10] and change the coal permeability.[11] For example, Meng and Li investigated the permeability of high-rank coals during early depletion of CBM and found that the permeability of high-rank coals was susceptible to effective stress.[12] Therefore, the mechanical behavior and permeability evolution should be the focus.

The mechanical behavior and permeability evolution have been investigated in recent years.[13,14] For example, Chen et al. studied the damage process of reconstituted coal specimens and its influence on permeability during an unloading process.[15] They combined X-ray CT scanning and permeability experiments to measure the mechanical behavior and permeability evolution of reconstituted coal specimens subjected to the same stress path and the same effective confining stress. Cai et al. explored the contribution of interactions between stress and damage on the evolution of permeability through X-ray computed tomography images and acoustic emission profiling together with concurrent measurements of the P-wave velocity.[16] Zhang et al. investigated the experimental relationships among the flowrate, permeability and fracture aperture in fractured media.[17] Qiu et al. designed an incrementally cyclic loading-unloading pressure test to quantify stress-induced microfracturing and fracturing under the condition of confining stress reduction.[18] On the other hand, Wang et al. experimentally investigated the role of gas desorption, stress level and loading rate on the mechanical behavior of methane infiltrated coal.[19,20] The deformation, strength and permeability evolution were studied through the conventional triaxial compression of initially intact coal. Zhao et al. studied the influence of gas adsorption on the permeability evolution of fractured porous media under 3D stress conditions.[21] The relationships among effective stress, gas desorption, matrix shrinkage, gas slippage, and permeability were explored.[22–27] The above experimental studies were all based on CTC tests. Before the application of the above results to different mining processes, it is necessary to identify the difference of the mechanical behavior and permeability evolution of coal under the CTC tests and the simultaneous action of the unloading confining stress and loading axial stress (SUL) tests.

This study investigated the mechanical behavior and permeability evolution of gas infiltrated coals during protective layer mining. This paper is composed of three parts. First, the change of the abutment stress in front of the working face was monitored at LW face 3211 of Songzao Mine in Chongqing, China. This field monitoring obtained the concentration coefficients of the abutment stress. A stress path with the loading rate of axial stress and the unloading rate of confining stress was thus determined for the triaxial compression tests. Second, a coupling experiment on the mining-induced mechanical behavior and permeability evolution of coal under the SUL path was conducted in a complete deformation process, from elastic deformation to failure. The coupling mechanism between the mining-induced mechanical behavior and permeability of coal was explored. Finally, the implication of the above experimental results to the safety assessment for underground protective layer mining was discussed.

2. Measurement of in-situ abutment stress during protective layer mining

This section will present the field measurement for the change of in-situ stress during the mining process. These results can provide a stress path for the laboratory tests for the measurement of the mechanical behavior and permeability evolution of coal.

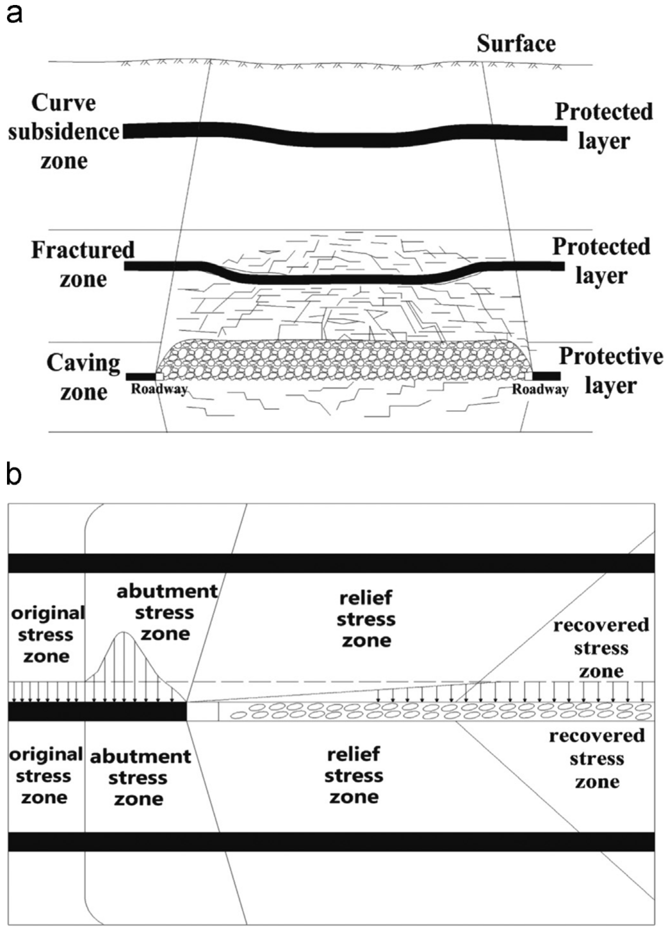

Fig. 1. Schematic diagram and stress distribution of the protective layer mining. (a) Schematic diagram of the protective layer mining. (b) Stress zones of coal and rock seams along the strike direction.

2.1. Stress zones of coal and rock seams along the strike direction

Protective layer mining is one of the most effective mining methods for gas control in China.[28,29] This method is schematically drawn in Fig. 1(a). It divides the coal seam into protective layers and protected layers. The protective layers are mined first for the reduction of the gas content in adjacent layers. The protected layers are protected by mining the protective layers. The stress in the protected layers is released by mining the protective layers such that the fractures in the protected layers are open and the permeability is enhanced. As shown in Fig. 1(b), the layers along the strike direction can be divided into four stress zones: the original stress zone, abutment stress zone, relief stress zone, and recovered stress zone. Protective layer mining disturbs the protected layers and breaks the in-situ stress balance. This disturbance causes the coal seams to deform and even to be damaged. The peak abutment stress in the protected layers is obviously decreased. Therefore, different mining methods may have their stress paths and cause different mechanical behavior and permeability evolution of coal seams.

2.2. Field monitoring of stress at LW face 3211

LW face 3211 is the first mined working face at the third depth