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Effects of coal damage on permeability and gas drainage performance

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ABSTRACT

Coal permeability is a measure of the ability for fluids to flow through coal structures. It is one of the most important parameters affecting the gas drainage performance in underground coal mines. Despite the extensive research conducted on coal permeability, few studies have considered the effect of coal damage on permeability. This has resulted in unreliable permeability evaluation and prediction. The aim of this study is to investigate the effect of coal damage on permeability and gas drainage performance. The Cui-Bustin permeability model was improved by taking into account the impact of coal damage on permeability. The key damage coefficient of the improved permeability model is determined based on the published permeability data. A finite-element numerical simulation was then developed based on the improved permeability model to investigate the damage areas and the permeability distribution around roadway. Results showed that the tensile failure occurs mainly on the upper and lower sides of the roadway while the shear failure symmetrically occurs on the left and right sides. With the increase in the friction angle value, the damage area becomes small. A good agreement was obtained between the results of the improved permeability model ($\gamma = 3$) and the published permeability data. This indicated a more accurate permeability prediction by the improved permeability model. It is expected that the findings of this study could provide guidance for in-seam gas drainage borehole design and sealing, in order to enhance the gas drainage performance and reduce gas emissions into underground roadways.

1. Introduction

Gas drainage has been an effective method to guarantee mining safety and lessen global warming effect [1–3]. Coal permeability is a key parameter which to a great extent determines the gas flow in coal and thus the gas drainage performance [4,5]. Investigations on permeability have been extensively conducted, and many permeability models were established, e.g. Somerton et al., made some lab experiments, in which they tested the permeability of many coal species under different stress conditions [6–16]. Based on the experiments results, stress-permeability relationships for the fractured coal were derived by them [7,8]. Furthermore, other researchers also took into account the impact of gas sorption/adsorption on permeability changes and developed some permeability models, among which, Cui-Bustin (C&B) permeability model is one of the most common [17–21]. In this model, Cui and Bustin thoroughly considered the impact of mean confining pressure and adsorption-induced volumetric strain on the permeability change.

However, it should be noted that previous scholars mainly focus on the influence of coal mechanical properties and gas sorption/adsorption on permeability variation, and the mechanical deformation was generally assumed to be elastic. Few studies have taken into account the effect of coal damage on permeability [22]. The damage to coal mass commonly occurs during mining activities and consequently results in great increase in permeability value. The neglect of damage impact could bring much inaccuracy in permeability evaluation and prediction.

Therefore, in this study, a damage-based permeability model is developed based on the Cui-Bustin permeability model, and then is applied to investigate the permeability distribution of damaged coal around roadway via finite element method (FEM) numerical simulation. The damaged areas around the roadway and the effect of coal friction angle are investigated. Meanwhile, the key damage coefficient of the improved permeability model is determined based on the published permeability data around roadway. Finally, the potential guidance from the improved permeability model on the gas drainage is identified.

2. Model implementation

Due to the large complexity and uncertainty of underground coal mine conditions, numerical simulation is a good alternative for onsite research. Numerical simulation allows the implementa-

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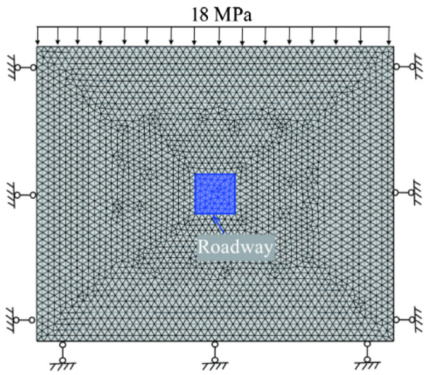


Fig. 1. Two-dimensional simulation model.

Table 1
Coal properties used in this model.

Property name	Value
Young's Modulus (GPa)	4.5
Density (kg/m^3)	1250
Friction angle (°)	40
UCS (MPa)	15
UTS (MPa)	0.5

tion of the sensitivity analysis. Therefore, to complete the research goals of this study, a numerical simulation model (Fig. 1) is established by using a FEM simulation solver. The length and width of the model are 36 and 30 m, respectively. The overburden pressure of 18 MPa is applied to the model top. The bottom boundary of the model is vertically fixed while its lateral boundaries are horizontally fixed. In the middle of the model, the roadway (4 m × 4 m) is excavated. The coal properties used in this model are given in Table 1.

To reveal the effect of coal damage on permeability, a term γD is introduced to the Cui-Bustin permeability model. Thus this model is improved as follows:

$$k = k_0 \exp\left\{\frac{3}{K_p}[(\sigma - \sigma_0) - (p - p_0)] + \gamma D\right\} \quad (1)$$

where k is the permeability; and k_0 the initial permeability; K_p the modulus of the pore volume; σ the mean confining pressure; and σ_0 the initial confining pressure; p and p_0 the fluid pressure and the initial pressure, respectively; γ the damage coefficient; and D the damage variable. D equals to $1 - |\varepsilon_{t0}/\varepsilon_1|^2$ for the tensile damage, while it equals to $1 - |\varepsilon_{c0}/\varepsilon_3|^2$ for the shear damage, here, ε_{t0}, ε_{c0} are the maximum tensile principal strain and maximum compressive principle strain, respectively, and ε_1, ε_3 the first principal strain and the third principle strain, respectively [23].

The improved C&B permeability model is implemented into the numerical simulation model to evaluate permeability distribution around the roadway.

3. Results and discussion

3.1. Damage areas around the roadway

Stress redistribution around the roadway causes coal damage, which greatly affects the permeability changes around roadway. In this study, the first strength theory is adopted to estimate the tensile failure around roadway, i.e. if the maximum tensile stress is more than the uniaxial tensile strength, then the tensile damage initiates. The Mohr-Columb criterion is adopted to estimate the shear failure around roadway.

Fig. 2 shows the damage areas around the roadway. It can be seen that: (1) the tensile failure occurs mainly on upper and lower sides of the roadway, and the failure area on the upper side is slightly larger than that on the lower side; (2) the shear failure symmetrically occurs on the left and right sides of the roadway; and (3) the shear damage area is larger than the tensile failure area.

According to the Mohr-Columb criterion, the friction angle of coal affects the damage distribution. To study this effect, four different friction angle values (10°, 20°, 30° and 40°) are implemented into the simulation model, respectively. The simulation model results are given in Figs. 3 and 4. As the maximum tensile stress theory is used to estimate the tensile failure, the tensile failure areas with those four different degrees are almost the same as shown in Fig. 3. However, shear damage areas are closely related to the friction angle (Fig. 4). With the increase in the angle value,

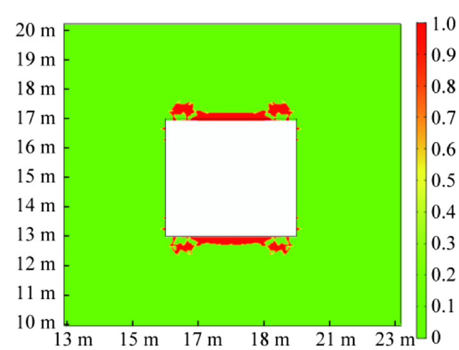
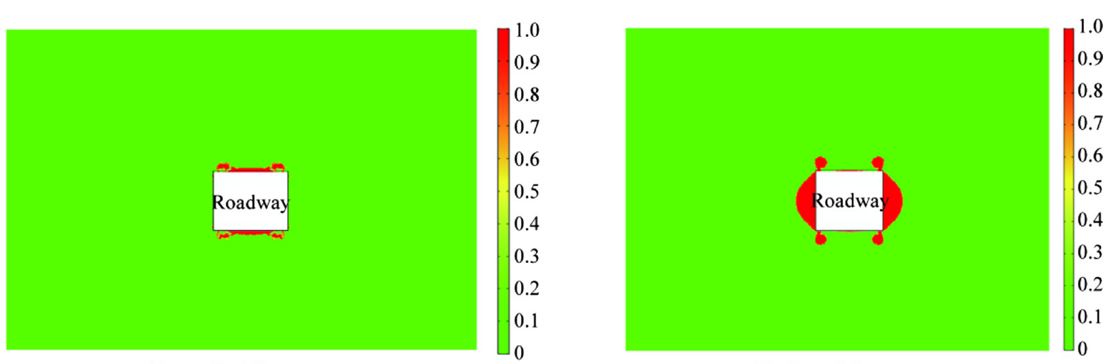


Fig. 3. Tensile damage area around the roadway.



(a) Tensile failure area (b) Shear failure area

Fig. 2. Damage areas around the roadway.