Research on strip pressure relief drainage technology in deep coal roadway

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Abstract: Aiming at the characteristics of coal and gas outburst disasters in Jianxin Coal Mine, based on the compound energy mechanism of coal roadway outburst in deep mining and the distribution law of the roadway surrounding rock fracture zone, the pre-drilling pressure relief floor rock roadway and the cross-bed borehole drainage coal roadway gas are proposed. Regional anti-outburst measures have been applied in engineering. The application shows that this technical measure can greatly improve the permeability of the coal seam and the effect of pressure relief extraction, and ensure the safe and rapid excavation of coal roadways.

1.Introduction
Coal mining is undergoing a process where mining conditions become increasingly complicated. Coal rocks in deeper part of a mine under high crustal stress, high gas concentration and high temperature have different mechanical properties with their shallow counterparts including complicated and diverse changes in stress field in surrounding rocks, large scale of distortion and high rheology of the surrounding rocks, transit from brittle to tensile, and sudden changes of their dynamic response[1-2]. In addition, nowadays, coal mining applies intensive mining technologies that accelerate the excavation process and reduce energy costed in plastic strain happening in the coal rocks near the working face; in this way, the elasticity of surrounding rocks will accumulate to achieve high energy level. Engineering stress and external induced energy have significantly increased, which to some extent have increased the risk of coal rock gas dynamic disasters[3-4]. The mechanism of coal and gas outburst in deeper mines becomes more complex, making dealing with it more difficult. Furthermore, existing fundamental theory studies do not meet the needs of practical engineering exercises. Therefore, in the context of deeper mining and changing mining conditions, we need to keep updating our knowledge and work out new measures to prevent dynamic disasters such as coal outburst.

A general direction on dynamic disasters prevention in coal and gas deep mining is to take measures by using comprehensive technologies such as pressure relief in specific places, gas drainage, controlling inducing energy and changing the dynamic tendency and mechanical properties of coal rocks, targeting the dominating elements of risk and discriminating the energy levels of crustal stress and gas. The prevalent Chinese regulations do not allow applying outburst prevention measures on the working face of a coal seam with severe outburst. Therefore, in a single severe outburst hazard-prone coal seam, outburst prevention and pressure relief in pre-excavation floor rock roadway by gas drainage as part of the drilling process is a widely applicable and promising technique.
Basic Facts and Analyses on the Features of Coal Roadway Tunneling

The geological structure in Fengcheng mining area Jianxin Mine is relatively simple. The occurrence of the single major coal seam B4 is relative stable with a coal thickness of 1.7~2.4 m, maximizing at 4.0 m, and its south-to-north inclination of 8°~23° with the larger reserve at shallow parts. The deepest mines are located at syncline grounds in Qujiang town and Shishang town, which are almost horizontal. This mining area is one of coal and gas dynamic disasters-prone mines in China. As mining goes deeper and intensifies, this mining area, like many of its counterparts in China (such as Chongqing and the South of Anhui province), have sighted abnormal gas dynamic phenomena caused by crustal stress. For example, drilling test for and the effect of protection measures on outburst risk on the working face fell far behind the indexes specified in the applicable regulations and standards[5].

During deep mining processes, beforehand regional gas drainage and partial comprehensive outburst prevention measures have been applied in all working faces, reducing the risk of gas outbursts. As a result, outburst incidents led by gas have decreased while coal and gas dynamic phenomena led by crustal stress have increased.

Mechanism of Gas Dynamic Disasters in Deep Coal Seams and Principles of Pressure Relief and Outburst Prevention Technologies

3.1.Mechanism of Outbursts in Deep Coal Roadways

Energy produced by outbursts, mainly elastic potential energy in coal rocks, intrinsic gas energy, kinetic energy by coal and gas outbursts and energy by progressive failure (stable failure without outbursts), all of these add up to a comprehensive energy equation of coal dynamic disasters:

\[ E_{\text{wall rock}} + E_{\text{coa}l \text{ mass}} + E_{\text{gas}} + E_{\text{external}} = E_p + E_r \]

In this equation, \( E_p \) represents energy needed in progressive failure; \( E_r \) represents energy needed in coal outbursts.

In coal and gas dynamic disasters, the main energy comprises of intrinsic gas energy and disposable elastic potential energy in coal rocks. Slow gas release does not work on outbursts, but only when coal rocks break suddenly, coal exposure will increase immensely, so that gas in coal rocks will desorb and swell rapidly and its intrinsic energy will release quickly, thus leading to disasters. It is the same reason that only quick release of coal rocks’ elastic potential energy will result in speedy failure of coal rocks. As a result, time is an essential factor in coal rocks failure and instability. Triggered by external factors, coal rocks at critical state release more energy than what is needed in progressive failure in a same time period, and the excessive energy will lead to failure and instability with signals of outbursts.

On top of the combined sources of outbursts in coal roadways, deep mines are positioned in a more complicated geological environment featuring high crustal stress, so the excavation process is under dual impact of gas and high crustal stress and the mechanism of outbursts will be much more complicated.

Fengcheng mining area is now in the stage of deep mining with coal seams being under high crustal stress and coal rocks under high elastic energy. When the content of gas in coal rocks is not much or meets the standard level after beforehand gas drainage (i.e. reducing intrinsic gas energy), drainage by drilling has a rather limited effect on pressure relief and highly concentrated elastic energy which leads to coal seam deformation will finally result in the expansion of coal seams and produce bursting pressure on \( B \) area, which will be susceptible to continuous displacement under adequate bursting pressure. While the failure process of coal rocks happening like an avalanche in \( A \) area will transform into coal and gas outbursts or apparent dynamic disasters caused by crustal stress.

3.2.Theory of Pressure Relief and Outburst Prevention in Pre-Excavation Floor Rock Roadways

Under high stress environment, when deep coal rocks are in the state with post-peak characteristics, the surrounding rocks will have areas that are under complicated stress. Under certain conditions, the surrounding rocks will from time to time undergo a situation where there will be an alternation between
expansion zone and compression zone whose sizes (widths) will increase at an equal ratio. In this case, partial fractures will appear; the stress peak of the surrounding rocks will drop and the width of pressure-relief area will significantly enlarge.

To sum it up, due to relatively large difference of crustal stress between shallow and deep mining, the width of pressure-relief areas near the surrounding rocks will differ. Deep mining suffers from high crustal stress, so there might be partial fractures near the surrounding rocks and the width of the pressure-relief area will clearly increase.

Based on the analysis of the evolution of elastic-plastic rheology of the stress in surrounding rocks of floor roadways, relieving pressure against coal seams by excavating a roadway in an appropriate position in the floor seam before excavating the proper coal roadway. In this manner, the elastic energy in the coal seam as well as in the floor and roof seam can be previously released and the permeability of the coal seam proper as well as the solidity of the coal rocks will increase. By releasing pressure in the floor rock roadway or extracting gas through crossing holes, the elastic energy of outbursts and gas potential energy can be further reduced or even dismissed, thus achieving outburst prevention in coal roadways.

4. Experiments on the Technology of Pressure-Relief and Extraction on Pre-Excavation Floor Roadways through Crossing Holes

The 1128 floor rock roadway in Jianxin Coal Mine is arranged 11m directly below the coal roadway, and the gas concentration and scalar change curve of the drilling through the layer in Jianxin Coal Mine is shown in Figure 1. It can be seen from Figure 1 that the maximum concentration of mixed gas drawn by drilling through the layer is 23%, and the daily gas drainage volume can reach 580~3200 m$^3$/d, the drainage is relatively uniform, and the drainage effect is significant.

![Figure 1. curve of gas concentration and the quantity of gas extraction in 1128 floor rock roadway](image)

The testing roadways have adopted regional outburst prevention measures by gas extraction through drilling holes in pre-excavation coal roadway strips. The results are as shown by Table 1

| Roadway      | Number of Tests | Length (m) | Extracted Gas Volume (m$^3$) | Performance Tests | Extraction Rate (%) | Extraction Time /d | Result   |
|--------------|-----------------|------------|------------------------------|--------------------|---------------------|---------------------|----------|
| Jianxin mine | 1               | 164        | 65232                        | 5                  | 4.03~5.39           | 40                  | 91       | Qualified |
| 1128 Gateway | 2               | 345        | 173548                       | 10                 | 3.09~4.94           | 47                  | 81       | Qualified |

It can be seen from Table 1 that the drainage effect of 1128 floor rock roadway in Jianxin Coal Mine is significant. The highest gas drainage rate is 40%~47%, and the residual gas content will reach
3.09~5.39m³/t after 81~91d, which is much lower than 8m³/t, realized the elimination of coal outburst in the strip area of the coal roadway to be excavated, and provided a guarantee for the safe driving of the coal roadway.

After the regional outburst prevention measures have been proved effective, the pre-excitation gateways were put into examination and circulating projection has been made about the risks of partial outbursts during excavation. After the regional outburst prevention measures have been adopted in 1128 gateway in Jianxin mine, the risk predictors of partial outbursts were all relatively small with the indicator $K_1$ of drilling cuttings and gas desorption being 0.11~0.45ml/g·min$^{1/2}$, lower than the threshold value of 0.50ml/g·min$^{1/2}$, thus ensuring safe and fast excavation.

5. Conclusions

Based on the analysis on elastic-plastic rheology of the surrounding rocks of the floor roadway, shallow mining endures a relatively smaller crustal stress and the radius of the relieved area in the surrounding rocks is rather small. In deep mining, under high crustal stress and high temperature, the surrounding rocks might break or crack and the radius of the relieved area will greatly increase, farther beyond that of shallow mining.

Under the coal seams with severe outbursts, taking measures to relieve pressure in pre-excavation coal roadway strips and prevent outbursts in gas extraction areas can effectively prevent outbursts in coal roadway strips by reducing the outburst energy of the original coal rocks and can reduce dropping coals and vibration during excavation.

According to observations on the testing coal roadways, by combining pressure relief on a pre-excavation floor rock roadway 11m right below the roadway and outburst prevention in gas extraction area, the permeability of the coal seam and the performance of pressure-relief drainage can be greatly improved, thus ensuring safe and fast coal roadway excavation.

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