Influence of Surrounding Rock Stress on Gas-Solid in Deep Coal Seam Roadway

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\textbf{Abstract.} In order to study the stress distribution in the deep hard coal seam roadway environment, the gas seepage law under the stress of the surrounding rock is analyzed. The self-made triaxial infiltration apparatus is used to simulate the damage deformation, gas seepage flow, seepage velocity and axial pressure curve, then we establish the segmented simulation equation. The dynamic simulation of coal seam excavation area and the data of gas seepage in the heading face are measured and collated by using FLAC3D software. The results of laboratory measurement of wall stress and gas flow velocity are in good agreement with the measured data. The gas seepage velocity of different parts of hard coal seam roadway area is difference under deep surrounding rock stress. It is found that the gas infiltration velocity has the characteristic of segmentation, that is, the velocity characteristic of gas seepage velocity in the top, bottom and roadway of coal roadway are different from those of roadway. At the same time, we establish the mathematical model. The discovery of the gas migration characteristics of the deep coal seam under the action of the deep surrounding rock stress can guide the coal roadway working face gas control.

\textbf{Introduction}

With the increase of the depth of coal mining, the coal and gas outbursts in the coal roadway are becoming more and more serious [1]. In the process of coal seam mining, the equilibrium state of the original stress field is destroyed, and the distribution of the ground stress is more complicated, and the equilibrium state of the gas in the coal seam is also broken. The process of stress redistribution and the change of gas pressure in coal body will have some influence on the mechanical properties and permeability of coal. Under the action of coal seam stress and gas participation(coal and gas solid-gas coupling), the stability of coal and rock mass is destroyed, and the massive emission of coal and gas is the important reason leading to coal and gas outburst [2]. In addition, the deep coal seam is affected by the increase of the stress of the surrounding rock, the permeability of the coal seam is low and the gas seepage is special [3]. Therefore, it is necessary to study the influence of ground stress and gas pressure on the damage and deformation of coal and the seepage characteristics of gas in coal body, and further construct the gas-solid coupling mechanism which can accurately describe the failure characteristics and gas seepage of coal body.

The domestic scholars has done a lot of research and obtained important results, on the influence of surrounding rock stress on gas seepage in coal roadway under deep mining. Zhang Tianjun's [4]research found that the pressure of the mine in front of the working face is the main influence factor of gas gush and he also made a quantitative analysis. Liu Xiaohu's[5] research found that the rise of gas gush amount is slightly lag behind the increase of the coal seam pressure. Cai Jiande and Li Huamin[6-7] found that during the periodical pressurized period the speed of gas gush is in a good agreement with the surrounding rock pressure. Wang Jiachen[8] found that the permeability of coal
rock in working face increases with the decrease of stress state during the process of face mining, and this leads to a rapid change of gas output and escape velocity. He Manchao[9] found that gas gush speed change during the coal mass under pressure of external load is the main reason for the change of the gas pressure by using the 110 construction method.

This paper takes main coal mining seam of Shuanghe coalmine of Jixi Mining Group as an example, using the method of laboratory investigation combine with numerical simulation and field data determination to verify, analyzing the relationship between the gas seepage characteristics of coal mining area and coal seam roadway area of deep surrounding rock, building a mathematical model of gas seepage rate and the deep surrounding rock stress, so as to find the action rules of among the coal and gas outburst of hard coal seam and the stress of deep surrounding rock. This theory has a theoretical and practical significance for controlling of mine gas disaster in hard coal seam.

Experimental Study

Sample and Experimental Device

The three-axis gas-solid coupling coal seepage test system is composed of three-axis press, which consists mainly of true triaxial pressure chamber, hydraulic servo system, gas seepage system, monitoring and control system. System composition shown in Figure 1, the composition of the composition shown in Figure 2. The test specimen is taken from the main coal seam in Shuanghe Coal Mine of Heilongjiang Longji Jixi Mining Group. The coal sample standard is 50 mm in diameter and 100 mm in height, and the coal forming pressure is 200 kN. Processed specimens are placed in 80 °C drying oven for 24 hours, then are wrapped with plastic wrap and set aside.

Methods and Processes

This experiment adopts methane gas. The experimental constant confining pressure is set as 0.25MPa which is the average gas pressure measured in the mine, the constant temperature is 20 °C the same as the room temperature. The process is as follows:

(1)The coal sample is put into the equipment, then methane gas will be injected to the device and kept for 24 hours after stabilizing the instrument's confining pressure, axial pressure and temperature as well as checking the tightness of the device.

(2) Gradually changing the axial pressure, after the sample absorbed methane for 0.5 hours, then release the methane for 5 minutes, at the same time measure the speed of the gas seepage.

(3) Three coal sample experiments are repeated.

(4) The arithmetic mean of the measured data is used to draw the seepage velocity and axial stress curve of the data.

Results and Discussions

The curve of seepage velocity and axial stress is shown in figure 3.
The mathematical model is modeled according to the measured data, as shown in equation (1):

\[
\begin{align*}
    v &= v_b + \frac{d\nu}{d\sigma}(a-c) \\
    v &= v_c - \frac{d\nu}{d\sigma}(c-d) \\
    R^2 &= 0.9163
\end{align*}
\]

(1)

In the formula, \(v\) is the seepage, unit is \(mL/s\), \(v_b\) is the lowest seepage velocity, unit is \(mL/s\), \(v_c\) is the highest seepage velocity, unit is \(mL/s\), \(\sigma\) is the ground pressure, unit is \(MPa\); \(R^2\) is the coefficient of determination, that is the accuracy of formula fitting.

The Relationship between Deep Surrounding Rock Stress and Seepage Characteristics

FLAC3D Numerical Simulation

Shuanghe mine field is located in the middle of the Jixi coalfield's south belt, south wing of Jixi synclinorium, the northern approached to the Pingyang-Mashan overthrust fault. In the south, there are large normal faults of northeast and northwest, formed a triangle zone. The main structure of the coal field is fault, only deep and shallow area exist small anticlines. Those anticlines are always widely and flat. First order tectonic is rare in this area, most are small and medium structures. The range of main coal seam is moderately metamorphosed bituminous coal, asphalt is joint and the gloss is not development, the coal is hard but fragile, columnar joints development, fracture with uneven structure, the structure of the coal is relatively complex, generally for blade shape, granular structure, ladder shaped, shell shaped fracture.

Using the theories of gas geology, rock mechanics and seepage mechanics, we adopt methods of numerical simulation, theoretical analysis, numerical experiment and field verification to carry out the mechanical mechanism and application of coal mine gas occurrence and migration [10-12]. It mainly aims at the mechanical analysis under geological conditions and gas occurrence and migration. In order to further analysis of coal roadway excavation process of surrounding coal damage and stress, it takes the Shuanghe coal mine of Jixi Mining Group's coal roadway conditions as the background, the parameters of the retrieved coal samples were measured in the laboratory.

Using the numerical simulation software FLAC3D, we establish a 3D model. The model's four boundaries are applied constraining force in horizontal direction, and the bottom boundary of the model is fixed, the horizontal displacement of the boundary are set to zero, the top stress of the model is loaded as same as the weight of the coal seam above. The gravitational acceleration is 9.8m/S2, bulk density of coal seam is 2500kg/m3, the bulk modulus is 2.2GPa, shear modulus is 2.2GPa, tensile strength is 8.7Mpa, internal friction angle is 27°, cohesion is 3Mpa, the thickness is 6m. Focus on and

Figure 3. Seepage velocity and axial stress curve.
analyze the important area, in the establishment of numerical model, refine the region cells. if the numerical model is large enough, the mechanical parameters and initial condition of model as much as possible in line with actual engineering.

On the basis of the Shuanghe coal mine seam roadway which width is 4.2m and height is 4.2m, establishing a model which size is 62.5×62.5×62.5 to show the area of coal roadway in the plastic zone and the distribution of the horizontal and vertical stress, as shown in figure 4.

![Figure 4. Coal roadway in the plasticity range and the distribution of horizon and vertical stress.](image)

As can be seen from figure 4-a in the plastic damage range is relatively large, the range of the two side-wall plastic zone is biggest up to 1.4m, other position of the plastic zone damage range is 1.15-1.3m, the maximum failure depth of the tunnel top up to 1.4m, at the top of the tunnel, and the ends of the semi-circular roof, the plastic zone damage range reach to 1m, two sides of the soleplate is seriously damaged, and the depth is 1m. As can be seen from figure 4-b, two sides of the tunnel's stress is concentrate, the bottom of the left side tunnel rock range within 0-1.0m, spring line (two sides of tunnel connect with circular roof) is the most concentrate position of stress, the maximum stress value is 38.8Mpa. There comes the stress reduced area in roadway's roof and floor, and the roof's minimum stress value is 0.81Mpa, and a 1.4m high arch parabola shape is above. In two sides of roadway surrounding rock depth about 1.2m appeared stress drop area, the stress value is 1-1.5Mpa. We can be seen from figure 4-c, the stress is concentrate in the upper roof range about 1.0-2.2m, roadway floor in 0.9-1.3m has a wide range of stress concentration, and small range on both sides of roadway floor below 0.9-1.3m, there is the maximum stress construction and the value is 33Mpa.

**The Relationship between Actual Stress and Gas Seepage under the Influence of Deep Surrounding Rock Stress**

Measuring the position of the point according to the figure 5-a in the mine that has been tunneled, using gas analyzer for coal cuttings (Figure 5-b) to measure the gas analytical value, and using rock load observation instrument and rock drilling stress monitor instrument (Figure 5-c), to measure the crustal stress of the surface of the roadway, and the stress of coal hole, the determination of crustal stress is to verify the accuracy of the simulation model.

![Figure 5. Measuring position and instrument.](image)

After the velocity of gas flow and the stress of the surrounding rock were analyzed, we can get a simulate data model as shown in figure 6.
As you can see in figure 6, there are subsections in the velocity of gas seepage-crustal stress change curve, the gas flow velocity decreased slowly in section \(a - b\), point \(b\) is the lowest velocity of gas flow and it is also the 10MPa crustal stress point. Section \(b - c\) gas flow velocity has been rising fast, reaching the maximum stress point and the crustal stress is 20MPa. Section \(c - d\) gas flow rate reaches the peak and the seepage velocity gradually decreased with the increase of axial pressure, but the decrease was small, after reduced to a certain extent it tends to be stable.

**Simulated Result Based on Measurements from Laboratory and Analysis from Field Measurement**

The actual crustal stress measurement results show that:

1. The practical measured gas flow rate and the stress curve of surrounding rock are basically the same as those measured under laboratory conditions. It shows that in the ideal environment, the laboratory research has certain reference value, and can play a proof role in the actual measurement curve;

2. FLAC\(^3\text{D}\) numerical simulation results basically reflect the true distribution of stress in the surrounding rock of coal seam roadway, it shows that the numerical model is correct and reliable, it can be used for reference and guidance in the field.

3. Horizontal stress cloud diagram indicates that the stress level is stable and less concentrated, the stress value is not strong, hence the horizontal stress has little effect on the gas seepage velocity.

Through numerical simulation and field measurement analysis of surrounding rock stress we can find that:

1. The surrounding rock stress in coal roadway roof and floor is relatively small, gas seepage rate decrease with the surrounding rock stress increase, coincide with the \(a - b / a' - b'\) segment of Figure 3 and figure 5. The reason is that under the pressure of surrounding rock stress the original crack has been compacted, and the new crack has not been generated, hindered gas seepage flow release.

2. The coal roadway surrounding rock stress is relatively concentrated, the stress values are relatively large, gas seepage rate increase with the surrounding rock stress increase, coincide with the \(b - c / b' - c'\) segment of Figure 3 and figure 5. The reason is that the coal body structure is has been destroyed by surrounding rock stress, the increase of the pore structure of coal deformation and gas seepage pore. The increase of pore pressure will expand the pore structure of coal, decrease the adsorbed gas layer and reduce the gas adsorption, and the gas seepage rate and velocity will increase.

3. Coal roadway arch line area, surrounding rock stress is most concentrate, the stress value is high, when gas seepage rate reach the peak, seepage velocity decrease with the surrounding rock stress increase, but the rate of decline is slow, it tend to be stable when reduced to a certain extent, coincide with the \(c - d / c' - d'\) segment of Figure 3 and figure 5, the reason is that the influence of coal stress in surrounding rock, the pore gradually become smaller, so that part of free gas changed into the adsorption state, the slippage effect gradually disappear, and the seepage velocity gradually decreased.
Summary

(1) The model is accurate and reliable that can reflect the distribution of the surrounding rock stress in the coal seam roadway, it clearly indicates that the change of gas seepage flow is changed with the stress state, it has certain prediction and guiding significance to field construction.

(2) The variation of gas seepage flow lags behind the change of stress state.

(3) The stress of surrounding rock is an important factor influencing the gas seepage characteristics of the main coal seam in Shuanghe coal mine.

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