Research on Mechanism and Prevention Technology of Rib Spalling In Fully-Mechanized Coal Mining Face with Soft and Unstable Seam

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Abstract. The present situation and influencing factors involved in rib-spalling at a fully-mechanized coal mining face with soft and unstable seam were analyzed. The stress characteristics and the mechanism of rib spalling were modeled. Several kinds of control principles and methods were proposed, after the comprehensive comparative analysis, the measure of coal wall injection Marithan powder was conducted, comprehensive prevention and treatment measures to optimize the parameters of fully mechanized mining face for aids had been adopted. Field test results show, after the implementation of comprehensive prevention and control measures of coal wall rib-spalling, the serious rib-spalling for the depth more than 0.7 m has been completely eliminated, and the range of rib-spalling reduced to 5% from 35% of the length of the working face. The occurrence probability of rib spalling were significantly reduced, and to ensure the normal mining of working face, economic and safety benefits were significantly improved.

1. Introduction

Long-term safety production practice shows that under complex geological conditions, a large range of coal wall rib-spalling often occurs in the process of mining in soft and unstable coal seams, result in an increasing of the non-supporting space at the end of the coal wall, and accidents such as slanting support and support failure, even lead to roof fall accidents at the working face, which directly affects the regular operation cycle of the working face. It also poses a great threat to the personal safety of workers. People's personal safety poses a great threat and brings difficulties to mine safety management [1]. Coal wall slice is not only related to natural conditions such as coal seam geological conditions and physical and mechanical properties of coal and rock itself, but also closely related to mining factors such as mining height, advancing speed of coal face, variation of coal seam thickness, working resistance of support, working condition of support and migration law of overburden rock in stope. In view of the mechanism and control of coal wall slice, domestic scholars have done a lot of research work [2]. Literature [3] considers that increasing the working resistance of support in fully
mechanized caving mining can reduce the pressure of coal wall, reasonable water injection can enhance the cohesion and shear strength of coal body, in addition, accelerating the advancing degree of working face and reducing mining height properly are also conducive to preventing and curing the side wall. Literature [4] Designed the pull-out experiment of flexible material and the strength experiment of coal sample strengthened by flexible material, constructed the constitutive model of "brown rope-slurry-coal body", proved that the new technology of "brown rope+grouting" for flexible reinforcement of coal wall can achieve full-length anchorage, broken coal body does not slip under the pulling force of brown rope, and the stability of coal wall has been significantly improved. Literature [5] the deflection characteristics of the coal wall with better integrity are analyzed by using the pressure bar theory. It is found that the upper and middle parts of the coal wall are easy to occur slice-side. By comparing with the field measurement results, two typical slice-side forms of the fully mechanized face with large mining height are obtained: the half-wall slice-side and the whole slice-side of the coal wall. The measures of improving the efficiency of the guard plate, increasing the resistance of the support and moving the support in time are given, which can reduce the occurrence of large coal slice in the coal wall of the working face.

However, the domestic scholars have little research results on the mechanism of coal wall rib-spalling in fully mechanized mining face of soft and unstable coal seam, and the technical measures of coal wall control are more focused on the field practice. Therefore, it is necessary to further study the mechanism of coal wall rib-spalling in soft and unstable coal seam and the technical measures of prevention and control [6].

2. Engineering background
The Cunninghamia lanceolata deposit is located in the border area between Sichuan Basin and Yunnan-Guizhou Plateau. The direction of the mountain system is basically the same as that of the tectonic line, and is generally in the East-West direction. 4302 fully mechanized mining face is located in the eastern mining area of the mine. The working face adopts the comprehensive mechanized mining method of longwall retreat, and the roof is managed by all caving method. The working face has a strike length of 780m and a slope length of 140 M. The elevation of the working face is + 28.5 ~ + 147.9 m, the surface elevation is + 415 ~ + 630 m, the average burial depth of the working face is about 385 m, the main mining 2 # coal seam is soft and unstable coal seam, and the dip angle is 2 ~6 with an average dip angle of 4 and the thickness of the coal seam is 3.5 ~6.2 m with an average thickness of 4.1 M. There are 1-2 layers of gangue in the coal seam. The thickness of the gangue is 0.1-0.4m. Affected by geological structure, some sections of the coal seam are thinned and the coal seam is black granular-powder. The direct bottom is clay rock with a thickness of 2.6-2.9 m. The pseudo-top is mudstone with a thickness of 0.1-0.6m. The direct roof is sandy mudstone with low hardness and thickness of 2-3 m. Sandstone with a thickness of more than 5m and calcareous cementation has a relatively high strength. See Table 1 for details.

| Name      | Lithology | Stiffness | Thickness (m) | Lithologic Character                                      |
|-----------|-----------|-----------|---------------|-----------------------------------------------------------|
| roof      | main roof | sandstone | 6~8           | Deep grey medium-thick layered siltston                   |
|           | direct roof | sandy mudstone | 4~6          | Grey sandy mudstone and sandstone                         |
|           | false roof | mudstone   | 1~3, 0.1~0.6  | Sandy mudstone in grey mudstone                          |
| floor     | hard floor | claystone | 1~6, 2.6~2.9  | Grey-white claystone, grey sandy mudstone, lower 4 # coal seam |
|           | sandstone mudstone | 4~8        | >5            | Gray sandy mudstone and sandstone are dominant beneath 4# coal seam |
3. Measurement and Mechanism Analysis of Coal Wall Slab

3.1. Statistical survey of film bands on site

In order to fully grasp the condition of the slice in 4302 fully mechanized mining face, the researchers have partially measured the position, height and depth of the slice in the face. According to the statistics of observation data, the relationship curve is drawn with the position of slice-side at the working face as abscissa and the average depth of slice-side every day as longitudinal coordinate. As shown in Fig. 1, the maximum depth of slice-side is 105-140 m at the working face position. The relationship curve is drawn with the position of the slice as abscissa and the average height of the slice as ordinate. As shown in Figure 2, the maximum height of the slice is found at the position of 100-140 M. Therefore, the most serious slice is determined between 70~96(105-140 m) shelves.

![Figure 1 Coal wall slab depth curve](image1)

![Figure 2 Curve diagram of coal wall slab height](image2)

During the normal advancing process of the working face, the coal wall is serious, the roof is broken, and it takes a lot of time to deal with the leaking refuse of the working face every day. According to the field statistics, the average daily coal cut is no more than 0.6 knives, that is, the daily footage is about 0.4m, the working face is in the situation of collapse with mining, the scraper conveyor of the working face is in a long-term crushing state, and the biting and dead frame situation of the working face occurs every day, and approaches every day. Half the time is spent in dredging. In order to ensure the safe and smooth mining of working face, it is necessary to study the mechanism of coal wall slice in the soft and unstable coal seam of 4302 working face under such complex geological conditions, so as to ensure the safe and smooth mining of working face [7].
3.2. **Analysis of the mechanism of coal wall slice**

The research results show that the probability of occurrence of coal wall slip in normal mining face is very low, but when the working face encounters special and complex geological conditions, it is often prone to occurrence of coal wall slip and end leakage. Literature [8] considers that two kinds of failure modes are the main causes of the slice wall in the stope, and for most of the soft and unstable coal seams, the shear failure of the coal wall is the main failure mode, as shown in Figure 3 (a).

The shear strength of soft coal seam itself is relatively low. When the coal wall is affected by self-weight and roof pressure, transverse tensile stress will occur inside the coal wall, resulting in creep deformation of the soft coal body, thereby releasing or alleviating the stress. Once the shear stress in the coal wall is greater than its shear strength, shear sliding failure will occur [9]. The surface occupies most of the sliding surface of shear failure. If the height of coal wall and slice is relatively small, it can be simplified to a plane model, as shown in Figure 4 (b), the Mohr-Coulomb strength theory is used as the basis and can be expressed by formula.

\[ G = D - S = C_h \sec \alpha + N \tan \phi - S \leq 0 \]  

In the formula, G is the safety margin; D is the shear force along the shear plane; S is the sliding force along the shear plane; C is the cohesive force of the coal body; h is the failure height of the shear plane; alpha is the angle between the shear plane and the coal wall; phi is the internal friction angle of the coal body; N is the normal force on the shear plane; q is the roof load concentration; N and S are mainly composed of roof pressure and failure body. The roof pressure P is qhtana, and the weight W of sliding body is H2 gamma tana/2. According to Mohr-Coulomb strength theory, it can be concluded that:

\[ \alpha = 45^\circ - \phi / 2 \]  

\[ N = (p+W) \sin \alpha \]  

\[ S = (p+W) \cos \alpha \]  

By substituting formulas (2), (3), (4) into formula (1), shear failure criteria of coal wall can be obtained.

\[ G = C_h \sec \alpha + (q_h+h^2 \gamma / 2) (\sin \alpha \tan \phi - \cos \alpha \tan \alpha \leq 0 \]  

From the analysis of the above formulas, it is concluded that the main influencing factors of the coal wall are the physical and mechanical properties of the coal body itself and the roof pressure of the
stope. Therefore, the main measures to solve the problem of the coal wall in the soft and unstable coal seam are to change the physical and mechanical properties of the coal body, reduce the roof pressure on the coal wall and enhance the shear strength of the coal body [10].

4. Countermeasure of Coal Wall Slab Control

According to the analysis of geological conditions of 4302 working face and the study of the mechanism of coal wall slice, 4302 working face is mainly affected by many factors, such as serious roof gangue leakage and coal wall slice collapse after coal cutting. Based on the comprehensive analysis, the comprehensive control measures are put forward, which are mainly based on the method of injecting Malisan into coal wall and supplemented by optimizing the parameters of fully mechanized mining face.

4.1. Optimizing the Technological Parameters of Fully Mechanized Mining

(1) Improve the initial support force and working resistance of the bracket. Reasonable arrangement of distance between Emulsion Pumping Station and working face, monitoring and monitoring of support status, optimizing the way of removing support, strengthening the operation management of workers, etc.

(2) Reduce mining height. Reducing the mining height is 4.1m, and adopting the way of retaining the bottom coal to reduce the mining height is not suitable to retain the top coal.

(3) Reasonable Reduction of Cutting Speed or Stopping and Pulling Forward Frame.

(4) Increase the use efficiency of the guard plate. After removing the frame, the protective plate is installed immediately. Only 1 to 2 shelves in advance of the shearer can the protective plate be retracted to ensure that the coal wall is supported by the protective plate to the maximum extent.

4.2. Reinforcement of Coal Body by Malisan

Marisan is a kind of polymer polyimide resin material with low viscosity and two components. Pump is used to inject it into coal body. Under the dual action of high pressure and self-expansion, cracks in coal body or concrete can be extended and all cracks produced can be filled.

4.2.1. Grouting position. According to the broken condition of the coal wall and roof, the 60#-96# support and the local section of the ventilation roadway are selected as the reinforcement section of Malishan grouting. See Figure 4

![Figure 4](image-url) Location of grouting section in working face
4.2.2. Layout parameters of grouting holes. The grouting drilling hole is arranged in parallel on the coal wall side of the 60# ~ 96# bracket section, and the vertical coal wall is drilled with a hole diameter of 42mm, a depth of 4.0m, a spacing of 5~6m, and the height of the grouting hole is from the coal seam. The position is about 0.8m, and the injection amount of Ma Li slurry in each hole is different, which is determined according to the actual situation on site, as shown in Figure 5 and Figure 6. The grouting method and parameters of the airway are similar, which can be adjusted appropriately according to the site.

![Section sketch of grouting hole](image)

**Figure 5** Section layout of grouting boreholes

![Layout plan of grouting holes](image)

**Figure 6** Design drawing of grouting borehole

4.2.3. Grouting engineering process. A 42 mm pneumatic drill bit is used to construct grouting holes and a 40 mm grouting pipe with a stop plug is used. When the double liquid enters the grouting pipe, the chip is blocked and the pressure rises. The grouting fluid presses the rubber stopper through the small hole of the flower tube to make it close to the hole wall of the grouting hole. The pressure rises again. The grouting hydraulic chip breaks into the reinforced stratum and continuously diffuses, so as to achieve the final design pressure and stop grouting.
4.3. Application effect evaluation

(1) Band and roof fall accidents have been greatly reduced. After the implementation of comprehensive control measures, the peak abutment pressure in front of the coal wall moves forward, and the degree of the influence of abutment pressure on the coal wall decreases; the shear strength of coal body is increased, the depth and height of the coal wall are reduced, and the safety effect is remarkable.

(2) The average number of knives per day has increased considerably. Before injection of Malisan, the coal wall of 70-9865 after injecting Malisan, the working face can work normally, the condition of coal wall and roof is good, and the average daily coal cutting is about 3 knives.

(3) The economic benefit is obvious. After injecting Malishan, 4302 working face produces more than 20,000 tons of raw coal per month than before. After removing the cost of injecting Malishan, there are still some economic benefits.

5. Numerical Simulation and Result Analysis

5.1. Stress Distribution of Surrounding Rock before Injection of Malishan

From the direction of strike monitoring, in the process of advancing the working face, there is an increase in stress at both ends of the working face, the maximum stress is 28.507 MPa, and the stress at both ends gradually changes to the original rock stress state. Because of the stress release in the mining face, a stress reduction area is formed in the middle of the working face. In addition, the stress on one side of the wind tunnel near 4302 face is lower than that on the other side. This is because the surrounding rock on this side is relatively fragmented and does not have a large supporting capacity, so the stress transfers to a distant place, forming a low stress area. The specific stress nephogram is shown in Figure 7.

Monitoring from the dip direction, the stress at both ends of the working face is larger, but the maximum stress is 30.189 MPa, which is larger than the maximum stress in the strike section. The main reason is that the dip direction is mainly affected by faults in the middle of the working face, and the influence at both ends is less. Therefore, the phenomenon of stress concentration is not very obvious, but the fault position on the strike is more affected, which results in a larger stress concentration phenomenon. Similarly, the stress in the middle of the working face is smaller, and the stress near the coal wall is smaller. The stress tends to transfer to the deep surrounding rock, and the stress increases. The stress distribution nephogram in the inclined direction of the working face in the forward mining process is shown in Fig. 8.
5.2. Stress Distribution of Surrounding Rock after Injection of Malishan
From the direction of strike monitoring, after the reinforcement of coal and rock mass by injecting Malishan into the working face, the stress of the coal and rock mass at one end of the strike direction increases, the maximum stress increases to 31.985 MPa, while the stress at the other end is very small, only about 10.0 MPa. This is mainly due to the mining of the upper protective layer. The coal wall at one side of the working face is located in the upper protective layer, empty area, so the stress is very small, and the other side is in the stress rising area formed after mining of the upper protective layer.
thus forming different stress state at both ends of the working face. In addition, the maximum stress occurs in the coal body, which shows that the effect of Malishan coagulation is obvious, and the coal body's integrity and bearing capacity are improved. The stress nephogram of the strike during the advancing process of the working face strengthened by injecting Malishan is shown in Fig. 9.

From the direction of inclination monitoring, after strengthening the surrounding rock, the stress of the surrounding rock in the inclined direction is 32.463 MPa, and the stress increases, which indicates that the bearing capacity of the surrounding rock has been improved, and it has a positive effect on the support of the working face and the stability of the surrounding rock. In addition, by strengthening the coal wall of the working face, the stress of the coal wall increases, which indicates that the coal wall has a certain bearing capacity, and has a great effect on reducing the coal wall slice during the advancing process of the working face. The stress cloud pattern of surrounding rock in inclined direction during the advancing process of working face is shown in Fig. 10.

![Stress cloud of post-grouting strength](image.png)

**Figure 9** Stress cloud of post-grouting strength
5.3. Evaluation of Simulation Calculation Effect

The numerical simulation software is used to simulate the coal body integrity and surrounding rock stress changes before and after injection of Malisan in the mining process of 4302 working face. The main conclusions are as follows:

(1) Comparing the stress of surrounding rock at both ends of working face before and after injection of Malisan, the range of 4-5 m after injection of Malisan has changed from original broken state to relatively complete state, but the surrounding rock is still in a relatively broken state, indicating that Malisan has a good condensation effect on the coal wall of working face.

(2) Before and after the injection of Malisan into the coal wall of the working face, the coal body forms a whole, which has a certain protective and supporting effect on the upper broken roof, alleviates the frequent roof caving in the mining process of the working face, shortens the roof treatment time, and also improves the coal quality.

6. Conclusion

1. Theoretic analysis and practical application prove that the wall of fully mechanized mining face in soft seam is mostly shear failure. The comprehensive prevention and control technology of optimizing the parameters of fully mechanized mining and reinforcing the coal body with Malishan grouting can effectively prevent the wall from falling out, biting frame and dead frame, effectively prevent and control the occurrence of disaster accidents such as the wall wall of working face, eliminate the hidden safety hazards of mining face and increase it. The recovery of coal resources improves the working efficiency, reduces the labor intensity of workers, saves a lot of manpower, material and financial resources, and realizes safe, efficient and stable production in the working face.

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