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Analysis of Outburst Risk Prediction Characteristics of Fully Mechanized Caving Face in Extra-Thick Coal Seam

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Abstract: *In order to study the prediction method of outburst risk in extra-thick coal seam mining face, based on the gas geological conditions of 16215 working face in Jinhe Coal Mine of Yaojie mining area, the mechanical state of surrounding rock in the gestation stage of coal and gas outburst and the limit equilibrium area of coal body in front of working face are analyzed theoretically. The mechanical environment of coal and rock mass in different mining stages of extra-thick coal seam is studied, and the corresponding outburst prediction method is determined and verified on site, which can provide reference for outburst prediction of working face under similar conditions.*

Keywords: *Extra-thick coal seam; Fully mechanized caving face; Theoretical analysis; Prominent risk prediction; Methods*

1. Introduction

According to the "Coal and Gas Outburst Prevention Rules, " after the effect of outburst prevention measures in the working face area is effective, regional verification should also be carried out in the non-outburst danger area, or the outburst danger prediction of the working face should be carried out [1] to ensure the safe production of the working face. The thickness of the coal seam in the Yaojie mining area is generally greater than 20 m, and the thickness of the local coal seam is even greater than 35 m, while the predicted drilling hole depth is generally only 8 ~ 10 m, and the predicted drilling construction equipment does not support the construction of larger hole depth. Drilling, resulting in whether it is to take regional verification or face outburst risk prediction, can not control the top coal body at a higher level of the coal seam. After taking regional comprehensive outburst prevention measures, whether the top coal in the higher level has the outburst danger of the working face and how to judge its outburst danger is a difficult problem that has been plaguing the safe mining of the fully mechanized caving face in the extra-thick coal seam[2].

2. Engineering Background

The 16215 working face is located in the eastern part of the sixth mining area. The mining level is + 1496 m. The working surface is located between the Halagou and the southern slope of the western ridge. The ground elevation is + 2025 ~ + 2271 m, and the vertical depth is 550 ~ 771 m. The loess is covered and the gully is developed. The northern part of the surface is the oil shale return air roadway in the seventh mining area, the oil shale intake air roadway in the seventh mining area, the oil shale intake air roadway in the seventh mining area and other system concentrated roadways, the southern and eastern parts are solid coal, and the western part is 16214 working face goaf. The 16215 working face is 520 m long in strike and 120 m wide in dip. The main coal seam is the second layer. The thickness of the coal seam is 16.8~ 45.4 m, and the average thickness is 30.8 m. The thickness of the coal seam is thick in the south and thin in the north. It is the mining of extra-thick coal seam. The fully mechanized top coal caving mining method is used to mine the whole height at one time, and the roof is managed by the whole caving method. The designed mining height is 4 m, and the mining-caving ratio is 1: 3~ 1: 10. The actual mining height is 2.8 m, and the mining-caving ratio is up to 1: 15.

3. The Mechanical State of Surrounding Rock in the Gestation Stage of Coal and Gas Outburst

The mining operation destroys the original stress balance, so that the load borne by the coal and rock mass in the mining space is transferred to the surrounding coal and rock mass, and the surrounding coal and rock mass is subjected to higher load, resulting in strength failure, strain softening, flow deformation and stress concentration [3]. This phenomenon is more prominent in the coal wall in front of the working face, and often forms a bearing pressure limit equilibrium zone in front of the coal wall. This quasi-static deformation and failure of coal rock prepares the conditions for mechanical failure for subsequent outburst excitation, so it is called the outburst gestation stage [4]. The outburst usually occurs in front of the mining face, so the coal and rock mass in front of the working face becomes the key research object. The purpose of studying the stress and strain state of coal and rock mass in front of the working face is to reveal the failure and instability mechanism of coal and rock mass in front of the working face. The elastic potential energy of coal and rock mass in front of the working face is also characterized by stress and strain. Therefore, in order to analyze the mechanical mechanism of outburst inoculation, it is necessary to have an understanding of the stress and strain of coal and rock mass in front of the working face before outburst.

When the mining face is advancing normally, due to the transfer of the overburden load in the goaf space to the coal wall in front of the working face, the vertical stress of the coal and rock mass in a certain range in front of the working face is greater than the original vertical stress (called the concentrated stress), and the concentrated stress action zone is called the abutment pressure zone. Under the action of abutment pressure, strength failure occurs in some coal bodies, and after failure, they continue to bear with their residual strength. The area where strength failure has occurred (plastic zone) is the limit equilibrium area of abutment pressure. The coal seam from the peak position of the abutment pressure to the exposed surface of the coal wall should belong to the limit equilibrium zone of the abutment pressure[5] (as shown in the area with a width of X0 in Fig.1).

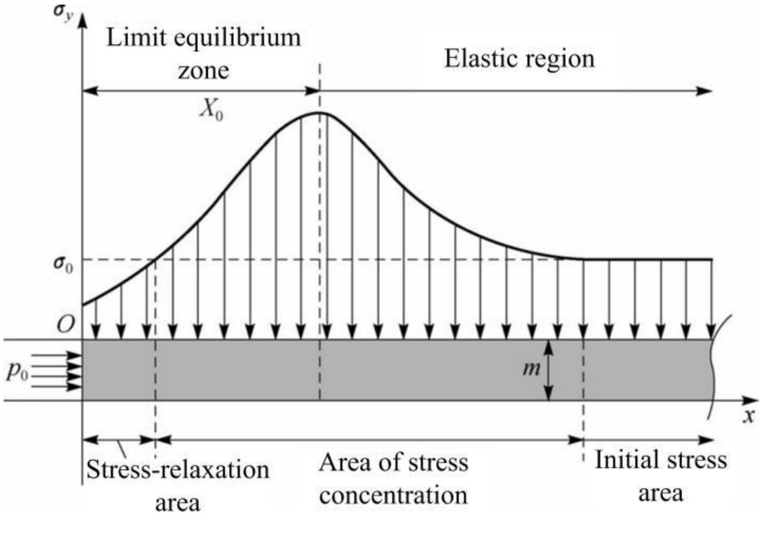

Fig1. *Division of abutment pressure in front of working face*

As shown in Fig.2, a unit body with a width of dx and a height of m is taken in the coal wall. The unit body is in a three-dimensional stress state. The stress in the x-axis direction is σ_x on the side of the coal wall, and the other side is $\sigma_x + d\sigma_x$. The pressure in the y and z directions is σy and σz, respectively. Because the stress of the element is mainly studied along the x-axis direction, and the change along the y-axis and z-axis is small, the stress increment in the y-axis and z-axis directions is ignored, and σ_y and σ_z are approximately regarded as constants. The cohesion between the coal seam and the contact surface of the roof and floor is c_1, and the internal friction coefficient is f_1. The cohesion of coal is c_2, and the internal friction coefficient is f_2.

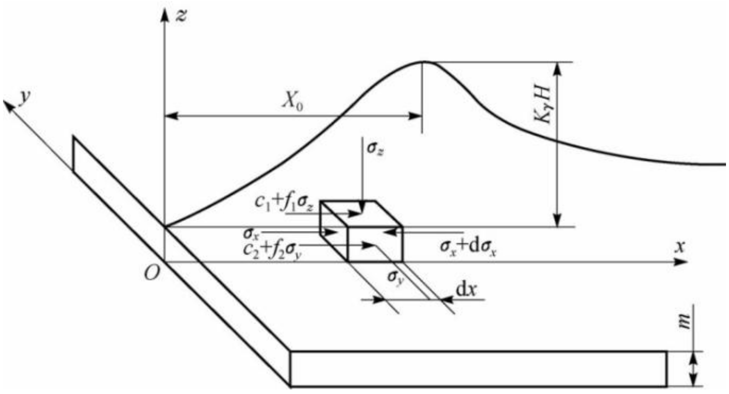

Fig2. *The stress state of the limit equilibrium zone in front of the working face*

The distance from the peak of the abutment pressure to the coal wall, that is, the width of the limit equilibrium zone X_0, is expressed as:

$$X_0 = \frac{m\sigma_t}{2f_1\sigma_c}\ln\left[\frac{K_\sigma\gamma_s H + \frac{1}{f_1}\left(c_1 + mc_2 + mf_2\sigma_y\right)}{\frac{\sigma_c}{\sigma_t}p_0 + \sigma_c + \frac{1}{f_1}\left(c_1 + mc_2 + mf_2\sigma_y\right)}\right] \tag{1}$$

In the formula, σc is the uniaxial compressive strength of coal, MPa ; σt is the uniaxial tensile strength of coal, MPa ; the reaction force of the coal wall by the support is p_0, MPa ; K_σ is the concentration factor of bearing pressure ; γ_s is the average bulk density of overlying strata, t/m^3; H is the mining depth, m.

It can be seen that the width of the limit equilibrium zone of the abutment pressure of the working face increases with the increase of the maximum concentration stress $K_\sigma\gamma_s H$, the thickness of the coal seam m, the uniaxial tensile strength of the coal σt, and decreases with the increase of the friction coefficient f_1 between the coal seam and the roof and floor, the uniaxial compressive strength σc of the coal, and the pressure p0 on the exposed surface of the coal wall.

The width X_0 of the limit equilibrium zone of the abutment pressure is usually regarded as an important index to predict the outburst danger of the working face, and it is considered that the limit equilibrium zone of the abutment pressure is the area to prevent the outburst excitation, because the gas in the limit equilibrium zone of the abutment pressure has been released in large quantities, and the gas pressure gradient in the limit equilibrium zone of the abutment pressure has been greatly reduced accordingly. The coal body is in the post-peak area of strength failure, and its stress has also been released to a large extent, and the total energy stored in the coal body is reduced. Therefore, the larger the width of the area, the smaller the outburst risk of the working face.

4. ANALYSIS OF MINING MECHANICAL ENVIRONMENT AND PREDICTION CHARACTERISTICS OF EXTRA-THICK COAL SEAM IN 16215 WORKING FACE

4.1. The Influence of Top Coal Caving on Outburst in Initial Mining Period

In view of the high mining strength and large mining space of the top coal caving face, there is a big difference in the engineering mechanical environment of the top coal caving mining between the initial mining period and the normal mining period (as shown in Fig.3), and the risk prediction of the working face has its own characteristics.

According to the theory of mine pressure and related research results, during the initial mining period of the fully mechanized top coal caving face, when the mining and caving ratio is greater than 1: 3, the stress concentration of the coal body around the open-off cut roadway is higher. During the initial mining period, with the increase of the mining and caving ratio, the risk of dynamic disasters such as outburst increases significantly. The existing mining practice in China shows that even if the effect of pre-pumping regional measures is up to standard, the in-situ stress-dominated outburst cannot be completely eliminated. When the mining and caving thickness is small, due to the natural pressure relief and gas emission effect of the open-off cut roadway on the surrounding coal body in the initial mining period, the elastic energy and gas internal energy of the surrounding coal body have been partially released. The elastic potential energy released in a short time range and the gas internal energy released in the coal during the coal caving process are very limited, and the possibility of dynamic disaster is small. When the mining is relatively large, the risk of outburst and rock burst will increase significantly.

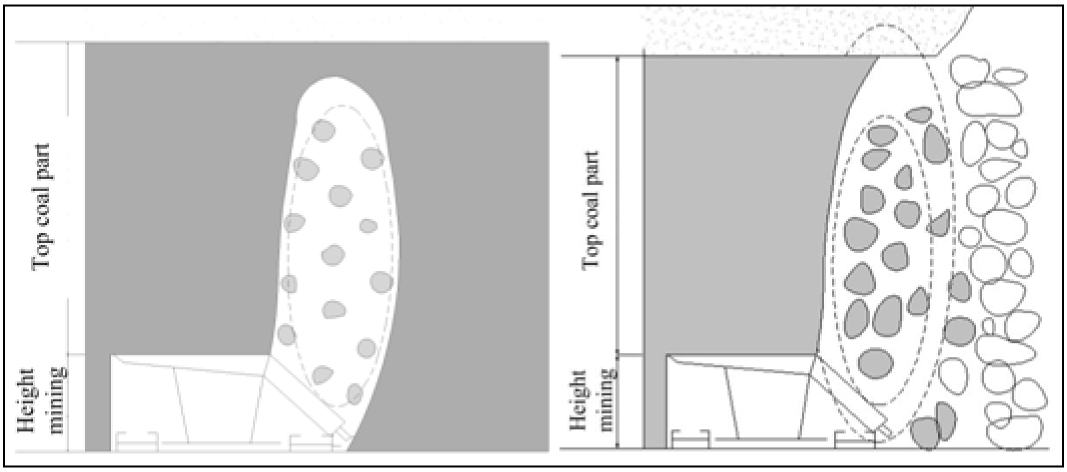

Fig3. *The schematic diagram of engineering environment in the initial mining period and normal mining period of fully mechanized caving face*

4.2. Influence of Top Coal Caving on Outburst in Normal Mining Period

On the one hand, with the increase of mining and caving ratio, the influence range of abutment pressure of coal wall in front of working face tends to expand, the peak coefficient of concentrated stress tends to decrease, and the pressure relief zone and concentrated stress zone increase. The elastic energy release range and energy of coal and rock mass in front of the working face increase during the caving process, while the increase range of elastic energy release concentrated in the range of 20 m in front of the working face is obviously reduced. On the other hand, with the increase of mining and caving ratio, the limit stress equilibrium area in front of the working face increases, the initial point of coal seam pressure relief gas moves forward, the gas pressure relief discharge path increases, the discharge time prolongs, and the gas pressure in front of the coal wall decreases, which are all conducive to inhibiting gas from participating in outburst work.

During the normal mining period of fully mechanized caving face, it is precisely because of the comprehensive factors such as the low original gas content or pressure of the coal seam, the evolution and distribution of the stress field and gas flow field of the working face and the rheological effect of the surrounding rock that a safety barrier sufficient to resist dynamic damage is formed. Up to now, there is no report on the outburst of top coal caving, mechanical mining or blasting mining process in the normal mining period of top coal caving mining face.

4.3. The Influence of Structural Factors on Outburst

When there are geological structures such as faults, folds and coal seam thickness changes in front of the working face, the superposition of advance abutment pressure and tectonic stress will produce complex stress concentration. The ' see side ' of the working face and the vicinity of the structural area are still the focus of outburst prevention. The mining practice shows that during the normal mining period, with the increase of the mining-caving ratio, the peak position of the front abutment pressure concentration is far away from the coal wall and the stress concentration coefficient is relatively reduced. Therefore, the increase of the mining-caving ratio during the normal mining period is beneficial to the prevention and control of the in-situ stress-dominated outburst to a certain extent, but it may also lead to the increase of rib spalling, roof leakage, gas emission and the pressure of fire prevention and dust prevention.

4.4. Prediction Characteristics of Outburst Danger in Fully-Mechanized Caving Face of Extra-Thick Coal Seam

1) Prediction of outburst danger of working face in initial mining period

In the initial mining period of top coal caving, the front and rear of the working face are all solid coal seams. According to the above numerical simulation and theoretical analysis, the influence range of pressure relief and gas emission in the open-off cut roadway is 3 times the height of the roadway. Before the first weighting of the top coal caving face, the concentration coefficient of the abutment pressure increases obviously with the advancing distance, and the peak value of the concentrated stress of the top coal is close to the coal wall in front of the coal face, that is, the stress gradient is large. In the initial caving period, the first caving coal is more prone to dynamic disasters than the second caving coal. The top coal caving mining in the initial mining period should ensure that the front and rear 10 m range of the working face advancing direction and the goaf direction and the top coal have no outburst danger. Therefore, the prediction of working face in the initial mining period of top coal caving mining has the following characteristics:

1) The first working face prediction work in the initial mining period of top coal caving mining should be carried out in front of the open-off cut roadway, and the 10 m range of the two sides of the open-off cut roadway should be predicted.
2) It is predicted that two rows of boreholes should be arranged in the two sides of the open-off cut roadway along the advancing direction of the top-coal caving face and the direction of the goaf. One row of boreholes is arranged in the coal mining layer, and the other row of boreholes controls the top-coal caving layer to the roof. The final hole is located 10 m outside the contour line of the two sides of the open-off cut roadway, and the predicted borehole spacing is 10 ~ 15 m along the width direction of the working face. In addition, if there is bottom coal, a row of bottom coal prediction boreholes should be added.

In order to further increase the safety and reliability, the method of only coal mining without top coal can be adopted in the initial mining period of 20 m range of self-opening cut in fully mechanized caving face.

2) Prediction of outburst danger in working face during normal mining period

In the normal mining period of top coal caving mining, the front is the solid coal seam and the rear is the goaf. According to the above numerical simulation and theoretical analysis of top coal caving mining, after the first weighting of the roof is completed, the abutment pressure concentration coefficient increases slowly with the advancing distance. When the overlying strata of the stope are fully mined, the abutment pressure concentration coefficient tends to be stable. The distance from the peak point to the coal wall of the working face does not change much with the advancing distance, and the stress gradient in front of the working face decreases. Under the same conditions, the larger the coal seam mining height (mining-caving ratio), the smaller the abutment pressure concentration coefficient and peak value, and the larger the pressure relief zone in front of the working face.

Therefore, during the normal mining period of top coal caving mining, two rows of boreholes should be arranged along the advancing direction of the working face. One row of boreholes is arranged in the coal mining layer, and the other row of boreholes controls the top coal caving layer, with the drilling depth of 10 ~ 12 m. In addition, other operations are the same as the initial mining period of top coal.

In addition, in view of the large thickness of caving coal mining and general fully mechanized mining and blasting coal mining, the large working face space, the stability of coal heterogeneous structure is reduced, and the prediction advance distance and measure advance distance of caving coal mining in normal mining period are higher than those of general coal mining face. According to the ' prevention and control of coal and gas outburst rules ', the prediction of normal mining period of top coal mining is generally 3m ahead, and the advance distance of measures is generally not less than 4m. The advance distance of geological structure fracture zone measures should be further increased, which can be taken as 5m.

5. WORKING FACE OUTBURST PREDICTION INDEX TEST METHOD

5.1. Working Face Prediction Drilling Layout

(1) Initial mining period. According to the above analysis, in the initial mining period of top coal caving mining, with the increase of mining and caving ratio, the risk of dynamic disasters such as outburst and rock burst increases significantly. Therefore, the drilling of regional pre-drainage measures should control the 20 m range outside the open-off cut roadway. For the regional verification or working face prediction link, before mining, it should be ensured that there is no outburst danger in the 10 m range before and after the advance of the open-off cut roadway and the top coal above. During the mining period of 16215 working face, continuous cycle prediction is carried out. One set of prediction boreholes is arranged every 10 m along the dip direction of the working face. Each group contains three prediction boreholes. The depth of the borehole is 10 ~ 12 m. The borehole should be arranged in the soft layer as far as possible to control the bottom coal of the working face, the coal body of the working face and the upper coal body (if there is no bottom coal, it is not necessary to control the bottom coal prediction borehole). The inclination angle of the upward hole is 30°~ 60°, and the thickness of the top coal is 6~ 10 m. The borehole arrangement is shown in Fig. 4 (a). Prediction holes must be arranged within 5 m near the coal seam structure disorder, fault, deflection and other structures.

(2) Normal mining period. During the normal mining period, a group of prediction boreholes are arranged every 10 m in the working face, each group contains three boreholes, which control the bottom coal, the coal body and the upper coal body of the working face respectively (if there is no bottom coal, the bottom coal prediction boreholes can be controlled without construction). The prediction borehole depth is 10 ~ 12 m, and the boreholes should be arranged in the soft layer as far as possible. The drilling layout diagram is shown in figure 4 (b). In addition, other operations are the same as the initial mining period of top coal caving.

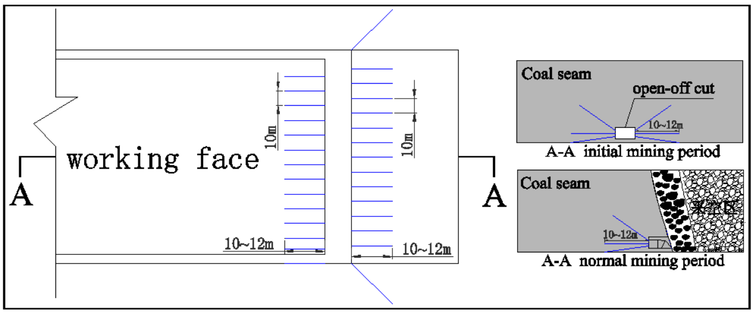

Figure4. *16215 working face outburst prediction drilling layout diagram*

5.2. Examining Test Indicators

The drilling cuttings index method, composite index method and R value index method are comprehensively used to predict the outburst of the working face. The selected indexes are the amount of drilling cuttings S, the gas desorption index K1($\Delta h_{2)}$ value of drilling cuttings, the initial velocity q and R value of borehole gas emission. Before the investigation results of the sensitive index of the outburst prediction of the working face are obtained, the safety production management is temporarily carried out with reference to the critical value of the reference index provided by the 'coal and gas outburst prevention and control rules', that is, S_0=6.0kg/m,K_{10} = 0.5mL/ (g·min$^{1/2}$), Δh_{20} = 200Pa, q_0=5L/min,R_0=6..

The diameter of all predicted boreholes is φ42mm. The φ42mm drill bit and twist drill pipe are driven by air coal drill, and the construction speed is controlled at 1m/min as far as possible. The amount of drilling cuttings S was measured every 1 m from the 2 nd m, and the initial velocity of gas emission q was measured within 2 min after the drilling was suspended, and the R value was calculated according to formula (2). The gas desorption index K_1 (Δh_2) value of drilling cuttings was measured every 2m.

$$R=\left(S_{\max}-1.8\right)\cdot\left(q_{\max}-4\right) \quad (2)$$

In the formula, S_{max} is the maximum amount of drilling cuttings along the hole length of each borehole, L/m; q_{max} is the maximum initial velocity of gas emission in each borehole, L/min.

5.3. On-Site Inspections

A total of 29 outburst predictions were made in the process of mining 200 m in 16215 working face. During the field investigation, S, K1 and q prediction indexes did not exceed the standard, and there were no abnormal phenomena such as clamping and suction drilling during drilling construction. In 16215 working face, the amount of drilling cuttings S, the gas desorption index K1 value of drilling cuttings, and the initial velocity q of gas emission from boreholes were used to perform cyclic prediction. The measured S_{max}=2.4kg/m, K_{1max}=0.35mL/(g·min$^{1/2}$), q_{max}=1.89L/min, safe mining was realized without taking local outburst prevention technical measures.

6. Conclusion

The mechanical environment of mining surrounding rock in the mining face of extra-thick coal seam is different from that of medium-thick coal seam, and the outburst prediction method and prediction range are also different. The initial mining and caving period and structural area are the areas with relatively large outburst risk in the working face. According to the gas geological conditions of 16215 working face, the control range and layout parameters of outburst prediction drilling in working face are determined, which ensures the safe mining of working face.

References

[1] Cheng Yuanping, Zhou Hongxing. Research progress on sensitive index and critical value of coal and gas outburst prediction [J]. Coal Science and Technology, 2021, 49 (01) : 146-154.

[2] Wang Enyuan, Zhang Guorui, Zhang Chaolin, et al. Research progress and prospect of coal and gas outburst prevention and control theory and technology in China [J]. Coal Journal, 2022,47 (01) : 297-322.

[3] Kang Hongpu, Gao Fuqiang. Mining-induced stress evolution and surrounding rock control in coal mine [J]. Journal of Rock Mechanics and Engineering, 2024,43 (01) : 1-40.

[4] Hu Qianting, Zhou Shining, Zhou Xinquan. Mechanical mechanism of coal and gas outburst process [J].Journal of Coal, 2008,33 (12) : 1368-1372.

[5] Tu Min, Lin Yuandong, Zhang Xiangyang, et al. Study on the evolution of overburden structure and the reasonable width of section coal pillar in large space island stope [J]. Journal of Mining and Safety Engineering, 2021,38(5):857-865.

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