Study on Sealing Technology of Gas Drainage Borehole under Damage of Surrounding Rock in Deep Mine Roadway

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Abstract. In order to solve the problems of poor drainage effect and low efficiency caused by poor sealing quality of deep gas drainage boreholes, based on the gas geological conditions in Huainan mining area, comprehensive theoretical analysis and field engineering practice, the distribution law of surrounding rock fracture zone in different lithologic roadways was studied, and the sealing technology combining pressure grouting, screen pipe protection and deep and shallow hole grouting was put forward. Field tests showed that the technology was effective. The average gas extraction concentration and hundred hole extraction purity of boreholes are 3.75 times and 3 times higher than those of common boreholes respectively, and the field application effect is remarkable.

1. Introduction

The progress of gas control concept and the continuous development of outburst prevention technology have played an important role in the reduction of coal mine gas accidents in China, but high gas, high ground stress, low permeability and other factors in deep coal mining still seriously threaten the safe and efficient production of coal mines [1-2].

At present, gas pre-extraction is still one of the main technical measures to prevent outburst in the first protective layer of coal seam and the process of single outburst coal seam mining [3-4]. However, such phenomena as low gas extraction efficiency and poor extraction effect still exist in the borehole, and one of the important reasons is that the borehole formation effect and compactness are not good. At present, most coal mines adopt the hole sealing method of "two blocks and one injection", and the hole sealing depth, hole sealing length and other factors are mostly affected by the gas geological conditions [5-6]. Based on the gas geological conditions in huainan mining area, the failure characteristics of deep tunnel under different surrounding rock conditions and the sealing technology of gas extraction borehole are studied, which provides guidance for gas extraction under similar conditions.

2. Project profile

Huainan mining area is one of the most important coal production bases in China. Most of the mines in the area are coal seam group mining, with many layers, small spacing, single layer thickness (max thickness 6~10m), large total thickness and good continuity of coal seam. The gas geology in the area...
is complex, the gas pressure in the coal seam is high \((P_{\text{max}} = 6.8 \text{MPa})\), the content is large \((W_{\text{max}} = 25 \text{m}^3/\text{t})\), the coal is soft (robustness coefficient \(f_{\text{min}} = 0.17\)), and the permeability is low (\(\lambda = 0.001 - 0.008 \text{m}^2/\text{MPa}^2\cdot\text{d}\)). In the new area, the coal seam is buried more than 800m deep. After the mining is carried out in the depth, the ground stress and ground temperature hazards are aggravated (the maximum measured main stress is 32~37MPa, the ground temperature is generally 31℃~37℃, and the local temperature is up to 40℃).

At present, the hole sealing method of "two blocks and one injection" is widely used in underground gas extraction and drilling in Huainan mining area. However, due to the different complexity of geological conditions, phenomena such as low extraction concentration and air leakage exist in the field application process, which seriously affect the normal extraction and replacement of the mine.

3. Determination of hole sealing depth of deep rock roadway in HuaiNan mining area

3.1. Roof failure characteristics of deep rock roadway

In DingJi coal mine, the failure range of surrounding rock of the first mining 11-2 coal seam floor was observed on site, with the track roadway and mining water bunker in the first mining area west of the 11-2 coal seam (width of roadway section 5000mm, 2800mm) and the elevation of -910m (buried depth 935m) as the research object. The roadway was located at 10-15m of the coal seam floor, and the lithology was mainly sandstone. FIG. 1 shows the fracture distribution of surrounding rock in different monitoring sections.

The relation between the fracture radius \(R\) and the roadway radius \(R\) of the roadway surrounding rocks in the middle and hard rock strata is shown in equation (1).

\[
R = (\sqrt{i}) \cdot R \quad (i = 1, 2, 3, 4)
\]  

In the middle and hard rock roadway deep in Huainan mining area, the minimum sealing hole length can be determined according to formula (1). The distribution relationship between roadway radius and zone fracture radius is shown in Fig. 2.

3.2. Failure characteristics of deep rock roadway floor

The surrounding rocks of the roof and floor of the first 11-2 coal seam in the eastern part of Panyi mine are mainly soft rock, and the surrounding rock fractures are relatively developed and the local roadway deformation is serious. Most of the roadway in the roof and floor of the first 11-2 coal seam in the eastern part of Pani mine will be arranged in soft rock, and the floor heave is obvious. A multi-point displacement meter is installed on the roadway floor at the track stone gate to measure the movement law of roadway floor rock strata, as shown in Fig. 3 and 4.
According to the deformation of roadway floor surrounding rock, the floor deformation can be divided into three stages: ① Within 45 days after roadway tunneling, the deformation movement was intense; ② after tunneling, 45~80d is the gentle stage of deformation and movement; ③ After excavation for 80d, it is a relatively stable stage of surrounding rock deformation. Under the action of high stress, the rheological characteristics of surrounding rock are remarkable in the deep soft rock roadway of huainan mining area. The deformation of surrounding rock is the most serious, the convergent deformation of two sides is the next, the roof subsidence is the smallest. The large rheology of floor roadway not only brings many unfavorable factors to mine ventilation, transportation and other work, but also brings difficulties to the sealing and maintenance of the pumping hole, resulting in poor pumping effect.

For middle and hard rock floor roadway radius r is generally 2.5m, and the thickness of roadway surrounding rock failure layer is generally 7.1m; For large rheological roadway of soft rock, 7~9m of perforating pre-pumping borehole is still in the unstable stage of failure. Considering the heterogeneity, discontinuity and anisotropic brittle materials of the roadway strata, the complexity of geological conditions and the characteristics of the drilling Angle through the stratum, the sealing hole length of the extraction hole should be considered with a certain coefficient, generally 1.25-1.5.

Therefore, in huainan mining area, the length of hole sealing measures for preventing outburst in coal seam gas zone in the belt of coal seam gas zone in rock roadway perforating layer of roof and floor in huainan mining area is generally 9 ~ 11m; For the geological structure zone or the rock section of the borehole through the stratum in the fractured area, the whole hole should be sealed.
4. Hole sealing process of extraction and drilling

4.1. Reasonable grouting pressure analysis for hole sealing in pumping hole

Based on the failure characteristics of surrounding rock of deep mining roadway in Huainan mining area, the grouting pressure of "two blocks and one injection" with pressure grouting and hole sealing method is calculated. According to the results of fluid mechanics and field grouting technology, the $P_Z$ expression of grouting pressure is obtained as follows.

$$P_Z = \mu (R_0 - r)^{2.21} / (0.093 T \delta^{0.21}) - P_0$$  \hspace{1cm} (2)

Type: $\mu$-Viscosity of cement mortar size, Pa·s; $R_0$-Radius of plastic failure zone of borehole, m; $r$-Radius of drill hole, m; $T$-Grouting time, s; $\delta$-Crack width, m; $P_0$-Drainage pressure in the fissure, Pa.

Due to the inhomogeneity of borehole formation, the borehole radius $r$ can be calculated according to formula (3).

$$r = k r_0$$  \hspace{1cm} (3)

Type: $k$-Coefficient of drilling irregularity, Generally take 1.2; $r_0$-The hole radius is formed by drilling theory, m.

The radius of plastic failure zone of drilling hole $R_0$ satisfies equation (4).

$$5\pi r_0^2 = (1.05 - 1) R_0^2$$  \hspace{1cm} (4)

According to equation (4), the radius $R_0$ of the plastic failure zone is 10 times that of the hole formed by drilling theory.

In order to ensure the accuracy of the grouting pressure calculated by formula (1), the following formula can be used to test.

$$R = 283.82 P_Z^{0.53} M^{0.23} \mu^{-0.83} T^{0.55}$$  \hspace{1cm} (5)

Type: $R$-The diffusion radius of drilling slurry, m; $M$-Coal size modulus.

4.2. Screen hole protection technology

In order to avoid the phenomenon of caving and hole blocking when the borehole meets soft and broken surrounding rock, it is necessary to adopt the way of screen tube protecting the hole. At present, Huainan mining area mainly adopts the inserted screen tube, threaded connection and integral flexible screen tube. The advantage of this technology is that it can quickly feed the screen into the hole without lifting the drill, thus improving the construction efficiency.

4.3. Deep and shallow hole grouting hole sealing process

As shown in Fig. 5, the principle of grouting holes in deep and shallow holes is to use the grouting layer to block the surrounding rock and cracks around the borehole, so as to prevent the phenomenon of grouting running in the process of grouting in deep hole and high-pressure grouting in extraction borehole.

Fig. 5 Schematic diagram of depth hole grouting layout
5. Site inspection

Ding set mine in HuaiNan mining area, 1331(1) transport gateway uses with pressure grouting, sieve hole of the management and deep, shallow hole grouting technology on extraction of combining drilling hole sealing experiment was carried out, the hole diameter for Φ113mm, borehole radius \( r \) of 0.0678 m, drilling the plastic area radius \( R_0 \) is 1.01m. Adopt No. 425 Portland cement, water-cement ratio is generally less than 1:1, cement mortar slurry viscosity is about 15Pa·s;The drainage pressure in the fissure is \( P_0=0 \), the fissure width is generally no less than 0.5mm, the grouting time \( T \) is generally less than 10min, and the coal particle size modulus \( M \)=5-10. Considering the complexity of field geological conditions and field experience, in order to achieve the best grouting effect with pressure, the grouting pressure reserve enrichment coefficient is 1.2. According to the actual situation of sealing hole in HuaiNan mining area, the grouting pressure \( P_Z \) only needs to be greater than 2MPa.

Compared with the traditional gas extraction process, the gas extraction channel is more stable, and the phenomenon of hole collapse and hole blocking is effectively solved. The average extraction concentration of boreholes increased from 12% to 45%, increasing by 3.75 times. The extraction scalar of 100 holes increased from 3m³/min to 9m³/min, which increased by 3 times, and the field test effect was better.

6. Conclusion

(1) In HuaiNan mining area, the surrounding rock of hard rock roadway is mainly characterized by zonal fracture, while the surrounding rock of soft rock roadway is mainly characterized by rheological characteristics.

(2) According to the failure characteristics of surrounding rock in mining area, the sealing technology of grouting with pressure, screen tube and deep hole is adopted.

(3) The field results show that the extraction efficiency of gas extraction hole is greatly improved, and the extraction effect is increased by more than 3 times, and the field application effect is good.

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