

Research and Application of High Efficiency Pressure Relief Technology for Ultra-high Pressure Hydraulic Slotted Coal Seam

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Abstract: In order to solve the technical problem of efficient pressure relief of the impact coal seam, the principle of ultra-high pressure hydraulic slit relief and anti-impact technology is expounded, and the ultra-high pressure hydraulic slit device with working pressure up to 100MPa is selected as the pressure relief equipment of coal seam. The field test of high-efficiency pressure relief by ultra-high pressure hydraulic slotting in impact coal seam was carried out. The test showed that the slotting radius of No.3 coal in Tangkou Mine could reach 1.5m under the condition of 100MPa slotting pressure. The stress variation in seam area and large diameter drilling area is compared and analyzed. The stress in seam area decreases significantly by 40%. The stress of bolt (cable) and the deformation of surrounding rock in the slit area are investigated. Compared with the large-diameter pressure relief area, the increase value of bolt is lower and the increase value of cable is significant in the hydraulic slit test area. The technical benefits of hydraulic slotting and large-diameter drilling are summarized and compared. The engineering quantity of drilling with ultra-high pressure hydraulic slotting is reduced by 60%, and the coal output is 2.5 times of that of large-diameter drilling. The large-diameter drilling provides limited pressure relief space for coal seam, but the ultra-high pressure hydraulic slotting technology can effectively increase the deformation space in the coal body and reduce the elastic energy stored in the coal pillar, so as to achieve a good pressure relief effect. The field test shows that compared with large diameter drilling, ultra-high pressure hydraulic slotting technology has remarkable effects of pressure relief, shock absorption and shock prevention.

Keywords: Ultra high pressure hydraulic slotting; sktrie; pressure relief; kerf radius; large diameter drilling.

1. Introduction

With the deterioration of mining depth and conditions, frequent occurrence of rockburst has become the most concerning mine disaster in China's current society [1-3]. The statistical results show that more than 90% of rockburst accidents occur in coal seam tunnels. Currently, the main coal seam pressure relief technology is large-diameter drilling. Due to the increase in drilling power and volume, large-diameter drilling often leads the implementation of pre pressure relief in the working face. However, during the mining process of the working face, when there is a risk of impact during the monitoring of the advanced support section, it is difficult for the pressure relief drilling rig/drill truck to enter the advanced section for pressure relief in a timely manner. Therefore, there is an urgent need to develop new coal seam pressure relief technologies [4-6]. The coal high-pressure jet drilling and cutting pressure relief technology is a rapidly developing pressure relief method in recent years, mainly used in the fields of coal seam modification and permeability enhancement. During water jet drilling, coal and water are discharged outside the hole through the hole, and the surrounding coal moves towards the direction of the hole. At the same time, the expansion deformation of the coal body and the opposite displacement of the top and bottom plates occur, causing a certain range of stress reduction around the borehole, and transferring high stress to the deep part of the coal body, stabilizing the release of elastic strain energy in the coal rock mass, thereby achieving the effect of local pressure relief of the coal body [7-9]. The author conducted an efficient pressure relief test on coal seams with ultra-high pressure hydraulic cutting in Tangkou Coal Mine, Shandong Province,

to study the pressure relief effect of hydraulic cutting on coal seams, and provide scientific reference for the prevention and control of coal seam rockburst in Tangkou Coal Mine and other similar mines.

2. Overview of the Experimental Area

Shandong Tangkou Coal Industry Co., Ltd. is located in Nanzhang Town, Rencheng District, Jining City, with a production scale of 300 Mt/a. The main mining coal seam is 3 coal seams, with an average inclination angle of 5 ° and an average thickness of 3.1 meters. The mine is divided into 9 mining areas, with the main mining areas currently being the fifth, sixth, and seventh mining areas. The mine is equipped with two mining faces, namely the 5310 fully mechanized caving face and the 6315 fully mechanized caving face. There are 4 driving faces, of which the coal roadway driving faces are 7307 track chutes and 7307 belt chutes. The experimental site is the outer section of the 6315 working face. The roof strata in the experimental area have a weak impact tendency, and the coal seam has a weak impact tendency. The multi factor evaluation of the rock burst risk in the experimental tunnel area is classified as strong impact risk. The firmness coefficient f value of coal seam 3 # in this working face is 1.35, which belongs to coal seams with medium hardness or above. It is feasible to use high-pressure water to cut the coal body. According to the occurrence of the working face, the coal seam is stable, with the outer section being a coalbed area of three coal seams. The coal seam is relatively thick, ranging from 6.0 to 10.0m.

According to the physical and mechanical tests conducted by China University of Mining and Technology on the 3 coal seam of Shandong Tangkou Coal Industry Co., Ltd., the

average uniaxial compressive strength R_C of the 3 coal seam is 13.467 MPa, the average dynamic failure time D_T is 177ms, the average elastic energy index W_{ET} is 3.563, and the average impact energy index K_E test is 4.327. Based on the above identification results, it is determined that the impact tendency category of the 3 coal seam is Class II, that is, weak impact tendency. According to the physical and mechanical tests conducted by China University of Mining and Technology on the roof and floor of the 3rd coal seam of Shandong Tangkou Coal Industry Co., Ltd., it can be concluded that the bending energy index of each layer of the roof of the 3rd coal seam is $U_{WQ}=34.83KJ$, and the impact tendency category is determined to be Class II, which is weak impact tendency. The bending energy index U_{WQ} of the coal floor rock layer is 0.686KJ, and it is determined that the impact tendency category is Class I, which is a non impact tendency floor rock layer.

3. Ultra High Pressure Hydraulic Slotting Pressure Relief and Anti Impact Technology and Equipment

The principle of ultra-high pressure hydraulic slotting pressure relief and erosion prevention technology is to use ultra-high pressure water to cut and peel off the coal body, forming a certain range of groove space inside the coal body. The coal body around the groove space undergoes expansion deformation and forms a large pressure relief area. The large range of broken areas formed in the coal body have a good release effect on the energy accumulated in the coal body, and prevent the accumulation of high energy and the formation of permanent yield deformation in the coal body in this area. This greatly reduces the concentration of stress in the coal body in the slotting area, transfers high stress to the deep part of the coal body, and stably releases the elastic strain energy in the coal body, thereby achieving the effect of local pressure relief in the coal body [10-14]. The influence of cutting on the stress distribution of coal body is shown in Figure 1.

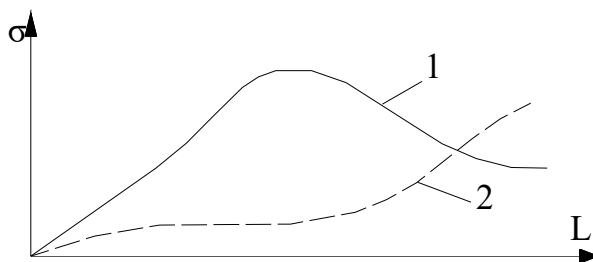


Figure 1. Schematic diagram of the influence of cutting on the stress distribution of coal body

This test uses the ultra-high pressure hydraulic slotting equipment developed by middling coal Technology and Industry Group Chongqing Research Institute, with the working pressure up to 100MPa. It is mainly composed of ultra-high pressure clean water pump, high and low pressure changeover slotting device, ultra-high pressure hydraulic hose, ultra-high pressure rotating water tail, and hydraulic slotting shallow spiral integral drill pipe. It is the only ultra-high pressure product in China that has obtained the certificate of mining safety mark. It has the advantages of convenient operation, safety, reliability, and low failure rate.

The ultra-high pressure hydraulic slotting equipment is shown in Figure 2.

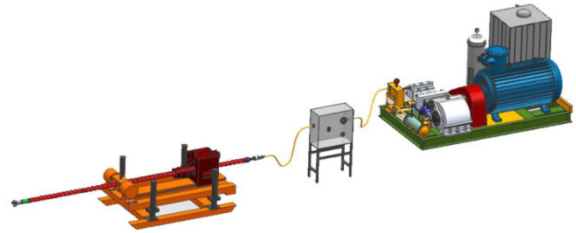


Figure 2. Schematic diagram of ultra-high pressure hydraulic slotting equipment

4. Field Test

A hydraulic slotting pressure relief test was conducted on the solid coal of the outer section of the 6315 working face within a range of 20m~120m from the first connecting roadway along the track of the 6315 working face. 18 slotting boreholes and 48 ordinary large-diameter comparative boreholes were arranged in the test area for comparative analysis of the pressure relief effect. Cutting hole drilling (G1~G18) has an aperture of 113mm, a depth of 25m, and a spacing of 3m (the spacing of the drilling arrangement is adjusted and optimized based on the on-site cutting radius inspection). Cut the gap drilling hole with a spacing of 2m from the bottom of the hole, and cut it until it is 8m away from the hole opening. Each drilling hole is expected to be cut with 8-10 cuts. Large diameter boreholes (D1~D48) have a diameter of 150mm, a depth of 25m, and a spacing of 1m between boreholes. Install stress gauges in the large-diameter drilling test area and the slotting drilling test area, and arrange drilling cuttings for calibration and drilling.

Investigation and analysis of cutting radius

Inspection of cutting radius and selection of complete support area within the roadway, utilizing $\Phi 113mm$ diamond composite drill bit, construction drilling hole K1, construction inspection drilling hole K2 at a distance of 1.0m from K1 drilling hole, and construction inspection drilling hole K3 at a distance of 0.5m from K2 drilling hole. K1, K2, and K3 drilling holes have a depth of 2m and an inclination angle of 2-3 degrees. K2 and K3 are inspection holes. A $\Phi 42mm$ borehole is carried out without hydraulic cutting. K1 is a slotted borehole, and ultra-high pressure hydraulic cutting equipment will be used to cut at a pressure of 100MPa. The water return situation and time of K2 and K3 boreholes will be observed and recorded. The layout of the slotted radius boreholes is shown in Figure 3.

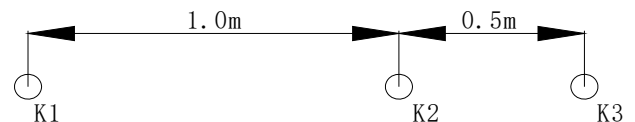


Figure 3. Schematic diagram of drilling layout for inspection of cutting radius

During the on-site construction period, K1 borehole was selected for the cutting radius test, with cutting pressures of 70MPa, 85MPa, and 100MPa, respectively. After cutting, the water outlet time of the borehole was investigated and the statistics are shown in Table 1.

Table 1. Results of investigation on the cutting radius of drilling hole K1

Cutting pressure	Effluent time /min	
	Spacing position 1m	Spacing position 1.5m
70MPa	10	\
85MPa	8	15
100MPa	5	12

According to Table 1, when the cutting pressure is 70MPa and the cutting time is 10 minutes at a distance of 1m from the cutting hole, water will flow out. When the cutting pressure is 85MPa, water is discharged at a distance of 1m from the cutting hole and a cutting time of 5min. Water is discharged at a distance of 1.5m from the cutting hole and a cutting time of 15min. When the cutting pressure is 100MPa, water flows out at a distance of 1m from the cutting hole and a cutting time of 5min. Water flows out at a distance of 1.5m from the cutting hole and a cutting time of 12min. Taking into account the efficiency of joint cutting construction, a joint cutting pressure of 100MPa and a joint cutting radius of 1.5m are selected.

(2) Statistical analysis of cutting and slag discharge volume

By analyzing and measuring the slag discharge situation of 17 constructed slotting test boreholes, as shown in Figure 4.

The number of single hole slitting cutters is 8-9, with a coal output of 4.2-5.8 tons and an average coal output of 0.52-0.77 tons per cutter. Consider the gap formed by cutting as a cylinder, and according to equation (1), calculate and record the radius of the gap formed after cutting under the condition of coal slag amount, which is 1.55-1.88m.

$$M = \pi \times r^2 \times h \times K \times \gamma \quad (1)$$

Where, M is the amount of coal chips discharged after cutting, t; K is the uneven coefficient of coal loss, ranging from 0.8 to 0.95; r is the equivalent radius m of the gap after cutting, m; H is the width of the gap after cutting, m; γ The bulk density of coal, Kg/m³.

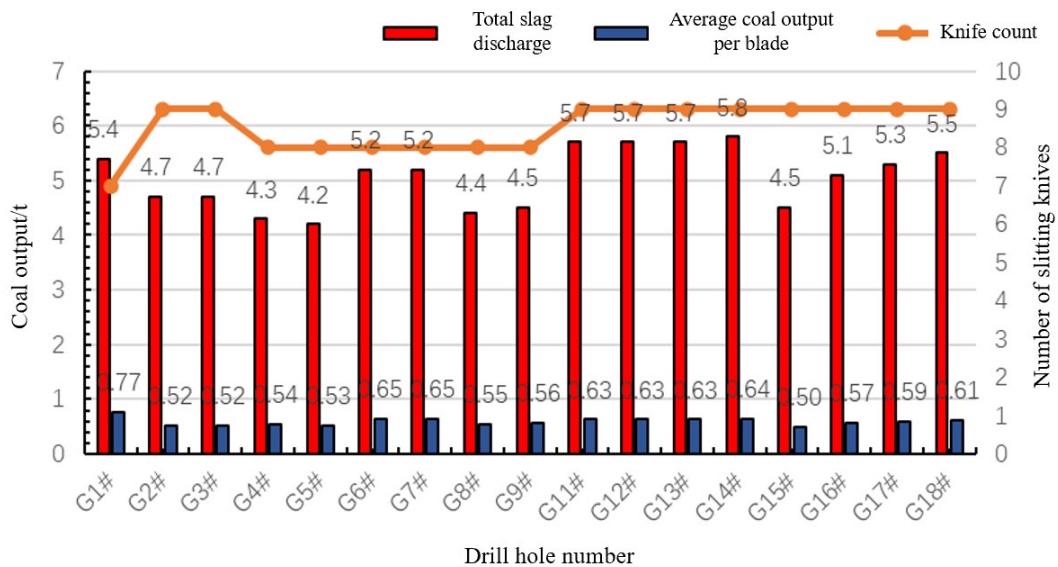


Figure 4. Statistics of slag discharge from slotted drilling

(3) Online monitoring and statistical analysis of stress in the cutting area

Before construction in the experimental area, arrange stress gauges in advance. Preliminary design: Six sets of stress gauges will be arranged in the experimental area to monitor the stress changes during the pre - and post construction processes of slot drilling and large-diameter drilling. Among them, stress gauges 80-82 are located in the slit test area, and stress gauges 83-85 are located in the large-diameter pressure relief area.

In the hydraulic slotting pressure relief test area, stress comparison was conducted before and after the construction of hydraulic slotting. The stress at the deep base points (Channel 1) of the 80-82 groups showed a decreasing trend. Among them, the stress at the deep base points of the 80 and 81 groups decreased significantly, with the maximum amplitude of the decrease being 2.12 MPa and 1.54 MPa, respectively. The stress at the shallow base point (Channel 2) remains stable and shows a slow upward trend, with no

significant changes, with increasing values of 0.55MPa and 0.35MPa, respectively. The 82 stress gauges showed a decrease of 0.33MPa and 0.18MPa at the deep base point (channel 1) and shallow base point (channel 2), respectively. In the large diameter pressure relief comparison area, 83 sets of stress gauges are in a slow pressure reduction process, with stress reduction values of 0.45MPa and 0.53MPa for deep base point (channel 1) and shallow base point (channel 2), respectively. The stress increase in groups 84 to 85 is significant, with stress increase values for deep base point (channel 1) and shallow base point (channel 2) being 2.11MPa and 0.15MPa, respectively. The stress increase values of 85 deep base points (channel 1) and shallow base points (channel 2) are 0.16MPa and 2.9MPa, respectively, and the amplitude of each stress increase and decrease is shown in Figure 5. Through the above comparative analysis, it can be seen that after adopting ultra-high pressure hydraulic cutting measures, the stress in the large diameter test area significantly decreases, and the internal pressure relief effect

of the coal body is good, and the influence on the stress of the coal body near the tunnel edge is relatively small.

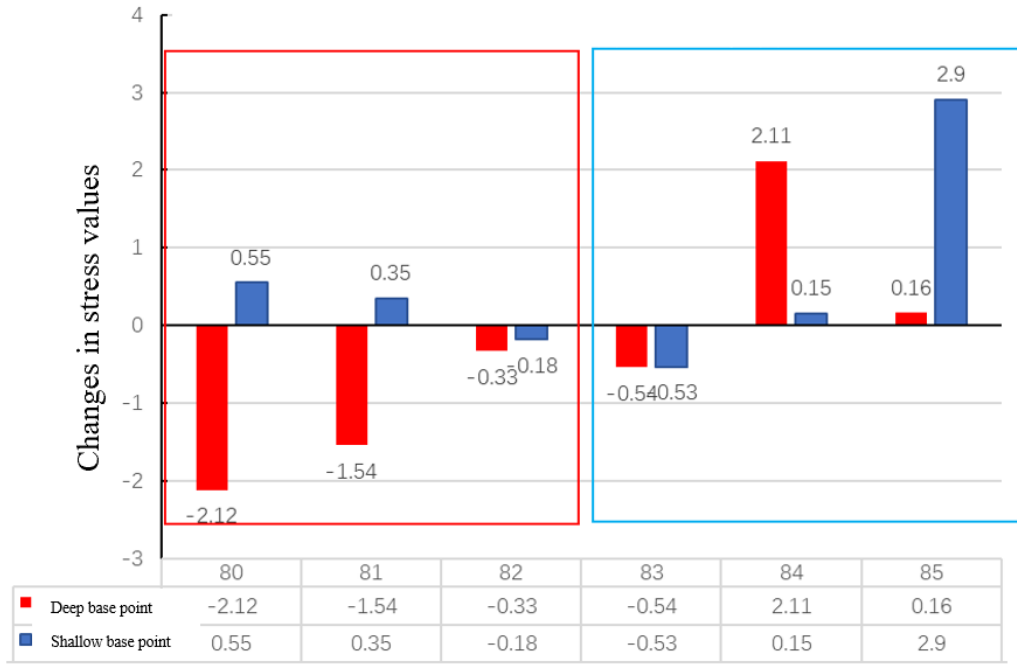


Figure 5. Amplitude of stress increase and decrease in each group

(4) Analysis of stress and surrounding rock deformation of anchor rods (cables) in the cutting area

In the hydraulic slotting test area, the tensile stress value of anchor rod 1 increased from 26KN to 34KN, the tensile stress value of anchor cable 2 increased from 94KN to 144KN, the tensile stress value of anchor rod 3 increased from 53KN to 67KN, and the tensile stress value of anchor cable 4 increased from 134KN to 141KN. The difference in stress values is shown in Figure 6. The hydraulic slotting test area has a lower anchor rod amplification value compared to the large-diameter pressure relief area, while the anchor cable amplification value is significant. By monitoring the lateral displacement meters at stations A and C, the observed data remained constant at 0, indicating that the roadway walls in each experimental area were not deformed. According to the analysis of stress increase and decrease amplitudes in the

experimental area of Figure 6, as the construction section inside the hydraulic slotting hole is 8-25m, it can be reflected that after taking slotting measures, the internal stress of the coal body in the slotting area decreases significantly. Due to the close distance between the shallow base point of the stress gauge and the depth of the anchor cable to the cutting position, the stress data showed a slight increase in the hydraulic cutting test area. However, the increase in stress of anchor bolts in the hydraulic slotting test area is lower than that in the large-diameter pressure relief area. Based on comprehensive analysis, there is a significant decrease in the stress of the coal body in the cut seam area. In addition, under the influence of the cut seam, there is a trend of stress transfer to the tunnel edge (0-8m), but the stress amplification value is relatively low, which has a lower impact on the deformation of the tunnel surrounding rock and the support of the edge.

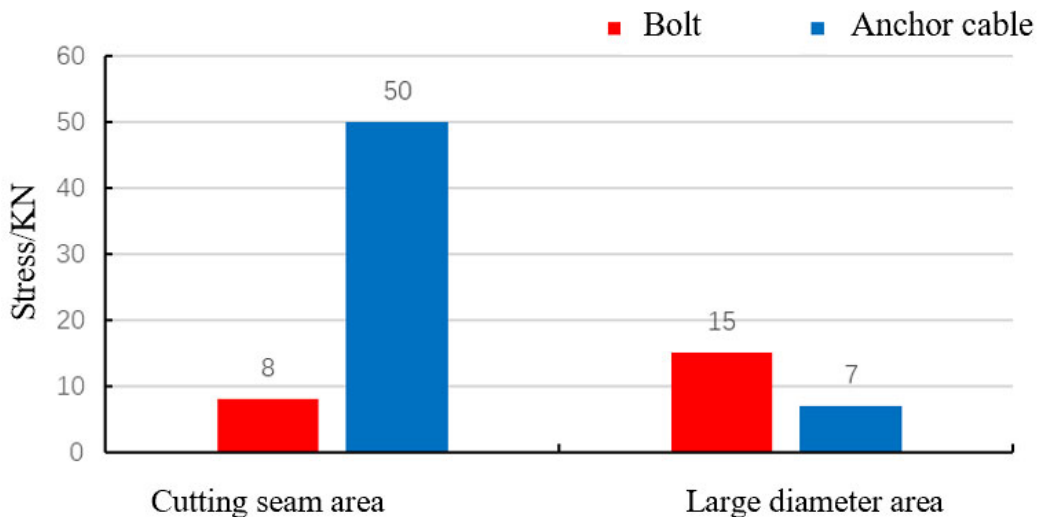


Figure 6. Stress amplification values of anchor cables in each experimental area.

5. Technical Benefit Analysis

(1) Comparison of coal output

The hydraulic slotting test area of the Tangkou coal mine track has a drilling diameter of 113mm and a drilling spacing of 3m. There are 17 slotting boreholes, and a total of 85.9t of coal has been cut. In the large-diameter drilling test area, with a diameter of 150mm and a spacing of 1m, 48 boreholes were drilled, and the coal output was 31.87 tons. From the above, it can be seen that using ultra-high pressure hydraulic slotting drilling reduces the engineering quantity by 60%, and the coal output is 2.5 times that of large-diameter drilling.

(2) Comparison of coal pressure relief effects

According to the current situation of large-diameter drilling construction by the mining party, the use of large-diameter drilling to weaken and relieve pressure on the coal body has a poor effect. Compared to the entire coal seam area, although the diameter of the drill bit is increased to 150mm by using large-diameter drilling, the pressure relief space provided for the coal seam is limited. Using ultra-high pressure hydraulic cutting technology to cut the coal body, a flat groove is formed inside the coal body. The radius of the cutting groove is about 1-1.5m, and the coal output from the cutting groove is increased by 2.5 times in diameter drilling. Greatly increases the deformation space inside the coal body, reduces the elastic energy stored in the coal pillar, and thus achieves a good pressure relief effect. On the basis of static pressure relief, it can effectively filter out underground vibration and achieve dynamic damping effect. And through precise control technology of slitting, it is possible to achieve uniform pressure relief of the coal body as a whole. In addition, after hydraulic cutting, the water content of the coal seam around the drilling hole significantly increases, which plays an auxiliary role in weakening and preventing coal seam erosion.

(3) Comparison of impact on lane support

The construction of large diameter dense boreholes (with a diameter of 150mm and local area construction densification, with a spacing of about 1000mm) also poses certain safety hazards due to the fragmentation of the anchoring section of the coal wall caused by the dense drilling construction, which affects the integrity of the coal wall and reduces the resistance of the roadway. By using ultra-high pressure hydraulic slotting technology, the drilling diameter is reduced (drilling directly 113mm), the drilling spacing is significantly increased (drilling spacing is 2m~3m), and during the slotting process, the coal wall is not cut within a range of 8m to avoid damage to the overall integrity of the coal wall, effectively ensuring the strength of coal wall support. And the use of hydraulic slotting technology can strengthen the pressure relief within the range of 8-25m inside the coal body, increase the coal output through drilling slotting, further increase the pressure relief space, and improve the pressure relief and shock absorption effect.

6. Conclusion

(1) Using ultra-high pressure water to cut and peel off coal, a certain range of groove space is formed inside the coal body. The coal body around the groove space undergoes expansion and deformation, forming a large pressure relief area. The large range of fractured areas formed in the coal body have a good release effect on the energy accumulated in the coal body, and prevent the accumulation of high energy and permanent yield deformation in the coal body in this area.

This greatly reduces the stress concentration of the coal body in the cutting area, and high stress transfers to the deep part of the coal body, stably releasing the elastic strain energy in the coal body, thereby achieving the effect of local pressure relief of the coal body.

(2) For coal seam 3 in Tangkou Coal Mine, the cutting radius can reach 1.5m under the condition of 100MPa, and the corresponding cutting time is 12 minutes. By calculating the amount of coal produced through cutting, the cutting radius is calculated to be 1.55-1.88m, which is consistent with the actual investigation.

(3) Through on-site experiments, it has been shown that after adopting ultra-high pressure hydraulic cutting, while increasing the spacing between boreholes and reducing the amount of drilling work, the amount of coal slag discharged is 2.5 times that of large-diameter boreholes. Through stress analysis in the experimental area, it was found that there was a significant decrease in stress in the slit area, with a stress reduction of up to 40%. In addition, for the analysis of the deformation of anchor rods (cables) and surrounding rock in the experimental area, after adopting hydraulic cutting measures, the deformation of the surrounding rock in the tunnel remains constant. This not only solves the problem of rapid pressure relief inside the coal seam, but also does not affect the stability of the tunnel support.

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