Analysis on distribution law of the abutment pressure of the integrated coal beside the road-in packing for gob-side entry retaining in fully-mechanized caving face

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Abstract: The three-dimensional damage constitutive relationship of coal is established and distribution law of the abutment pressure of the integrated coal beside the road-in packing for gob-side entry retaining in fully-mechanized caving face under the effect of given deformation of the main roof is analyzed by the damage mechanics theory. And the relationship between distribution of the abutment pressure and thickness of coal seam is explored. The presented result is of great theoretical significance and practical value to the study on stability control of the surrounding rock of road-in packing for gob-side entry retaining in fully-mechanized caving face.

Key words: road-in packing for gob-side entry retaining in fully-mechanized caving face; integrated coal beside the roadway; abutment pressure; damage mechanics

1 Introduction

The abutment pressure before fully-mechanized caving face is one of the main factors which affect the deformation of road-in packing for gob-side entry retaining in fully-mechanized caving face, its size and distribution law have an immediate effect on the deformation and damage of the roadway. In mining process, there is a high abutment pressure acting on the integrated coal beside the roadway, which includes advancing abutment pressure led by this working face and side abutment pressure led by the side working face where mining had finished[1]. Because of high abutment pressure, it is more difficult for the road-in packing for gob-side entry retaining in fully-mechanized caving face to be maintained than general roadway to be done. So, it is necessary to study the distribution law of abutment pressure of integrated coal wall to a deeper extent and uncover the relationship between the quality of overlying strata and the deformation of surrounding rock, which has important guiding effect to the study on stability control of surrounding rock in this kind of roadway.

In the process of deforming and being damaged, surrounding rock is neither continuum nor pure loose medium but equivalently continuous medium which is a state between the two formers. Because loose medium accounts for little of the whole study, the continuous medium damage mechanics can be used to study the distribution law of abutment pressure of the integrated coal beside the road-in packing for gob-side entry retaining in fully-mechanized caving face[2].

2 Three-dimensional damage constitutive relationship of coal

Coal is a kind of natural material that it has been going through a long geological process; inevitably, there are many cracks and pores of various sizes and shapes. Due to the extremely inhomogeneous inner structure, there are a variety of faults in the surrounding rock of road-in packing for gob-side entry retaining in fully-mechanized caving face, that is to say, there are many weak points of different strength in the surrounding rock. So the strength of the micro-units in coal is different. Considering the damage of coal in loading pressure process is continuous, and if the strength of micro-units accords with Weibull distribution[3], the damage probability can be calculated by Eq. (1).

$$\phi(\varepsilon) = \frac{m}{\varepsilon_0}\left(\frac{\varepsilon}{\varepsilon_0}\right)^{m-1}\exp\left[-\left(\frac{\varepsilon}{\varepsilon_0}\right)^{m}\right] \qquad (1)$$

Where, m, ε_0 are scale and morphological parameters

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of Weibull distribution respectively; ε is strain of the coal micro-unit; $\phi(\varepsilon)$ is damage probability when the strain is ε.

According to the damage mechanics of continual medium[4], damage parameter D can be defined as the ratio of the area which is damaged to the undamaged one,

$$D = S/S_0 = \int_0^{\varepsilon} \varphi(x)\, dx = 1 - \exp[-(\varepsilon/\varepsilon_0)^m] \quad (2)$$

Where, S is the area which is damaged; S_0 is whole area before the material is damaged.

Taking a micro-unit out from the coal in front of the working face, its stress state can be shown as Fig. 1. And the stress state can be simplified, given the stresses accord with linear elastic generalized Hook's law:

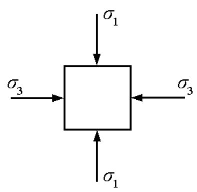

Fig. 1 Micro-unit of coal

$$\begin{cases} \sigma_1 = \lambda(\varepsilon_1 + \varepsilon_2 + \varepsilon_3) + \dfrac{E}{1+\mu}\varepsilon_1 \\ \sigma_2 = \lambda(\varepsilon_1 + \varepsilon_2 + \varepsilon_3) + \dfrac{E}{1+\mu}\varepsilon_2 \\ \sigma_3 = \lambda(\varepsilon_1 + \varepsilon_2 + \varepsilon_3) + \dfrac{E}{1+\mu}\varepsilon_3 \end{cases} \quad (3)$$

Where, σ_1, σ_2, σ_3 are three main stresses of the micro-unit respectively; ε_1, ε_2, ε_3 are its three main strains respectively; E is its elastic modulus; μ is its Poisson ratio and λ is a constant.

In order to simplify the calculation process, the Poisson ratio is given a value, $\mu = 0.25$, then Eq. (4) can be gotten.

$$\varepsilon_1 = \frac{\sigma_1}{E} - \frac{\sigma_3}{2E} \quad (4)$$

When the micro-unit is being damaged, its stresses accord with Misses yield criterion [5], that is:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_0^2 \quad (5)$$

Where, σ_0 is uniaxial compressive strength of the micro-unit.

When $\sigma_2 = \sigma_3$, Eq. (5) can be simplified as follows

$$|\sigma_1 - \sigma_3| = \sigma_0 \quad (6)$$

From Eq. (4) and Eq. (6), Eq. (7) can be gotten as:

$$\varepsilon_1 = \frac{\sigma_0}{E} + \frac{\sigma_3}{2E} \quad (7)$$

Where, $\frac{\sigma_0}{E}$ is a train when the micro-unit is cracked under the uniaxial stress, it also is the strain ε in Eq. (1). So,

$$\varepsilon = \varepsilon_1 - \frac{\sigma_3}{2E} \quad (8)$$

According to three-dimensional linear elastic isotropic damage constitutive equation, if $\mu = 0.25$, $\sigma_2 = \sigma_3$, the relationship between axial stress and axial strain was:

$$\sigma_1 = \frac{1}{2}\sigma_3 + E(1 - D)\varepsilon_1 \quad (9)$$

From Eq. (2), Eq. (8) and Eq. (9), the damage constitutive relationship between axial stress and axial strain under three-dimensional stress condition can be depicted as:

$$\sigma_1 = \frac{1}{2}\sigma_3 + E\varepsilon_1 \exp\left[-\left(\frac{\varepsilon_1 - \frac{\sigma_3}{2E}}{\varepsilon_0}\right)^m\right] \quad (10)$$

3 Distribution of abutment pressure under the effect of given deformation of the main roof

Abutment pressure is the result of overlying strata moving, and it has direct relationship with the configuration and movement law of overlying strata.

According to the analysis on surrounding rock movement law of road-in packing for gob-side entry retaining in fully-mechanized caving face, and setting the key strata over roadway as focus, mechanics model of key rock mass of road-in packing for gob-side entry retaining in fully-mechanized caving face can be established, which is shown as Fig. 2.

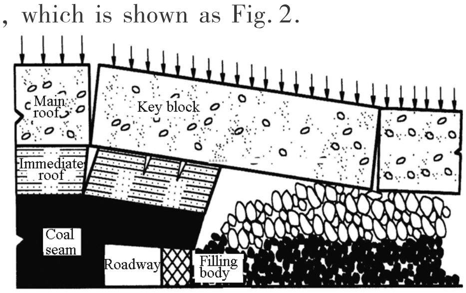

Fig. 2 Mechanics model of key rock mass of road-in packing for gob-side entry retaining in fully-mechanized caving face

In the model the main roof is seen as a rigid body, and inevitably it fractures, rotates and sinks, eventually it acts on the immediate roof and top coal in the form of given deformation. Taking a unit out from the coal before working face to study, at the beginning there is only initial stress acting on the unit. With the working face advancing, the unit enters the advancing abutment pressure area, and the stress (axial stress σ_1) increases gradually, loading displacement and strain ε_1 gradually increase too; when ε_1 increased to a certain value, axial stress would increase to its ultimate strength. With mining continues, ε_1 increases continuously, the unit comes into a plastic state, its carrying capacity keeps decreasing until it has been fractured. Therefore, the distribution law of abutment pressure in front of the working face corresponds with a whole loading process a sample rock is pressed on a rock test machine. Distribution law of side abutment pressure is approximately the same.

According to the documents[6], the given deformation of main roof in front of the working face has the character of power function, and it can be depicted as:

$$z_1 = a_1 x^{b_1} + c_1 \tag{11}$$

Where, setting the start point of a certain abutment pressure as an origin, x is the distance of a certain point along tendency, z_1 is its vertical displacement under the advancing abutment pressure; a_1, b_1, c_1 are undetermined constants.

If the thickness of immediate roof and coal is h, the strain under advancing abutment pressure is:

$$\varepsilon_1 = z_1/h \tag{12}$$

In stress-state of virgin rock the confining pressure of coal is σ_3. When the working face advancing, the coal in the area where abutment pressure acts on is damaged at different degrees, the confining pressure goes down and it is 0 at coal wall. So, the distribution of confining pressure in the region from coal wall to where the coal is in stress-state of virgin rock is in exponential form, which is

$$\sigma_3' = \sigma_3 \exp\left[\frac{1}{(x-d)}\right] \tag{13}$$

Where, d is the extent of the region influenced by the advancing abutment pressure.

Based on the above equations, from Eq. (10) to Eq. (13), the advancing abutment pressure is

$$\sigma'_1 = \frac{1}{2}\sigma_3 \exp\left(\frac{1}{x-d}\right) + E\left(\frac{a_1 x^{b_1}}{h} + c_1\right)\exp\left[-\left(\frac{\frac{a_1 x^{b_1}}{h} + c_1 - \frac{\sigma_3 \exp\left[\frac{1}{(x-d)}\right]}{2E}}{\varepsilon_0}\right)^m\right] \tag{14}$$

The integrated coal beside the road-in packing for gob-side entry retaining in fully-mechanized caving face is influenced not only by advancing abutment pressure but also by goaf-side abutment pressure. There are many factors affecting the side abutment pressure, one very important factor of them is the position where main roof is broken. The hypothesis can be the vertical displacement under the effect of side abutment pressure could be calculated by Eq. (15).

$$z_2 = a_2 (y + l)^{b_2} + c_2 \tag{15}$$

Where, y is the distance of a certain point along coal tendency; l is the distance from working face to the position where main roof is broken in the integrated coal; a_2, b_2, c_2 are undetermined constants.

By the method of solving advancing abutment pressure the equation used to calculate side abutment pressure can be gotten as:

$$\sigma'_1 = \frac{1}{2}\sigma_3 \exp\left(\frac{1}{y-d}\right) + E\left(\frac{a_2 (y+l)^{b_2}}{h} + c_2\right)\exp\left[-\left(\frac{\frac{a_2 (y+l)^{b_2}}{h} + c_2 - \frac{\sigma_3 \exp\left[\frac{1}{(y-d)}\right]}{2E}}{\varepsilon_0}\right)^m\right] \tag{16}$$

Therefore, the abutment pressure of the integrated coal beside the road-in packing for gob-side entry retaining in fully-mechanized caving face can be calculated by Eq. (17).

$$\sigma = \sigma_1' + \sigma_1'' \tag{17}$$

4 Experimental calculation and analysis

The working face $S_{2\text{-}6}$ of Changcun coalmine, Lu'an mining district, is a fully-mechanized caving face and the technology of road-in packing of gob-side entry retaining was adopted there. It can be used as an example to analyze the distribution of the abutment pressure of integrated coal.

The thicknesses of its coal seam and immediate roof are 6.07 m and 2.64 m respectively, the mining depth is 330 m. The distance from working face to the position where main roof is broken is 4 m. Primary rock stress is tested as $\sigma_1 = 7.8$ MPa, $\sigma_3 = 2.5$ MPa. The elastic modulus of coal is 5.6 GPa, which is the weighted mean of immediate roof's elastic modulus and coal seam's. Based on tests, the morphological parameters of coal's constitutive relationship are $m = 2$, $\varepsilon_0 = 8$. It's subsidence curve parameters are $a_1 = a_2 = 0.015$, $b_1 = 2$, $b_2 = 1$, $c_1 = 0.1$, $c_2 = 0.2$.

Put the above data into the Eq. (14), Eq. (16) and Eq. (17), and after calculation, the distribution law of advancing abutment pressure of working face can be shown as Fig. 3 and the distribution law of abutment pressure of integrated coal beside roadway is shown as Fig. 4.

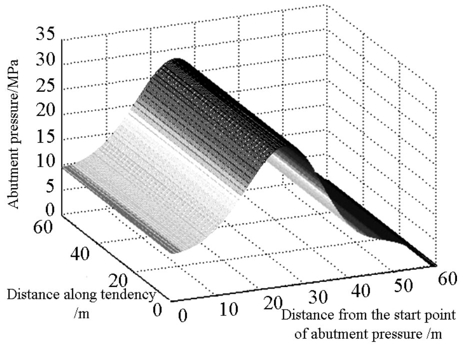

Fig. 3 Distribution law of advancing abutment pressure of working face

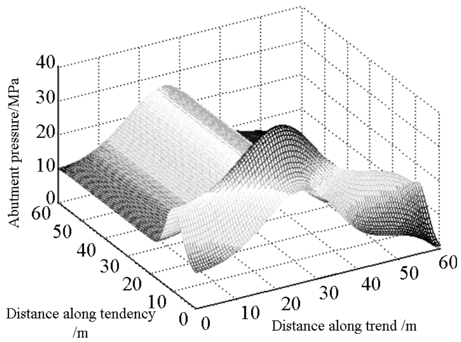

Fig. 4 Distribution law of abutment pressure of the integrated coal beside roadway

It is shown in Fig. 3 that the maximum of advancing abutment pressure is 28 MPa and about 32 m in front of the working face. Due to the superposition of side abutment pressure, the maximum of advancing abutment pressure of the integrated coal beside roadway is 36 MPa and about 6 ~ 8 m in front of the working face, which can be seen in Fig. 4.

The relationships between advancing abutment pressure, side abutment pressure and thickness of coal seam are shown in Fig. 5 and Fig. 6.

It can be observed in Fig. 5 that with the thickness of immediate roof and coal seam increasing the maximum of advancing abutment pressure goes away from working face, its value increases. When h is 8 m, the maximum is 30 MPa and the distance that the maximum away from working face is 31 m; while h is 12 m, the two parameters are 37 MPa and 37 m respectively. In Fig. 6, when h is 8 m the maximum of side abutment pressure of integrated coal is 10.5 MPa and it is 4 m away from coal wall; when h is 12 m the two parameters are 11 MPa and 8 m respectively. Therefore, when the whole thickness of coal seam and

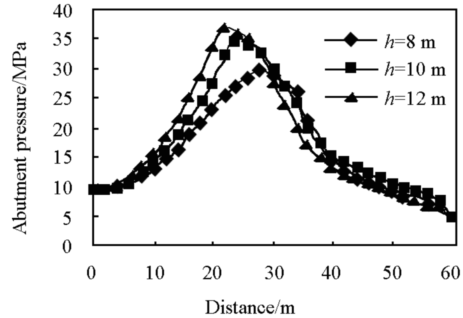

Fig. 5 Relationship between advancing abutment pressureof working face and thickness of coal seam

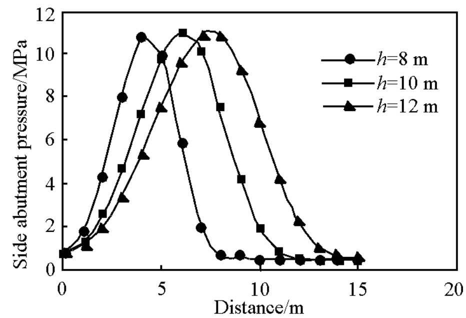

Fig. 6 Relationship between side abutment pressure and thickness of coal seam

immediate roof get bigger, not only the maximum of abutment pressure would increase but also the length of roadway influenced by abutment pressure would increase, but the area with high stress acting on would go away from the roadway.

5 Conclusions

1) High abutment pressure of integrated coal is one of main factors influencing the stability of road-in packing for gob-side entry retaining in fully-mechanized caving face. The damage mechanics theory was used to analyze the distribution law of the abutment pressure of the integrated coal in this paper, it provides scientific base for the stability control of surrounding rock of road-in packing for gob-side entry retaining in fully-mechanized caving face.

2) The distribution of abutment pressure of integrated coal beside the road-in packing for gob-side entry retaining in fully-mechanized caving face is relative to the thickness of immediate roof and coal seam. That is to say, the thicker they are, the higher abutment pressure is. When the length of road affected by abutment pressure is longer, the roadway is more difficult to be maintained. Contrarily, the smaller the thickness is, the lower the abutment pressure, and the roadway is easier to be maintained.

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