Presplitting cutting slots technique of roof cutting entry retaining and its impact on strata behavior law of workface in Baoshan coal mine

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Abstract. Presplitting cutting slots advance working face is the key technology of non-pillar gob-side entry retaining formed by roof cutting and pressure release. And the rationality of parameters not only affects the formation of the structural surface of joint-cutting, but also has a significant impact on the retaining roadway. In order to enrich and improve the system of presplitting cutting slots technology, this paper takes the 6302 working face in Baoshan Coal Mine as the research object to discuss the effect of presplitting cutting slots technology on the strata behavior law of the working face. Then the presplitting cutting height, cutting angle and the distance between blasting holes are determined as the key parameters based on theoretical calculation. And the working face hydraulic support monitoring data are analyzed statistically. The research shows that: when the cutting height, cutting angle and the distance between blasting holes is 5m, 15 °and 500 mm respectively, the structural surface of joint-cutting can form through cumulative blasting. The influence range of presplitting roof joint-cutting technology on underground pressure is 30m. Furthermore, the average holding power of the powered support decreased by 3.8mpa, and the first weighting interval and periodic weighting length of the roof respectively increased by 4m and 5.5m in the affected area.

Key words: mining without pillar and roadway formed automatically; roof cutting and pressure relief; mine pressure regularity; roof structure; key parameter

1. Introduction

With the gradual exploitation of coal resources in China, the reduction of coal resources [1] makes people pay more and more attention to the waste of resources caused by the traditional long wall coal pillar mining technology. How to improve the extraction rate of coal resources has become the core problem affecting the coal mining in China [2-3]. Therefore, it is an important direction for the sustainable development of coal resources to popularize and apply the technology of no pillar mining along the gob side entry. It can not only improve the coal recovery rate, but also effectively solve the major disaster accidents caused by the traditional coal pillar mining [4].

In recent years, experts and scholars at home and abroad have made great achievements in the study of the theory and technology of gob side entry retaining. In terms of surrounding rock movement and roof control: Li Sheng [5] et al. established the mechanical model of roof subsidence under the given deformation...
condition of the basic roof, deduced the calculation formula of roof subsidence, analyzed the multiple influencing factors of roof subsidence, and formulated the corresponding support scheme. Zhang Dongsheng et al. studied and analyzed the broken position of the basic roof along the gob side entry and the influence of different support methods on the roof activity through the similar material model experiment, and preliminarily studied the design parameters of the side filling. Xie Wenbing used UDEC numerical simulation software to simulate and analyze the characteristics of stress evolution and vertical displacement of roadway surrounding rock in different stages. In the aspect of filling materials and supporting technology beside the roadway: Tang Jianxin et al. studied and analyzed the feasibility of filling the gob side entry of common concrete roadway on the basis of the movement law and deformation characteristics of the roof strata in the gob side entry of the fully mechanized mining face in the gentle and medium thick coal seam. Kang Hongpu et al. studied the deformation and stress distribution characteristics of surrounding rock of deep gob side entry retaining through numerical simulation and field test, designed the underground test of deep gob side entry retaining and analyzed the relationship among basic support, strengthening support and roadside support, and proposed the design principle of deep gob side entry retaining and support.

Roof cutting and pressure relief automatic roadway forming is a new type of mining technology without coal pillar. Through presplitting cutting slots technology, the stress of surrounding rock of roadway is effectively improved, the support cost is reduced, and the working efficiency is improved. In recent years, people gradually pay attention to it, which is a new trend in the development of no-pillar mining technology [10]. At present, the research on automatic roadway forming by roof cutting and pressure relief mainly focuses on technical principle [11-12], surrounding rock control [13-14], and other aspects, but the research on roof cutting parameters is less. However, the cutting parameters are the key to the technology of presplitting cutting slots, which not only affects the distribution of mine pressure in the working face, but also has a significant impact on the effect of retaining roadway. In this paper, taking the 6302 working face of Baoshan Coal Mine as the actual engineering background, the key parameters of roof cutting in shallow thin coal seam are studied to enrich the theoretical and technical system of roof cutting and pressure relief automatic roadway without coal pillar.

2. The technology of roof cutting and pressure relief automatic roadway

2.1. Engineering geological conditions
The 6302 working face of Baoshan Coal Mine is located in the area of six coal mines and three plates. The strike length is 1007 m, the inclined length is 200 m, the remained roadway section is 890 m, the buried depth is $H = 53.5-73.7$ m, the occurrence is stable, the coal quality is relatively hard, the thickness of the coal seam is $1.5-1.6$ m, the average is $1.56$ m, and the dip angle of the coal seam is $1^\circ - 3^\circ$. The intermediate roof is fine-sandstone with an average thickness of $3.78$ m; the basic roof is sandy mudstone with an average thickness of $23.2$ m. The basic floor is sandy mudstone with a thickness of $3$ m. The histogram of coal seam and top and bottom slate is shown in Figure 1.

| Times | Columnar | Thickness/m | Rock name       | Lithology description                  |
|-------|----------|-------------|-----------------|---------------------------------------|
|       |          | 13.92       | Fine sandstone  | It is grayish white, thick layered, moderately sorted, argillaceous cemented, semi hard, with argillaceous bands |
| 23.20 | Sandy mudstone | Dark gray, angular fracture, horizontal texture, containing incomplete plant fossils, semi hard |
| 3.78  | Fine sandstone | It is grayish white, thick layered, mainly composed of quartzfeldspar, medium sorted, sub angular |
| 1.60  | Coal 66  | Black, weak asphalt litter, layered structure, banded structure |
| 3.00  | Sandy mudstone | Dark gray, thin layer, uneven fracture, horizontal texture |

**Fig. 1** Histogram of coal seam and roof and floor rock

6302 working face's main haulage crossheading is a roadway of gob side entry. The working face adopts the coal mining technology of full height mining at one time, strike longwall retreating and comprehensive mechanized, uses the total caving method to manage the roof of the goaf, and at the same time uses the combination of anchor and mesh to support the roof of the roadway.
2.2. Process flow of roof cutting and pressure relief automatic roadway

According to the general idea of "theory of roof cutting and short-wall beam" and the technical principle of roof cutting and pressure relief automatic roadway, the process flow of lane retaining is shown in Figure 2: after the formation of working face system, constant resistance and large deformation anchor cable are used to reinforce and support in the lane and goaf side, and the presplit seam is cut in advance of the working face (as shown in Figure 2 (a)); After the coal seam is mined in the working face, the temporary support shall be carried out in the roadway in time and the gangue retaining support shall be carried out along the cutting seam to prevent the falling gangue from flowing into the roadway (see Fig. 2 (b)); After the roof is fully collapsed and compacted, the temporary support in the roadway shall be withdrawn gradually, and the roadway side formed by the caving shall be treated with shotcreting to prevent air leakage in the goaf (see Figure 2 (c)). After the roadway is formed, it can be used as the next mining roadway, thus realizing a single roadway without coal pillar mining mode.

Fig. 2 Technological process of roof cutting and pressure relief with gob-side entry

3. Determination of cutting parameters

3.1. Cutting height

The cutting height refers to the maximum vertical distance from the bottom of the presplitting cutting seam hole to the end. In order to make the cut roof fill the goaf effectively under its own characteristics of crushing and swelling, and to limit the rotary sinking of the basic roof rock beam and the upper strata, the cutting height should be greater than the height of the goaf caving zone in principle. Assuming that there are m strata in the top cutting height, the following relationship should be satisfied:

\[ H_Q \geq \sum h \]  

(1)
\[ \Delta = \sum_{i=1}^{n} h_i + M - K_p \cdot \sum_{i=1}^{n} h_i = 0 \]  

(2)

According to formula 1-2, we can get the cutting height \( H_Q \):

\[ H_Q = \frac{\sum_{i=1}^{n} h_i}{M/(K_p - 1)} \]  

(3)

Where: HQ is the roof cutting height, m; \( \sum_{i=1}^{n} h_i \) is the thickness of each rock layer within the roof cutting range, m; M is the thickness of coal seam, m; KP is the average coefficient of expansion coefficient of rock layer, usually 1.3-1.5.

When \( k \) is 1.35 and mining height is 1.6 m in 6302 working face of Baoshan Coal Mine, the depth of presplitting slit hole is calculated to be 4.57m without considering floor heave and roof subsidence. According to construction experience and borehole columnar, the depth of presplitting slit hole is 5m.

3.2 Cutting angle

The cutting angle refers to the angle between the presplitting slit hole and the vertical direction (as shown in Fig. 3 (a)). After directional cumulative blasting is carried out in the advanced working face, the damage cracks between adjacent slit holes are connected to form a flat fracture surface or weak surface structure. After the working face is mined, the roof of the goaf will break and slide along the slit face under the influence of its own gravity and ground pressure. In order to make the goaf roof easy to slide, reduce the lateral cantilever length of the roadway roof and reduce the stress of the roadway roof, the reasonable angle should be set for the slit hole.

\[ \theta \geq \phi - \arctan \frac{h \cdot \Delta s}{L} \]  

(4)

By substituting \( T = \frac{qL^2}{2(h-\Delta s)} \), \( R = qL \) into equation (4), we can get the following results:

\[ \theta \geq \phi - \arctan \frac{2(h-\Delta s)}{L} \]  

(5)

Where, \( T \) is the horizontal thrust on the rock block, KN; \( R \) is the shear force on the rock block, KN; \( q \) is the load concentration of the basic roof, kn / M; \( L \) is the length of the basic roof rock, m; \( h \) is the thickness of the basic roof, m; \( \Delta s \) is the subsidence of block B, m; \( \phi \) is the friction angle between the rock blocks, °; and \( \theta \) is the roof cutting angle.

By substituting the rock mass parameters of Baoshan Coal Mine \( \phi = 27 ^\circ , l = 11m, \Delta s = 1.37M, H = 3.76M \) into equation (5), we can get \( \theta = 14.7 ^\circ \). Considering the convenience of construction and a certain safety factor, the pre-splitting roof cutting angle is 15°.

3.3 Slit hole spacing

In order to achieve good cutting effect, the damage cracks of adjacent slit holes should be through, and the criterion condition is that the sum of damage depth of two adjacent shaped charge blasting holes is greater than the center distance of two holes.  

Where: \( d \) is the center distance of adjacent slit boreholes; \( r_b \) is the radius of the cutting seam drilling hole; \( \lambda \) is the lateral pressure coefficient, \( \lambda = \mu / (1 - \mu) \), \( \mu \) is Poisson's ratio of roof rock mass; \( P \) is the original rock stress; \( P_b \) is the peak pressure of blast wave on the blast hole wall; \( D_b \) is the initial damage parameter of rock mass; \( \sigma_t \) is tensile strength of rock; \( \alpha \) is attenuation coefficient of explosion stress wave, \( \alpha = 2 - \mu / (1 - \mu) \).

The diameter of directional presplitting borehole of roof is 48mm, \( r_b = 24\text{mm} \); \( \mu = 0.3 \); \( P_b = 2200\text{MPa} \); \( D_b = 0.6 \); \( \sigma_t = 1.2\text{MPa} \); substituting equation (6), \( D \leq 574\text{mm} \). In addition, according to the actual situation of the project site and the requirements of convenient construction, combined with the calculation results, the spacing of pre splitting slit holes is selected as 500mm.

4 Analysis of stope ground pressure monitoring

The seam structural plane formed by the pre splitting seam of the roof of the retained roadway cuts off the stress transfer path between the roadway roof and the roof of the goaf, so it will affect the ground pressure law of the working face within a certain range. By monitoring the working resistance behavior law of the whole working face hydraulic support, the mine pressure behavior law of roof cutting and non cutting can be quantitatively analyzed, and the rationality of key parameters of roof cutting can be reflected to a certain extent. In 6302 working face of Baoshan Coal Mine, three hydraulic supports (19#, 69# and 129#) were selected for mine pressure monitoring. Among them, 19 # support was located in the influence area of 110 working method roof cutting, 69 # support was located in the middle unaffected area, and 129 # support was located in the influence area without roof cutting (as shown in Fig. 4).

Fig.4 Distribution of monitoring position of hydraulic support in working face

(a) 19# hydraulic support pressure curve
Fig. 5 Pressure monitoring curve of hydraulic support in 6302 working face of Baoshan Coal Mine

Table 1 Statistics of roof weighting step distance of 6302 working face

|                  | Roof weighting step distance of retaining roadway side | Roof weighting step distance of uncutting side | Roof weighting step distance in the middle of working face |
|------------------|--------------------------------------------------------|-----------------------------------------------|----------------------------------------------------------|
|                  | Initial weighting step /m | Circumferential weighting step /m | Initial weighting step /m | Circumferential weighting step /m | Initial weighting step /m | Circumferential weighting step /m |
|                  | 49                        | 33                           | 41                        | 30                           | 38                          | 18                          |
|                  | 43                        | 29                           | 43                        | 21                           | 38                          | 18                          |
|                  | 46                        | 31                           | 42                        | 25.5                         | 38                          | 18                          |

It can be seen from Figure 5 that the maximum pressure of the support at the side of the main transport crossheading (110 working method area) is 5.5MPa lower than that of the side support of the auxiliary transport crossheading (the influence area without roof cutting), in Baoshan Coal Mine 6302 working face. The average pressure is reduced by 19.38% by 3.8MPa; The maximum pressure is reduced by 12.1 MPa and the average pressure is reduced by 9.4MPa compared with the maximum pressure of the support in the middle of the working face (not affected by roof cutting). It can be seen from Table 1 that the first weighting step and periodic weighting step of the main haulage crossheading side (110 working method area) are increased by 4 m and 5.5 m respectively compared with that of the auxiliary transport crossheading side (the influence area without roof cutting); Compared with the weighting step distance in the middle of the working face, they are increased by 8m and 13m respectively.

From the above analysis, we can see that, the results show that under the influence of pre splitting cutting seam in the working face, the caving height of the direct roof of the working face is large and the block size is small (the coefficient of fragmentation and expansion is large), the filling effect of the goaf is good, and the goaf is usually filled with crushed and expanded gangue, and the space for the rotation of the basic roof is small, and the rotation angle is relatively small Therefore, the rotary deformation is small, so the pressure on the direct roof of gob side entry retaining is also small; However, the basic roof is not easy to fracture and the fracture step distance is increased. With the distance away from the presplitting seam, its influence on the ground pressure is gradually weakened. According to the analysis of the detection data, the influence range of the pre splitting cutting seam in the working face is 30m.
5 Conclusion

1) The analysis results of the stress state of the roof during the mining process of the working face in the shallow buried thin coal seam show that the roof breaking and cutting process is different from the rotary instability collapse of the roof in the medium thick coal seam, which is mainly manifested in the shear sliding instability collapse on the cutting face. Based on this, the key parameters affecting the roof cutting roadway formation of the shallow buried thin coal seam, such as the roof cutting height, roof cutting angle and the distance between the slit holes, are determined.

2) The results of model calculation and analysis show that the top cutting height should meet the requirement that the collapsed overlying strata can completely fill the mined out area, and at the same time, the cutting joint structural plane should deflect a certain angle to the goaf, so as to effectively cut off the stress transfer between the goaf roof and the roof of the retained roadway, so as to realize the cutting of the roof into the roadway.

3) According to the actual engineering conditions of 6302 working face in Baoshan Coal Mine, the roof pre-splitting cutting height is 5 m, the pre-splitting cutting angle is 15° and the distance between cutting holes is 500 mm. And the successful implementation in the actual project has an important reference significance for the popularization and application of automatic roadway forming technology without coal pillar in shallow coal seam mining.

4) By analyzing the working resistance monitoring data of the hydraulic support in the working face, it is concluded that: under the influence of the pre splitting and cutting seam in the working face, the collapsed broken and expanded gangue within the cutting roof can fill the goaf compactly, form an effective supporting structure for the roof of the goaf, reduce the rotary deformation of the basic roof, thus reducing the pressure on the roof of the working face and increasing the weighting step distance. Within the influence range of 30 m of roof cutting, the working support resistance of hydraulic support in working face is reduced by 3.8 MPa, with a decrease rate of 19.38%; The first weighting step increases by 4 m, and the periodic weighting step increases by 5.5 m.

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