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Application of Curtain Grouting Technology in Soft Coal Seam

Fan Zhang
School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo Henan 454003, China

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Abstract

In order to solve the problems of serious air leakage and easy hole collapse in the process of gas extraction from bedding boreholes in soft coal seams under deep mining conditions, an advanced curtain grouting method for pre-blocking cracks and pre-reinforcement of soft coal bodies was proposed and applied in the field. In this paper, the 38021 working face of Xinzhuang Coal Mine is taken as the engineering background, and the thickness of curtain grouting is determined by drilling cuttings method. The vertical strip grouting curtain body is constructed by the arrangement of oblique plum-shaped grouting holes and the grouting method of low pressure and slow permeability, so as to realize coal body strengthening and efficient sealing of fracture network. The application results show that the initial extraction concentration of borehole gas is increased by 30 %, the attenuation rate of extraction efficiency is reduced to less than 15 %, and the effective extraction time of borehole is extended to 3 months.

Keywords

Gas Extraction; Curtain Grouting; Drilling Cuttings Method; Gas Concentration

1. Introduction

With the continuous increase of mining depth, deep coal seams are generally faced with the complex geological environment of " three high and one low, " and the gas disaster is becoming more and more serious, which poses a major threat to coal mine safety production[1]. At present, borehole extraction is still the main means of gas control in coal mines, and its effect directly depends on the stability of boreholes[2]. Especially in deep soft coal seams, boreholes and surrounding coal bodies are more prone to deformation and failure, resulting in a significant reduction in extraction efficiency.

Aiming at the problem of borehole stability, many scholars have carried out in-depth research. Wang et al[3] established a mechanical model for the instability of outburst prevention boreholes, and revealed the failure mechanism and instability characteristics of coal and rock mass at the bottom and wall of the hole through

theoretical analysis. Based on the elastic-plastic theory, Guo et al[4]divided the coal body around the hole into four areas : stress reduction area, post-peak stress increase area, pre-peak stress increase area and original rock stress area. It is pointed out that the stress reduction area and the peak area are prone to collapse and bury drilling during the drilling process. Wang et al[5] established a mechanical model of borehole wall protection based on elastic-plastic surrounding rock-support theory, and analyzed the stress and deformation law of coal body around borehole under different internal pressure conditions by numerical simulation. Zhang Feiyan et al[6]studied the distribution characteristics of stress and displacement around the borehole based on the mechanical model of borehole, and pointed out that shear failure is the main form of borehole failure. The borehole wall is dominated by V-shaped failure and local tensile failure, while the deep coal body is common. Conjugate X-shaped shear failure. Zhang Xuebo[7] studied and analyzed the influence of buried depth on the stability of boreholes, and summarized the change trend of vertical displacement and stress of boreholes with different lateral pressure coefficients. Wu[8] modified Hoek-Brown criterion by reasonably incorporating the influence of intermediate principal stress, which significantly improved the accuracy and engineering applicability of borehole stability prediction.

In terms of borehole instability control, Pei [9] took the 90107 working face of Majunyu Coal Mine as the background. Aiming at the problem of poor stability and easy collapse of surrounding rock in the sealing section of soft coal borehole, the range of plastic zone and stress distribution were studied. The numerical simulation shows that increasing the support force can significantly reduce the radius of plastic zone and enhance its stability. Based on this, it is proposed to use the bag grouting sealing technology to suppress the deformation of the borehole through grouting to ensure the concentration of gas extraction. Through simulation and experiment, Pei Xiaoxiao[10] confirmed that hole collapse and plugging will seriously reduce the effect of gas extraction, and showed that the whole section screen hole protection technology can significantly improve the extraction performance. Cai[11] effectively solved the technical problems of coal crushing, hole collapse and difficult lowering of sieve tube after hydraulic punching by improving the integrated process of drilling-punching-hole protection. Wang Zhenfeng[12] developed a collection and transportation flower pipe structure suitable for gas extraction in soft coal seams to ensure the smooth flow of gas migration channels for the problem of easy blockage and damage of reserved flower pipes.

Therefore, based on the above research results and combined with the coal seam occurrence conditions of Xinzhuang Coal Mine, a method of advanced curtain grouting for coal wall is proposed.

2. Engineering background *e*

Xinzhuang Coal Mine is located in Miaoqiao Township, east of Yongcheng City,

Henan Province, at the junction of Henan and Anhui provinces. It belongs to a coal and gas outburst mine. The current approved production capacity of the mine is 1.8 million tons / year, and the main coal seams are No.22 and No.32 coal seams. The gas control measures mainly use underground drilling gas extraction. However, the strong coupling effect of high ground stress and high gas pressure makes the traditional borehole construction of underground bedding gas extraction encounter severe challenges, which are mainly manifested as two major technical bottlenecks :

1.Hole collapse accidents occur frequently, and the hole-forming rate is low : the soft coal body itself has low strength and poor self-stability. After the new free surface is formed in the drilling construction, under the joint drive of high confining pressure and gas pressure, the coal body around the hole quickly enters the plastic rheological state, and continuous radial deformation (shrinkage) and spalling instability occur. The field practice shows that the hole forming rate is generally less than 60 %, and a large number of boreholes are seriously deformed or completely blocked in a short time after the hole is formed, resulting in a very short effective service period of the borehole and a large number of invalid repetitions of the extraction project.

2.The phenomenon of air leakage and channeling is serious, and the extraction efficiency decays extremely fast : Affected by mining activities, the phenomenon of air leakage in the broken area of roadway coal wall is serious, and the broken soft coal structure is easy to form complex hidden fracture network channels in the dense hole area in the high ground stress shear area. Under the induction of extraction negative pressure, these channels become the highway of gas ' short circuit ' flow, resulting in serious gas channeling between adjacent boreholes (i.e., string holes). The measured data of Xinzhuang Coal Mine shows that the string hole rate is as high as 35 % -40 %. This mutual channeling not only seriously dilutes the gas concentration of the target borehole, but also greatly reduces the proportion of effective extraction gas, and destroys the uniform distribution of the extraction negative pressure field, resulting in a systematic attenuation of the efficiency of the entire extraction area, and the measured attenuation rate exceeds 50 %.

Therefore, seeking a technology that can systematically solve the contradiction between borehole stability and efficient gas extraction in deep soft coal seams has become the key to the urgent breakthrough in Xinzhuang Coal Mine and even the whole deep coal mining field. The proposal and application of curtain grouting technology is based on the deep understanding and systematic solution of this core pain point.

3. Principle of curtain grouting

When the roadway is excavated, the original stress state of the rock is destroyed, and the surrounding stress is redistributed. From the two sides of the roadway to the original rock stress area of the surrounding rock, three areas of pressure relief

zone, stress rise zone and original stress zone will be formed. The coal body in the pressure relief zone produces plastic failure after experiencing the transfer of the stress peak and forms a large number of cracks. Therefore, the most serious air leakage of borehole gas drainage often occurs in the pressure relief zone.

The core idea of curtain grouting technology is to carry out large-area grouting on the coal body in the broken area of roadway before gas extraction, and to construct a regional and continuous low permeability barrier- ' curtain body '. The curtain body is formed in the periphery of the target area (such as the strip of planned intensive construction extraction boreholes). It aims to transform the physical and mechanical properties of coal and rock mass and gas seepage characteristics from the macro scale to achieve dual goals :

1.Strengthening and stabilization of coal :

Mechanical reinforcement : The slurry (cement-based materials with good controllability) is effectively injected into the pores, primary and secondary fracture networks in the coal body under pressure. After the slurry is solidified, the consolidation body is implanted with numerous ' micro-bone beams ' and ' bonding bonds ' in the broken coal body, which significantly improves the cohesion C and internal friction angle φ of the coal body, that is, the overall strength and residual strength of the coal body are improved.

Inhibition of rheology and shrinkage : The ability of the strengthened coal to resist plastic deformation and creep caused by high ground stress is significantly enhanced. The coal body of the borehole wall is transformed from the state of ' easy rheological instability ' to the state of ' elastic-plastic stability ', which effectively curbs the occurrence of borehole shrinkage and spalling collapse, and provides mechanical guarantee for the long-term stable service of the borehole.

2.Efficient sealing of fracture network and reconstruction of seepage field :

Main channel plugging : The core goal of curtain grouting is to effectively plug the main hidden fracture channels connecting adjacent boreholes. By optimizing the matching between the particle size of the slurry material and the fracture, controlling the grouting pressure and flow rate, it is ensured that the slurry preferentially enters and fills the medium and large-scale fractures with strong conductivity and easy to cause holes.

Seepage field optimization : The curtain body changes the local seepage field of the coal seam. In the protection area of the curtain, the negative pressure of the extraction can act more effectively on the target coal body, promote the gas to flow along the designed direction (to the extraction borehole), inhibit the lateral and ineffective mutual flow, and optimize the gas migration path.

4. Laboratory Experiments

4.1. Sensor Calibration

According to the principle of curtain grouting, in order to achieve the ideal grouting

effect, it is necessary to divide the range of pressure relief zone, stress rise zone and original rock stress zone formed after roadway excavation. For this reason, the drilling cuttings method is carried out in 38021 working face.

Drilling arrangement

A total of 5 sampling boreholes were arranged in the test section, and the borehole numbers were 1 #, 2 #, 3 #, 4 # and 5 # respectively. In the sampling process, a coal electric drill is used to drill a borehole with a diameter of 42 mm perpendicular to the coal wall. The distance between the sampling borehole and the floor is 1.5 m, the hole spacing is 6 m, and the hole depth is 40 m. The arrangement of sampling boreholes is shown in Fig.1.

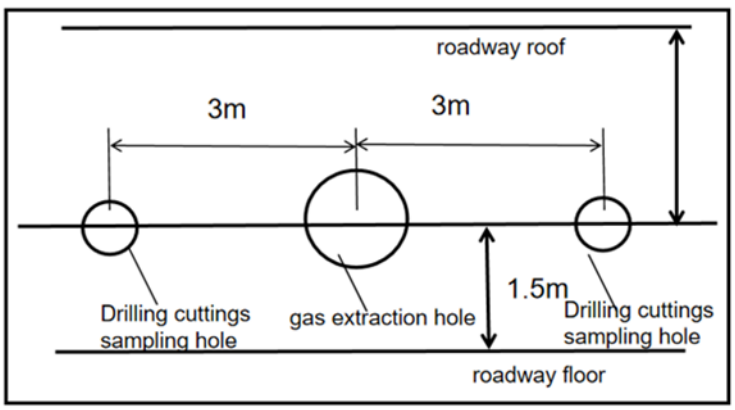

Figure 1. Sampling borehole layout diagram

The amount of drilling cuttings produced by 1 #, 2 #, 3 #, 4 # and 5 # boreholes per 1m is counted, and then the statistical data is processed by Origin. The curve of the amount of drilling cuttings with the depth of the borehole can be obtained, as shown in Figure 2.

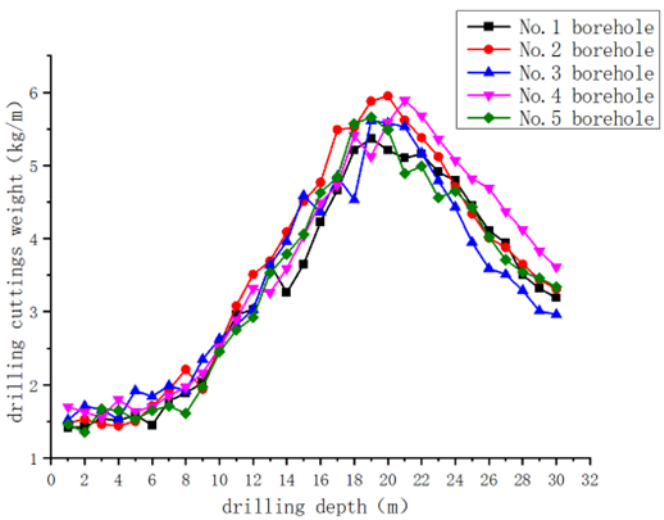

Figure 2. Variation curve of drilling cuttings and drilling depth

It can be seen from the above figure that when the drilling depth is 1m ~ 8m, the rate of increase in the amount of drilling cuttings is relatively slow. The amount of

drilling cuttings changes little in this interval and basically tends to be stable. This is because the area is distributed in the pressure relief area of the two sides of the roadway. The strength of the coal and rock mass in the pressure relief area is low, and the shear fracture will occur under the action of stress concentration, so that the coal and rock mass is relieved, and the amount of drilling cuttings generated when drilling inward is relatively small. When the borehole is drilled from 8m to 20m, the rate of increase in the amount of drilling cuttings is suddenly accelerated, and reaches a peak at 20m.This is because the borehole enters the stress concentration area, and the compressive strength of the coal and rock mass in this area is greater than the stress concentration value, and reaches the equilibrium state under the action of stress. The amount of drilling cuttings began to decrease slowly from 20m to 30m, but the minimum amount of drilling cuttings was still greater than the amount of drilling cuttings of 1m ~ 8m, indicating that as the concentrated stress continues to transfer to the inside, it will reach the original rock stress area, and the stress value in the original rock stress area is less than the stress value in the concentrated area and greater than the stress value in the pressure relief area. Therefore, the amount of drilling cuttings produced by drilling in this area will decrease but still greater than the amount of drilling cuttings in the pressure relief area. Therefore, the range of curtain grouting should cover the range of pressure relief area, and the depth of curtain grouting should be set to 10 meters in order to ensure the extraction effect.

4.2. Experimental site and construction method

In order to verify the feasibility of this method, the advanced extraction section of the return airway of 38021 working face, which is difficult to extract gas and has extremely serious hole collapse, is selected as the curtain grouting test area. The main mining coal seam of the working face is No.32 coal seam, the buried depth is 635 ~ 680 m, and the coal seam firmness coefficient f value is 0.47 ~ 0.74, which is a typical soft coal seam.

In order to ensure that the grouting slurry diffuses evenly in the soft and broken area of the coal wall and effectively seals the cracks, the inclined plum-shaped grouting hole arrangement is adopted on site. The arrangement can significantly improve the uniformity of slurry coverage and the integrity of curtain body, and enhance the bonding and sealing effect of loose coal body. The specific construction process is as follows :

(1) φ94mm drill hole with 15°-20° elevation angle oblique drilling, drilling depth of 10m, φ153mm drill hole 2m ; on the plane, it is arranged in a plum blossom shape, and the hole spacing is 6m, forming a three-dimensional cross grouting network.

(2) Flush the slag out of the hole, pull out the drill pipe, and put down a 2m long 127φ casing. The 1.5m position on the lower side of the casing and the 0.3m position on the upper side of the casing are respectively wrapped with cotton wire

rope, and a grouting hose is connected in the middle (for grouting between the casing and the hole wall). Put the casing into the hole, and then use the grouting machine to grout between the outer wall of the casing and the hole wall for fixing the casing.

(3) After grouting, wait for the cement to solidify (after one sub-compartment). Connect the casing with a 127φ stuffy head (there is a 19φ grouting port outside the stuffy head), and use the hydraulic grouting machine to grout the casing at the outlet of the stuffy head until the grouting pressure is stable at 1Mpa-1.2Mpa.At the end of the grouting, the orifice is closed, and the cement setting time is not less than one sub-compartment. After the cement slurry is solidified, the stuffy head is unloaded, and the coal seam is drilled in the 127φ casing.

4.3. Borehole gas extraction concentration and comparison

In order to verify the engineering effect of curtain grouting, the initial gas extraction concentration of 100 boreholes in curtain grouting area and non-grouting area was counted respectively, and the histogram shown in Fig.3 was drawn. In addition, the boreholes with higher initial gas drainage concentration were selected from the two groups of regions, and the gas concentration monitoring was carried out for a period of three months. Finally, a line chart of gas concentration changing with time was drawn, as shown in Figure 4.

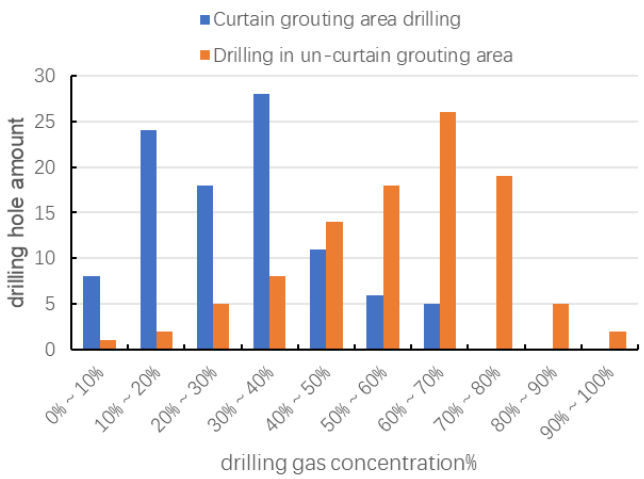

Figure 3. Gas drilling hole concentration distribution map

It can be seen from the figure that the initial gas extraction borehole concentration in the curtain grouting area is mostly concentrated between 50 % and 80 %, and the number of boreholes with a concentration between 60 % and 70 % accounts for the largest proportion. The initial gas drainage borehole concentration in the area without curtain grouting is mostly concentrated between 20 % and 50 %, and the number of boreholes with concentration between 30 % and 40 % accounts for the largest proportion. This is because a large area of pre-grouting can effectively block

the cracks in the broken area of the roadway and reduce the amount of air leakage in the roadway.

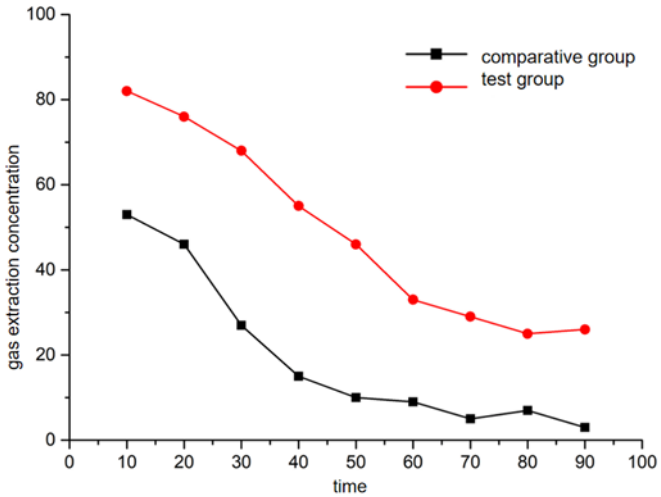

Figure 4. Gas concentration line chart

It can be seen from the figure analysis that in the three-month gas extraction monitoring, the concentration of gas extraction boreholes after curtain grouting is always above the concentration of gas extraction boreholes after curtain grouting, and the gas attenuation rate is relatively gentle, which can still reach about 30 % in the later stage of extraction. It is said that the large area of pre-grouting in advance not only blocks the fracture to reduce the air leakage, but also strengthens the coal structure, reduces the damage degree of various in-situ stress disturbances to the borehole during the extraction period, and prolongs the effective extraction time of the borehole.

5. Conclusions

(1) The determination method of curtain grouting range based on drilling cuttings method is effective and feasible. Through the variation characteristics of drilling cuttings with drilling depth, the pressure relief zone (1-8m), stress concentration zone (8-20m) and original rock stress zone (20-30m) of roadway surrounding rock are accurately divided. In order to ensure that the pressure relief zone with the most serious fracture development is completely blocked and the safety margin is taken into account, the curtain grouting depth is determined to be 10 meters, which provides a scientific basis for forming an effective regional seepage barrier.

(2) The oblique plum-shaped grouting hole and supporting technology have successfully constructed an efficient sealing curtain. A continuous and uniform vertical strip grouting curtain body was formed by using a 15 ° -20 ° elevation angle, a 10-meter hole depth, and a 6-meter spacing oblique plum-shaped hole arrangement method, combined with the 'casing wall + segmented grouting ' process. The curtain body significantly strengthens the mechanical strength of the coal body, efficiently seals the primary and mining-induced cracks, and solves the problem of

dilution of the extraction concentration caused by coal crushing and air leakage from the source.

(3) Curtain grouting technology significantly improves the gas extraction effect and borehole stability. The field application results show that the technology greatly improves the initial gas extraction concentration of the borehole, and the main body of concentration distribution increases from 20 % -50 % in the non-grouting area to 50 % -80 % in the grouting area. At the same time, the attenuation rate of extraction concentration is effectively controlled, the attenuation rate is reduced to less than 15 %, and the effective extraction period of borehole is extended to 3 months, which proves its continuous effectiveness in ensuring the long-term stability of borehole and maintaining efficient extraction.

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