Research and Application of Optimizing Pre-drainage Hole Layout along Seam

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Abstract. In order to solve the problem of the unsatisfactory pre-drainage effect of bedding holes, based on the theory of elastoplastic mechanics, the distribution of elastoplastic zone around the borehole and its influencing factors were analyzed, and it was found that the three-dimensional arrangement of the boreholes can increase the hole circumference of the drilled network Plastic zone volume, effective drilling length of borehole, coal seam permeability and gas drainage efficiency. Engineering application was carried out at the 3215working face of Wangpo Coal Mine. Three test schemes of dense parallel drilling, plane cross drilling and three-dimensional cross drilling were used, and the effect of extraction was investigated for comparative analysis. The test shows that the extraction efficiency of the three-dimensional cross-drilled hole is high, and the attenuation coefficient is small. Under the same amount of drilling, the extraction capacity of the three-dimensional cross-drilled hole is 1.7 times and 1.3 times that of the dense parallel drilling and plane cross-drilled hole. The drainage efficiency of three-dimensional cross drilling is 69% and 26% higher than that of dense parallel drilling and plane cross drilling, respectively.

1. Introduction
The geological conditions of coal seam mining in China are complex. With the deepening of the mining level, the gas content and pressure of the original coal seam are gradually increasing. At the same time, the high-efficiency and high-efficiency mining has led to a significant increase in the gas emission from the mine. More than 70% of the state-owned key coal mines in China are high-gas and outburst mines. The permeability coefficient of mining coal seams is generally 0.004 to 14.14m²(MPa²•d), of which more than 50% are difficult to extract coal seams[1-2].At present, in addition to the commonly used traditional drilling and drainage, China's improved coal seam permeability mainly includes hydraulic penetration, blasting cracking and protective layer mining, etc., but affected by factors such as coal seam storage conditions, geological structure and cost, the above methods have certain limitations in the field application, it is essential to explore effective gas prevention measures.

Before coal seam mining, it is necessary to reasonably select the parameters such as pre-draining borehole layout and extraction time according to the on-site pumping-digging-mining connection arrangement. At present, densely drilled holes with vertical coal walls are widely used in the field, but the drainage effect is not ideal. According to the theory of elastoplastic mechanics, after drilling, the stress around the hole is redistributed. When the stress exceeds the strength of the original rock, plastic deformation will occur, and it will expand from the periphery to the depth of the rock body. Cracks in
the plastic zone will develop, which can improve the permeability of the coal body and promote gas drainage. This paper mainly studies how to improve the connectivity of the plastic zone near the bedding borehole, optimize the layout of the borehole, improve the permeability of the coal seam, and effectively reduce the time for gas drainage to reach the standard.

2. Project Overview
Wangpo Coal Mine mainly mining No. 3 coal seam, the coal thickness is 4.20-7.89 m. The gas content of No. 3 coal seam is 4-18 m$^3$/t, which belongs to high gas mine. The permeability coefficient of No. 3 coal seam is 1.745-4.864m$^2/$(MPa$^2$.d).

The gas pre-drainage of mining-coal bed in Wangpo Coal Mine is mainly carried out by dense parallel drilling. Due to the unsatisfactory permeability of the coal seam, the extraction time is long, and the extraction-digging-mining connection is tight. When entering the coal seam gas content area, the face gas The amount of gushing increased, and the working face frequently exceeded the limit during mining. The main over-limit places were concentrated in the return wind channel and the upper corner. It was difficult to solve the gas overrun problem only by ventilation. Therefore, it is necessary to improve the pre-drainage method of the working face to increase the pre-drainage rate of the coal seam and reduce the gas emission from the coal seam. A test face was selected to investigate the extraction effect of three-dimensional cross-drilled holes, plane cross-drilled holes and dense parallel bedding holes, and to determine an optimal layout of the drainage holes. Promote the application in other working faces, and comprehensively improve the gas pre-drainage effect in Wangpo coal mining face.

3. Theoretical analysis of gas pre-drainage in mining-coal bed
Based on the ideal elastoplastic model, it is assumed that the coal rock around the circular borehole is homogeneous and isotropic, the original rock stress is in an isotropic isostatic state, and the length dimension of the borehole is larger than the cross-sectional dimension, which can be regarded as a plane strain problem. The stress calculation formula for the plastic zone of the circular borehole is derived from the equilibrium condition and the Mohr strength condition[3-4]:

\[
\sigma_r = C \times \cot \phi \times \left[ \frac{r}{R_b} \right]^{\frac{2 \sin \phi}{\sin \phi}} - C \times \cot \phi
\]

\[
\sigma_\theta = C \times \cot \phi \times \left[ \frac{r}{R_b} \right]^{\frac{2 \sin \phi}{\sin \phi}} \left[ \frac{1 + \sin \phi}{1 - \sin \phi} \right] C \times \cot \phi
\]

In the formula: $\sigma_r$ is the radial stress in the plastic zone; $\sigma_\theta$ is the tangential stress in the plastic zone; $r$ is the radius of any point in the plastic zone; $C$ is the cohesion of coal and rock; $\phi$ is the friction angle in coal and rock; $R_b$ is the radius of the borehole.

Equations show that the stress in the plastic zone is related to cohesion $C$ and internal friction angle $\phi$. According to formula 2, the change of tangential stress $\sigma_\theta$ from the periphery of the borehole is drawn. When the coal around the borehole enters a plastic state, the maximum value of $\sigma_\theta$ is transferred from the periphery of the borehole to the junction of the elastic and plastic areas; Deepening into the coal rock body, the coal rock stress gradually returns to the original rock stress state. Figure 1.
Figure 1. Plastic zone and stress distribution around the borehole

According to the condition that the stress at the boundary between the elastic zone and the plastic zone is equal to satisfy both the elastic and plastic conditions, the radius of the plastic zone $R$ can be obtained:

$$R = R_0 \times \left[ \frac{\sigma_0 + C \times \cot \varphi \times (1 - \sin \varphi)}{C \times \tan \varphi} \right]^{\frac{1}{\sin \varphi}} \quad (3)$$

Equation 3 can be obtained: ① The greater the stress $\sigma_0$ at the borehole, the larger the plastic zone; ② The smaller the index $C$ and $\varphi$ value reflecting the strength properties of the coal rock body, that is, the lower the strength of the coal rock, the larger the plastic zone; ③ The larger the drilling radius $R_0$, the larger the radius of the plastic zone $R$, and the relationship between the two is proportional.

The larger the plastic zone generated around the coal body in the borehole, the larger the crack range and the greater the permeability of the coal seam, the more beneficial it is to improve the efficiency of gas drainage. After the borehole is formed, there are stress concentration and breakage areas around the borehole. When the boreholes are crossed, increasing the number of intersections between the two boreholes can increase the volume of the plastic zone around the hole of the drilling network, thereby improving the permeability of the coal seam and increasing the amount of gas drainage; at the same time, the cross borehole arrangement can be effective to avoid the defect that the hole cannot be drawn out of gas or the amount of gas extracted is reduced due to the hole collapse and plugging in the simple parallel drilling hole layout mode.

4. Investigation on the influence radius of gas drainage

The key parameter that affects the effect of borehole extraction is the borehole extraction influence range. A large number of experimental research results show that there is the following mathematical relationship between the drainage influence radius and the extraction time, coal seam original pressure, and coal seam permeability:

$$R = K p_0^\alpha T^\beta \quad (4)$$

In the formula: $R$ - Drainage influence radius, m; $\kappa$ - Coalbed permeability, md; $p_0$ - Coal seam original pressure, MPa; $T$ - Coalbed methane drilling time, d, $\alpha, \beta$ - Coal quality parameter.

In the 3212 working face, the measurement experiment of the influence radius of extraction was carried out, divided into 3 groups, 5 holes in each group, the hole spacing was 3m and 2m, the group spacing was 50m, and the hole length was 50m.

The original pressure of coal seam, coal seam permeability, drainage time and radius of the actual test area were fitted and calculated. The relationship between the change in the extraction radius of the borehole extraction and the extraction time is shown in Figure 2.
The change rule of the influence radius of extraction is proportional to the permeability of the coal seam, the original pressure of coal bed methane, and the extraction time. The flow rate of boreholes (0.1732 m³/min) at 2m intervals in the initial stage of drainage is 2.4 times that of the arrangement (0.0714 m³/min) at 3m intervals, and the flow rate decay is slow. After 22 days of drilling, the flow rate decay at 2m intervals is accelerated, and the flow attenuation of the 3m spacing drilling slowed down. Considering the effective extraction time and extraction effect of the borehole, the interval between pre-drainage boreholes in No. 3 coal seam should be selected between 2 and 3m, and 2.5m.

5. **Gas pre-drainage drilling layout plan**

The test of pre-draining along layer drilling technology was conducted in 3215 working face[5-6]. The test drilling arrangement is shown in Figure 3. Ante sealing material is used for drilling and sealing. The length of the sealing section is 8m and the sealing depth is 15m.

![Figure 3. Schematic diagram of drilling arrangement in three test areas](image)

(1) Dense parallel drilling
The boreholes are arranged in a single row of holes, the hole spacing is 2.5m, 30 boreholes are constructed, the opening position is 1.3m from the bottom plate, and the elevation angle of the boreholes is 3°.

(2) Plane cross drilling
The drill holes are arranged in a single row, the hole spacing is 2.5m, 30 boreholes are constructed, the opening position is 1.3m away from the bottom plate, and the drilling elevation angle is 1°.

(3) Three-dimensional cross drilling
The drill holes are arranged with three holes, the hole spacing is 2.5m, 40 holes are drilled, the height of the upper row of drill holes is 1.5m, the face is 80°, and the elevation angle of the drill holes is 1°; the height is 1.0m, parallel to the working surface, the drilling elevation angle is 1°.

All drill holes are designed with a depth of 160m and a diameter of 94mm. After the completion of the three arrangements of drill holes, 10 groups of 20 holes are selected for the effect inspection.
6. Analysis of gas pre-draining effect

(1) Comparison of extraction characteristic coefficients

The average 100-meter drainage volume of the dense parallel drilling holes is 0.2493 m³/min.hm, and the attenuation coefficient is 0.2023 d⁻¹; the average 100-meter drainage volume of plane cross-drilled holes is 0.0335 m³/min.hm, and the attenuation coefficient is 0.1779 d⁻¹; the average 100-meter drainage volume of solid cross-drilled holes is 0.421 m³/min.hm. The attenuation coefficient is 0.0824 d⁻¹, as shown in Table 1. For the extraction borehole, the smaller the attenuation coefficient, the more favorable for gas extraction; the greater the average extraction volume per 100 meters, the higher the extraction efficiency. According to the analysis of the survey data, the attenuation coefficient of the three-dimensional cross-drilled borehole is the smallest, which is conducive to gas extraction; in a unit time, the extraction capacity of the three-dimensional cross-drilled borehole is 1.7 times and 1.3 times that of the dense parallel borehole and the plane cross-drilled borehole. The extraction efficiency of three-dimensional cross drilling is 68.9% and 25.7% higher than that of dense parallel drilling and plane cross drilling, respectively.

Table 1. Investigation results of different drilling methods

| Drilling category      | Drainage concentration (%) | single hole drainage volume (m³/min) | Attenuation coefficient (d⁻¹) | Average 100m drainage volume (m³/min.hm) |
|------------------------|----------------------------|------------------------------------|-------------------------------|----------------------------------------|
| Dense parallel drilling| 3%~27.8%                   | 0.002~0.0315                       | 0.2023                        | 0.2493                                 |
| Plane cross drilling   | 2%~95.0%                   | 0.001~0.099                        | 0.1779                        | 0.335                                  |
| Three-dimensional cross drilling | 2%~94.6% | 0.01~0.39                       | 0.0824                        | 0.421                                  |

(2) Comparison of extraction effects

See Figure 4 for the gas emission during the mining of 3215 working face in the area covered by different drilling methods. During working face mining, the average gas emission in the area covered by dense parallel boreholes is 39.1 m³/min, the average gas emission in the area covered by plane cross boreholes is 35.9 m³/min, and the average gas emission in the area covered by three-dimensional boreholes is 33.4 m³/min. In addition, the gas in the upper corner has exceeded the limit during the mining in the areas covered by the dense parallel borehole and the plane cross borehole, and there is no gas anomaly in the upper corner during the mining in the area covered by the solid cross borehole.

7. Conclusion

(1) When the layout of the three-dimensional cross-drilled hole is reasonable, there is a stress superimposed area around the cross-drilled hole, which increases the volume of the plastic failure zone,
can significantly improve the permeability of the coal seam, increase the gas drainage volume per unit time, and reduce the gas drainage compliance time.

(2) The three-dimensional cross drilling arrangement can effectively avoid the defect that the borehole cannot be drawn out of gas or the gas volume is reduced due to the collapse of the hole. The effective length of the hole improves the utilization rate of extraction drilling.

(3) During the extraction of three-dimensional cross boreholes, the attenuation coefficient is small; under the same drilling engineering volume, the extraction capacity of three-dimensional cross boreholes is 1.7 times and 1.3 times that of dense parallel boreholes and plane cross boreholes. The extraction efficiency of boreholes is 68.9% and 25.7% higher than that of dense parallel boreholes and plane cross boreholes, respectively.

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