Research on “Three Sealing and One Grouting” Sealing Technology

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Abstract. Taking the 3314 transportation roadway of Wangpo Coal Mine as the research background, the stress and strain characteristics of the roadway after support were studied by FLAC3D numerical simulation. It is determined that the reasonable sealing depth is not less than 15m, and then the “three sealing and one grouting” sealing technique is proposed on the basis of the "two sealing and one grouting" methods, and the two sealing methods are compared and analyzed. The results show that the total average gas concentration and the maximum average gas concentration of the "three sealing and one grouting" sealing technique are 9.5% and 16.5% higher than the "two sealing and one grouting" respectively, and the gas concentration of the borehole after 70 days of drainage is still up to 40%. The "three sealing and one grouting" sealing technique can effectively improve the efficiency of gas drainage.

1. Introduction
The sealing technology is an important part of the mine gas drainage project and a key factor affecting the gas drainage effect[1-2]. Gas drainage effect is closely related to sealing quality[3-5]. At present, most coal mines adopt the method of “two sealing and one grouting”. In the absence of specific analysis for differences in geological conditions, the sealing depth and the length of the sealing section are mostly determined by empirical methods[6]. The disadvantage of adopting the empirical method is that if the sealing depth and the length of the sealing section do not cover the fissure development area, it will cause air leakage and reduce the concentration of drainage, reduce the drainage efficiency, and even cause gas hazard.

Therefore, it is important to study the development range of cracks in surrounding rock of mining boreholes for sealing technology and gas drainage[7-8]. To this end, the “three sealing and one grouting” sealing technology based on the sealing depth is carried out to provide guidance for the drainage under similar gas geological conditions.

2. Test area overview
The production scale of Wangpo Coal Mine is 3.0Mt/a, and No. 3 coal seam is mined. The average coal thickness is 5.76m, which belongs to high gas mine. The test site is located at the 3314 working face transportation lane of Wangpo Coal Mine. The roadway is a rectangular with a thickness of about 2.4 m bottom coal. The test site is located at the 3314 working face transportation roadway of Wangpo Coal Mine. The roadway is a rectangular coal roadway with a section size of 5500 × 3400 mm. The
top coal is driving along the top and the thickness of the bottom coal is about 2.4m. The raw coal gas content is 15.35 m$^3$/t, and the coal seam hardness $f$ value is 0.75.

At present, the "two sealing and one grouting" sealing method is used in sealing. In the actual sealing, it is found that the gas drainage concentration is low, the sealing hole has air leakage phenomenon, and the drainage effect cannot meet the demand for gas treatment. During the construction of the 3314 working face layered pre-drainage hole, it was found that it was easy to collapse the hole at the depth of 7~9m, and it was difficult to drill holes. In order to improve the drainage effect, it is necessary to determine the drilling sealing depth and improve the existing sealing technology.

3. "Three sealing and one grouting" sealing principle
The original "two sealing and one grouting" method is used to seal the holes, that is, the two ends of the sealing section are sealed with high-efficiency sealing bags, and the middle section is injected with high-efficiency expansion sealing agent to form a bet.

As shown in figure 1. The total sealing depth is 12m, the effective sealing length is 10m, and the grouting section is 8m.

![Figure 1](#)

Figure 1. "Two sealing and one grouting" sealing diagram

Considering the reason for the leakage of the borehole, it may be that the sealing depth does not exceed the fissure development zone and does not play the role of sealing closed borehole. Therefore, the stress damage state of the borehole is analyzed by numerical simulation method to determine its reasonable sealing depth.

The orifice section of borehole is located in the natural discharge zone of the coal seam gas in the roadway, and the coal body crack develops. If the sealing started from the orifice, and the orifice section is easily leaked, and the length of the sealing section is shortened. In order to improve the sealing effect and control the sealing cost, the original "two sealing and one grouting" sealing section can be transferred to the deep part of the borehole without increasing the length of the sealing grouting section. At this time, the orifice section is in a natural discharge state. Due to the large number of boreholes in the roadway, the natural discharge of multiple borehole sections is likely to cause the gas concentration of the roadway to exceed the limited. To this end, a sealant is added as a third sealing at the orifice (No grouting), formed into a "three sealing and one grouting" sealing technology.

The sealing section is divided into two parts, the inner part and the outer part, by three times of sealing, and the outer end is not grouted, and only one grouting is performed in the deep section of the pressure relief belt or deep section within the natural discharge width. As shown in figure 2: from the deep part of the hole to the orifice, 1 sealing, 1 grouting, 2 sealing, 3 sealing, of which 1 sealing, 1 grouting and 2 sealing form an effective sealing section. No grouting is carried out between the 2 sealing and the 3 sealing. The 3 sealing are only used to prevent the gas in the roadway to exceed the limited that the gas in the hole section from bursting out in a short period of time.
4. Determination of reasonable sealing depth

According to the actual situation of the 3314 transportation roadway of Wangpo Coal Mine, the roadway model was established by using the numerical simulation software FLAC3D, and the results were processed by Tecplot.

(1) Stress results

Figure 3 shows the vertical stress distribution characteristics after roadway excavation and support. The stresses at the top, bottom and roadway gang near the coal wall are small. After the surrounding rock is crushed and crushed, the bearing strength of the surrounding rock is reduced, and the surrounding rock stress is transferred to the deep part to form a pressure relief zone, which is in accordance with the principle of surrounding rock self-stability[9].

The area with the largest stress is about 3.5 m away from the coal wall, and the stress concentration area is within 3~14 m from the coal wall. This area is easy to cause deformation and damage of the borehole, thus affecting the drainage effect.

(2) Displacement results

Figure 4 shows the horizontal displacement characteristics along the horizontal line of the lane center on the roadway section. The horizontal displacement decreases sharply from 0 to 3 m from the roadway gang, from the maximum of 45.9 mm to less than 5 mm, and gradually drift toward zero as it moves away from the coal wall.

(3) Distribution characteristics of plastic zone

Figure 5 shows the damage extent and damage properties of the surrounding rock of the roadway. The roadway is in a plastic failure state within 0~3.5 m, and the coal seam in the range of 0~2.0 m at the top of the roadway is in plastic failure state, and plastic yielding and elastic recovery occur in the middle part of the top. The bottom of the roadway is mainly an elastic recovery zone in the yielding state, and the bottom coal body of about 0~1 m has tensile failure.
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Figure 4. Horizontal displacement along the horizontal line of the lane center-line

Figure 5. Distribution characteristics of plastic zone of surrounding rock in roadway

In summary, due to the stress field, the coal body is about 0~3.5 m away from the coal wall under pressure and fracture, and the crack increases, and the stress is transferred to the deep part to form a pressure relief ring. Here, the grouting and sealing is easy to leak and the air leakage is serious, and the effective sealing section should exceed the area to improve the sealing effect.

Within 3~14m from the coal wall, it is a stress concentration area. The borehole in this range is prone to deformation and damage, and cracks are formed. Therefore, the drilling sealing depth should be at least 14m to ensure the passage through the fracture development area and block the air leakage passage. Taking into account the redundancy of the disturbance effect, the reasonable sealing depth of the 3314 transport roadway was chosen to be 15 m away from the sill.

According to the results of simulation analysis, considering the serious leakage of surrounding rock within 3.5 m from the coal wall and the influence of secondary cracks, the distance of the sealing section from the orifice is optimized to 5 m, and the effective sealing section length is 10m.

5. Comparative test and effect analysis

5.1. Test comparison scheme

At present, the sealing material of Wangpo Coal Mine adopts Anerte sealing agent, and the comparative test is divided into two groups, A and B. The sealing method of “two sealing and one grouting” and “three sealing and one grouting” are respectively adopted. details as follows:

Group A: The “two sealing and one grouting” sealing method is adopted, the total sealing depth is 12m, the effective sealing length is 10m, the grouting section is 8m, and the sealing is 10 pieces.

Group B: adopting “three sealing and one grouting” sealing method, the total sealing length is not less than 15m, the effective sealing length is 10m, the grouting section is 8m, and the sealing is 10 pieces.
Drilling requirements: The interval between the two groups is 5 m. The distance between the holes in the same group is 2.5 m, the depth of the single hole is more than 60 m, and the slag discharge in the hole is sufficient. An orifice flow meter is installed after each hole is sealed.

5.2. Analysis of test results
The drilling was carried out according to the test plan. After the sealing, the pumping was started. The concentration and flow rate of each hole were investigated every day, and the cumulative inspection time was about 10 weeks. The trend of the gas concentration of the drilling and extraction in the two processes with time is shown in figure 6 and 7.

Figure 6. Gas concentration changes with time Figure 7. Comparison of gas concentration of the two sets of sealing technology

Figure 8. Comparison of the average cumulative scalar amount of 100 m hole in A and B groups
(1) Time-effect comparison: as can be seen from figure 6, the average concentration of boreholes in group A is about 55% within 42 days; the average concentration of boreholes is about 41% in 42-76 days. Within 39 days, the average concentration of boreholes in group B was approximately 61%; in 42-73 days, the average concentration of boreholes was approximately 44%. When the "three sealing and one grouting" sealing technology is adopted, not only the extraction concentration is high, but also the drainage durability is good.

(2) Comparison of gas concentration: from figure 6 and 7, the total average concentration of borehole in group A and B are 51.57% and 56.04%, the maximum average gas concentration of borehole are 68.18% and 79.42%. The total average gas concentration and the maximum average gas concentration of group B are 9.5% and 16.5% higher than those of group A, respectively. Therefore, the "three sealing and one grouting" sealing technology has a better drainage effect.

(3) Comparison of cumulative scalar quantity of drainage: figure 8 shows that the average cumulative scalar volume of the previous Group B boreholes has not been as high as that of the Group
A boreholes. However, after 16 days of drainage, the average cumulative volatility of the Group B pores exceeds that of the Group A boreholes, and the advantages gradually increase with time. This shows that the "three sealing and one grouting" sealing technology can increase the amount of gas drainage and improve the gas drainage effect.

6. Summary
(1) The numerical simulation method is used to analyze the stress and strain characteristics of the surrounding rock after roadway support. The coal body crushing area is within 3.5m from the coal wall. The length of the drilling grouting must be greater than the length of the area in the direction of the drilling to ensure that the sealing slurry is effective.

(2) Within 3~14 m from the coal wall, it is a stress concentration area. In order to ensure that the sealing length can pass through the entire fracture development area to block the air leakage passage, and considering the redundancy of the disturbance effect, it is determined that the drilling sealing depth is not less than 14 m.

(3) According to the determined sealing depth, the traditional “two sealing and one grouting” sealing technology and the optimized “three sealing and one grouting” sealing technology are compared. The total average gas drainage concentration of the two are 51.17. % and 56.04%, the maximum average gas drainage concentration are 68.18% and 79.42%, respectively. The total average gas concentration and the maximum average gas concentration of the boreholes when using the "three sealing and one grouting" are 9.5% and 16.5% higher than the "two sealing and one grouting" respectively, and the gas concentration of the borehole is as high as 40% after 70 days of drainage. Therefore, the "three sealing and one grouting" sealing process can effectively improve the gas drainage effect.

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References
[1] Zhang TG. (2001) Mine gas comprehensive treatment technology. Coal Industry Press, Beijing.
[2] Ma Q. (2017) Research and application of “three plugs and one injection” sealing technique of boreholes drilled along seam. J. Safety in Coal Mines, 7: 74-77.
[3] Gao ZY, Zhang ZG, Yin B. (2009) Research on improving the quality of polyurethane sealing. J. Mining Safety and Environmental Protection, 8(36): 37-38.
[4] Chen J, Jin LZ. (2003) Research on the effect of polyurethane sealing on gas drainage. J. Coal Engineering, 8: 47-49.
[5] Zhang LJ, Chang GZ, Lin BQ etc. (2013) Application of new PD materials in gas drainage drilling and sealing. J. Coal Engineering, 1: 43-45.
[6] Hao FC, Sun LJ etc. (2014) Study on the shortest sealing depth considering plastic softening and capacity expansion. J. Journal of China University of Mining&Technology, 43(5): 789-793.
[7] He YQ, Wang YM. (2016) Research and application of reasonable sealing depth of gas drainage in coal seam. J. Zhongzhou Coal, 5: 4-7.
[8] Sang P, Yang L, Han W. (2014) Research and application of “two plugs and one injection” straight hole drilling and sealing technology. J. China Coal, 40(3): 98-101.
[9] He MC, Jing HH, Sun XM. (2002) Soft Rock Engineering Mechanics. Science Press, Beijing.