

Study on Enhanced Drainage Technology of High Pressure Jet Caving in a Soft and Low Permeability Coal Seam

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Abstract: In order to promote the pre-drainage of the gas-permeable coal seam and eliminate the coal and gas outburst danger of the coal seam, high-pressure jet caving and hydraulic flushing measures are adopted. Firstly, the coal seam permeability evolution model of high-pressure jet punching and hydraulic flushing process is constructed and solved. The evolution of coal permeability after punching and the law of gas migration in coal; the industrial test of high-pressure jet punching technology shows that: high-pressure jet punching and hole-forming combined with gas drainage measures can save the amount of drilling and strengthen drainage effect of the gas, compared with the direct pre-drainage of coal seam gas. And it is more effective to eliminate the outburst danger during the excavation process, and improve the tunneling speed of the roadway and ensure the safe production of mines.

1. Introduction

With the extension of mines to the deep, gas and ground stress have more and more important impact on the exploitation of coal resources, and coal and gas outburst disasters is becoming increasingly serious[1]. According to the requirements of coal and gas outburst prevention[2], pre-extracted coal seam gas is one of the important means to prevent coal and gas outburst. Most of China's coal seams are characterized by low gas permeability and poor pre-pumping effect. In order to increase the permeability of the coal seam, a large number of methods of coal seam anti-filtration have been studied and tested[3-7], such as deep hole loosening blasting measures, CO₂ gas phase fracturing measures, hydraulic measures such as high pressure water jet, hydraulic pressure Crack, hydraulic slitting, etc. These technologies are all tested in the Yangquan mining area. After comparison, the high-pressure jet punching and hole forming technical measures promote the pre-drainage of gas in the soft and low-permeable coal seam in Yangquan mining area, which is convenient and efficient.

2. Mechanism Analysis of High Pressure Jet Punching Holes

The high-pressure hydraulic punching holes measure relies on the impact capability of high-pressure water, causing the coal body to break and gradually forming a larger-sized hole[8]. For coal and gas outburst coal seams with lower hardness, the high pressure water jet will impact the coal body to induce controlled drilling holes, and release a large amount of gas while discharging a large amount of coal slag. This process significantly increases the size of the hydraulic punching, and causes significant changes in stress around the holes. Under the higher stress, creeping damage occurs in the coal around the hole, and the radial movement along the hole leads to the decrease of the coal body stress within the influence of the hole. The crack of coal seam opens and penetrates, which greatly increases the permeability of the coal seam and increases the

desorption of gas in the coal promotes gas drainage.

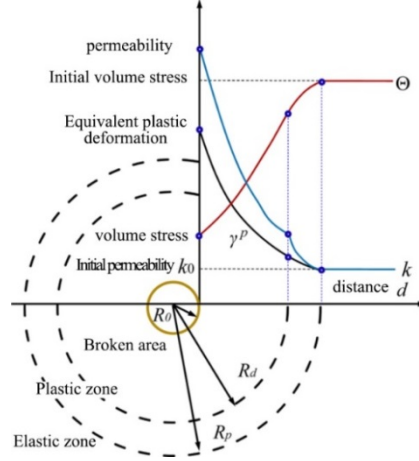


Fig.1 coal seam Stress distribution and permeability change around hydraulic flushing

3. Evolution law analysis of coal permeability in high-pressure jet punching

3.1 The establishment of permeability evolution model of high pressure jet perforation

The effect of gas drainage in coal seams is mainly determined by the permeability of coal seams. During the process of punching formation, the coal around the holes is subjected to strong stress disturbances, and the permeability is greatly improved. After the end of the punching, the permeability evolution in the coal is mainly controlled by the effective stress change and matrix shrinkage effect during gas drainage. Assumption:

(1) The stress perturbation during the punching process is equivalent to the change of the coal permeability. Namely, the change of ground stress is considered, and the change is instantaneous, ignoring the gas flowing during this period.

(2) The initial permeability change during punching formation has an effect on the permeability. The stress increase and matrix shrinkage caused by gas flow during gas drainage have a further influence on permeability.

When the permeability evolution is in the elastic phase, there is a negative exponential relationship between permeability and volume stress:

$$k_1 = k_0 \exp[b(\Delta\Theta)] \quad (1)$$

In the middle, k_1 is permeability of coal in elastic stage; k_0 is initial permeability of coal; b is Permeability factor on Volume stress; Θ is Volume stress, $\Theta = \sigma_1 + \sigma_2 + \sigma_3$

When the stress state of the coal body reaches the yield point, the coal body will undergo plastic deformation and enter the plastic deformation stage. The coal permeability in the plastic deformation stage can be expressed as:

$$k_2 = \left(1 + \frac{\gamma^p}{\gamma^{p*}} \xi\right) k_0 \exp[b(\Delta\Theta)] \quad (2)$$

In the middle, k_2 is permeability of coal in plastic deformation stage; ξ is permeability increase factor;

When the coal enters the residual strength stage, the permeability will tend to be stable:

$$k_3 = (1 + \xi) k_0 \exp[b(\Delta\Theta)] \quad (3)$$

It can be obtained from equations (1), (2) and (3) that the evolution of coal permeability caused by hydraulic punching can be expressed by a piecewise function:

$$k_0^e = \begin{cases} (1 + \frac{\gamma^p}{\gamma^{p*}} \xi) k_0 \exp[b(\Delta\Theta)], 0 \leq \gamma^p < \gamma^{p*} \\ (1 + \xi) k_0 \exp[b(\Delta\Theta)], \gamma^p \geq \gamma^{p*} \end{cases} \quad (4)$$

In the middle, k_0^e is coal permeability at the end of punching;
The cubic law of permeability and porosity is available:

$$\phi_0^e = \begin{cases} \phi_0 (1 + \frac{\gamma^p}{\gamma^{p*}} \xi)^{1/3} \exp[b(\Delta\Theta)/3], 0 \leq \gamma^p < \gamma^{p*} \\ \phi_0 (1 + \xi)^{1/3} \exp[b(\Delta\Theta)/3], \gamma^p \geq \gamma^{p*} \end{cases} \quad (5)$$

In the middle, ϕ_0^e is coal porosity at the end of punching; ϕ_0 is initial porosity in coal.

3.2 Geometric model establishment and boundary conditions

Based on the above control equations, the evolution model of coal permeability after punching formation is established and numerically simulated. Establish a two-dimensional model using solid mechanics modules and PDE modules. The mechanical boundary of the model is: the top of the model adopts the stress boundary, the gravity of the upper rock is applied, the bottom of the model adopts the fixed displacement boundary, and the two sides of the model adopt the same stress boundary and apply the lateral stress. Gas flow model: Zero-flow boundary is adopted on the top and bottom of the coal seam, and a constant pressure boundary is adopted around the punching hole.

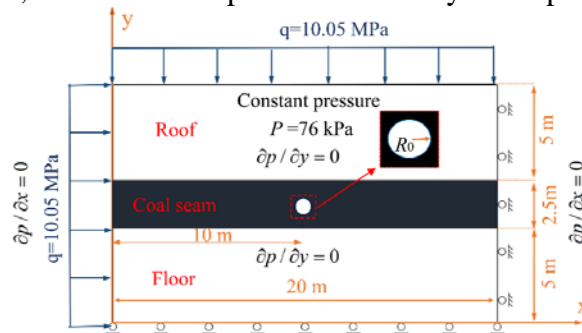


Fig.2 2D model diagram

3.3 Evolution characteristics of coal permeability in high-pressure jet punching on soft and low permeability coal seam

Taking the drilling radius of 0.4 m as an example, the evolution characteristics of equivalent plastic deformation, volume stress and permeability of the coal around the borehole are as shown in Fig.3.

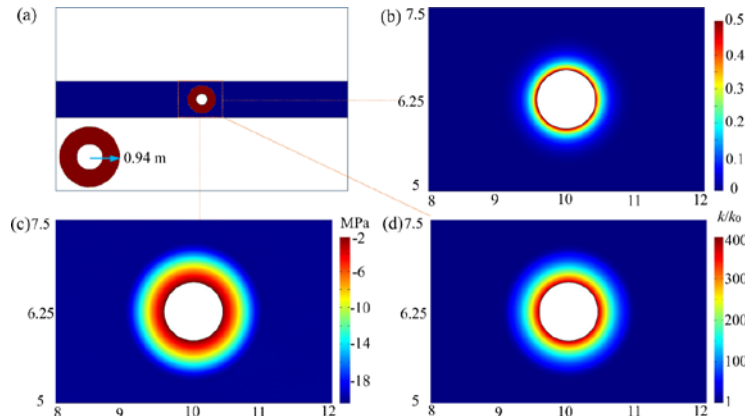


Fig.3 Evolution characteristics of permeability of high-pressure jet and hydraulic flushing

It can be seen from Fig.3 that after the formation of a bore having a radius of 0.4 m, an increased permeability zone having a radius of 0.94 m is formed in the coal surrounding the borehole. Under the combined effect of the plastic failure of the coal body and the reduction of the body stress, the permeability of the coal around the borehole is greatly improved. At the same time, the equivalent plastic deformation of the coal body is the largest at the hole wall of the borehole, which is about 0.5; the body stress is the smallest, about 2MPa; the larger the permeability increase ratio of the coal body is about 400 times the original permeability.

In addition, during the simulation process, the monitoring line was set up to monitor the equivalent plastic deformation, volume stress and permeability of the coal around the borehole. The monitoring results are shown in Fig.4.

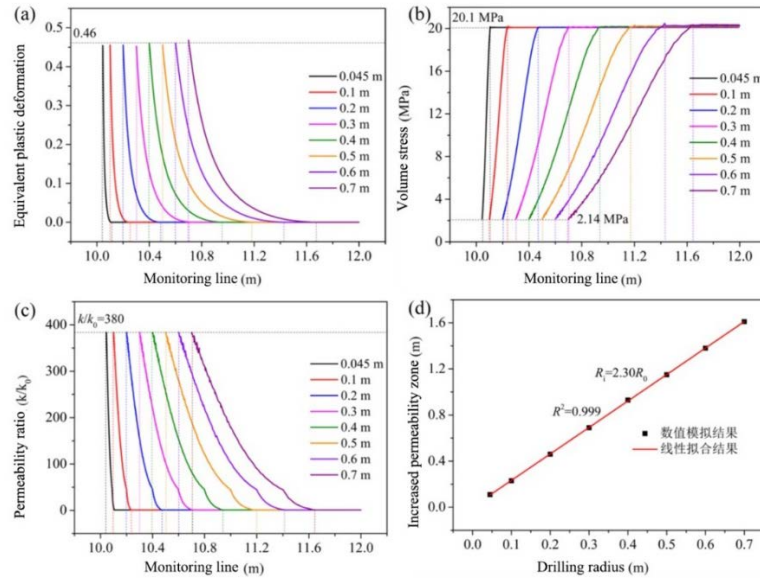


Fig.4 Evolution characteristics of coal permeability around borehole under different drilling radius

It can be seen from Fig.4 that as the drilling radius increases, the plastic zone and the pressure relief zone radius of the coal around the borehole gradually increase, which leads a gradual increase in the radius of the coal permeability increase zone around the borehole. However, at the hole wall of the borehole, the maximum plastic deformation of the coal around the borehole is constant at 0.46, the minimum volumetric stress is constant at 2.14MPa, and the maximum permeability is constant at 380 times the original permeability. And the radius of the borehole increases, the radius of the anti-permeability zone of the coal around the borehole increases linearly with the radius of the borehole. Therefore, the use of hydraulic punching to increase the radius of the borehole can be compared to the borehole. The coal body in a wide range is subjected to pressure relief and permeation.

4. Conclusion

(1) The coal body permeability evolution model of high-pressure jet punching forming process is constructed and solved, and the evolution of coal permeability and the law of gas migration in coal after punching are obtained.

(2) The high-pressure jet punching and hole-forming intensive industrial test is carried out in Xinjing mine. Compared with the direct pre-drainage of coal seam gas, the high-pressure jet punching and hole-forming combined with gas drainage measures saves the amount of drilling and strengthens the gas. The drainage effect is more effective in eliminating the protruding danger during the excavation process, and improving the tunneling speed of the roadway can ensure the safe production of the mine.

Acknowledgments

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References

- [1] Yuan Liang. Strategic thinking of simultaneous exploitation of coal and gas in deep mining[J]. Journal of China Coal Society, 2016, 41(1): 1-6 .
- [2] State Administration of Work Safety Supervision and Administration. Prevention of coal and gas outburst regulations[S]. Beijing: Coal Industry Press, 2009 .
- [3] YAN W, WU X. Three-dimensional Measurement System Design of Binocular Electronic Endoscope[J]. Journal of Applied Science and Engineering Innovation, 2018, 5(4): 117-120.
- [4] Nie Zheng . Application of cardox dioxide blasting technique in coal mines[J]. Coal Technology, 2007, 26(8): 75-79.
- [5] Li Xiaohong, Lu Yiyu, Zhao Yu, et al. Study on improving the permeability of soft coal seam with high pressure pulsed water jet[J]. Journal of China Coal Society, 2008, 33(12): 1386-1390.
- [6] Guo Wenqi, Han Wei, Zhang Wenyong, et al. Study on mechanism and application of hydraulic fracturing and permeability improvement gas drainage in underground mine[J] . Coal Science and Technology, 2011, 39(12): 60-64.
- [7] Feng Wenjun, Su Xianbo, Wang Jianwei, et al. The mechanism and field test of permeability improvement by hydraulic flushing in three-soft and single coal seam[J]. Coal Geology & Exploration, 2015, 43(1): 100-103.
- [8] Hao Fuchang, Sun Lijuan, Zuo Weiqin . Hydraulic flushing aperture variation and anti-blocking technology considering rheological property[J]. Journal of China Coal Society, 2016, 41(6): 1434-1440.
- [9] Hao Longyun, Wang Rui, Zhao Yuetai, Fang Kuanjun, Cai Yuqing. The enzymatic actions of cellulase on periodate oxidized cotton fabrics[J]. Cellulose, 2018, 25(11): 6759-6769.