Study on Advanced Anchor - grouting Support of Mining Roadway in Close Lower Coal Seam

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Abstract. Aiming at the problems of difficult support of mining roadway under goaf of the close distance coal seam, obvious large deformation, and long-term continuous deformation of surrounding rock, an advanced bolt-grouting support system is proposed. The system can effectively solve the problem of roadway support from the design system, construction system, and monitoring and evaluation system, and realize the intelligent evaluation of bolt-grouting support. Based on the actual engineering background of 29204 working face in Dongqu Coal Mine, the supporting material and scheme, grouting parameters, and construction technology are studied and analyzed. Finally, the supporting scheme is adjusted and optimized timely by combining with the intelligent evaluation system of anchor grouting. The field practice results show that the advanced bolting-grouting support system has good applicability to roadway deformation under different conditions. The maximum subsidence of the roof in the test section is reduced by 73.48 % compared with the original support scheme, and the maximum stress of the anchor cable is reduced by 50.68 %. The research results provide a set of safe and effective support system and feasible technical ideas and methods to solve the problem of surrounding rock control of mining roadway under goaf of the close distance coal seam.

1. Introduction

As the main energy in China, coal is of great significance for the development of China's production [1, 2]. In recent years, with the increasing scope and breadth of coal mining, complex geological conditions and high ground stress environment make the control of roadway surrounding rock more difficult. Especially for close coal seam, the traditional support method is difficult to effectively control the stability of the roadway [3, 4]. Therefore, in order to solve the problem of roadway surrounding rock control, a set of safe and effective support technology is urgently needed.

In recent years, domestic and foreign scholars have carried out a lot of research work on roadway support in close coal seams. In advance support of coal seam mining under goaf, aiming at the difficulty of top coal support under goaf in thick coal seam slicing mining, Chai et al. [5] put forward the anchor support mode based on shed support, 'short dense anchor cable reinforcement+anchor suspension', which provided a certain reference for roadway support under goaf. Wang and Fang et al. [6, 7] proposed a variety of combined support technologies for the deformation of roadway surrounding rock under the goaf of close coal seam group, which effectively ensured the stability of roadway surrounding rock and provided a method for solving the problem of roadway surrounding rock control under the goaf. In the study of advanced bolting and grouting support, Li [8] used the method of combining numerical simulation with field practice to study and analyze the theory and technology of grouting anchor cable advanced support in mining roadway, which provided a certain reference for advanced bolting and grouting support. Ning et al. [9] analyzed and verified the advance control range and grouting reinforcement technology and timing according to the distribution and evolution of mine pressure in secondary mining roadway and the characteristics of measured anchor cable tension value, which provided a method for supporting failure caused by the broken surrounding rock. Yao et al. [10] improved the traditional passive advance support technology and proposed the method of grouting anchor cable advance active support, which provided a certain reference for the advance anchor grouting support technology of mining roadway. Professor Lu [11] optimized the timing of grouting bolt support by combining field measurement and numerical calculation results, which provided a method for grouting parameter design. In the aspect of advanced support monitoring and management, Zhang et al. [12] carried out non-destructive testing and early warning analysis of bolt support quality in the deep roadway and proposed early warning technology of roadway surrounding rock stability based on axial bolt load detection.

In summary, many scholars at home and abroad have carried out a lot of research work on the problem of roadway support. However, for the Xishan mining area, the high stress environment and the upper coal seam goaf cause the surrounding rock of the roadway to show obvious large deformation and long-term continuous

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deformation characteristics, and the traditional support system is frequently unstable. Therefore, the traditional support method must be improved. Taking Dongqu Mine in Xishan Mining Area as the research background, this paper puts forward a kind of advanced bolting and grouting support system, and studies the design system, construction system, and monitoring and evaluation system. Through field industrial test, the application effect of advanced bolting and grouting support system is verified, which provides a certain reference for solving the problem of serious deformation of mining roadway under close coal seam goaf.

2. Engineering overview

Dongqu Mine is located in the Gujiao mining area of Xishan Coal and Electricity. The 29204 working face is located in the second mining area of +860 level, which belongs to 9# coal seam, the average depth is 240 m, the dip angle is 0-5°, and the average thickness is 2.67 m. The rock properties of the roof and floor of the working face are mainly sandy mudstone, as shown in Fig. 1. The average distance between 8# and 9# coal seams is 4.35 m, belonging to the close coal seam.

Lithology	Thickness(m)	Lithological description
Sandy Mudstone	3.55	Black gray, extremely brittle, oblique joints developed
Limestone	2.40	Dark gray, hard, fissured
Medium Sandstone	4.46	Light gray, dense cementation
Siltstone	6.74	Black gray, joint development
Limestone	2.93	Dark gray, hard, fissured
Marl	1.65	black, granular or muddy structure
Mudstone	0.70	Black, muddy structure
8# Coal	3.13	Black, mainly bright coal, dark coal
Sandy Mudstone	4.35	Black gray, extremely brittle, oblique joints developed
9# Coal	2.67	Black, mainly bright coal, dark coal
Sandy Mudstone	2.74	Black gray, extremely brittle, oblique joints developed

Figure 1. Roof and floor situation of working face

In recent years, affected by 8# coal mined-out area, roadway stress concentration, roof crushing, and 'π' beam deformation occurred in 29204 working face of Dongqu Coal Mine. Therefore, it is necessary to develop a set of advanced bolting and grouting support system suitable for the site conditions of the Xishan mining area.

3. Advance bolting and grouting support system

Advanced bolting and grouting support system is a dynamic system which is based on ' grouting anchor cable + on-line monitoring of mine compaction ' and intelligent evaluation method of bolting and grouting. The advanced bolting and grouting support system mainly includes three aspects: design system, construction system and monitoring and evaluation system.

Among them, the design system mainly adopts the method of combining engineering practice with numerical simulation to study and determine relevant parameters from three aspects of supporting materials, supporting scheme and grouting parameters. The construction system is mainly through the construction technology design and site construction supervision to ensure the design effect; the monitoring and evaluation system is mainly divided into two parts: one is to supervise and evaluate the situation after the site construction to ensure that the construction requirements are met; the second is to monitor the field implementation effect in the process of advancing the working face, and evaluate the implementation effect in real time through the self-developed intelligent evaluation system of anchor injection. When the site does not meet the construction requirements, timely adjustment and optimization of construction technology; when the field implementation effect is not ideal, the design system is optimized in time to determine the best scheme to achieve the optimal control effect.

4. Field practice of advanced bolt-grouting support

4.1 Selection of supporting materials

In view of the roof strata of 29204 working face roadway in Dongqu Coal Mine, the field sampling was first conducted and the standard specimens were made. Then the relevant indoor mechanical tests are carried out to determine the physical and mechanical properties and composition of the rock. Related parameters are shown in Table 1.

Table 1. Parameter table of physical and mechanical properties of roof rock

Name	Uniaxial compressive strength/ MPa	Elastic modulus /MPa	Uniaxial tensile strength/ MPa	Cohesion /MPa	Internal friction angle /°
Sandy mudstone	19.57	5671	4.48	3.86	58.5

Combined with the actual field detection, the coal seam spacing is 4.35m. Combined with the physical and mechanical properties of roof strata, the hollow grouting anchor cable of SKZ22-1/1860 was selected, and ZHM-III Gu'anfeng grouting reinforcement material was selected.

The length of the anchor cable is calculated by the limit equilibrium theory in elastic-plastic mechanics. The specific calculation formula is as follows [13]:

$$R = a\left[\frac{(K_1\gamma H + K_2 C\cdot\cot\varphi)(1-\sin\varphi)}{P_i + K_2 C\cdot\cot\varphi}\right]^{\frac{1-\sin\varphi}{2\sin\varphi}} \quad (1)$$

In the formula, K_1 is the repeated mining coefficient; γ is coal density, kN/m^3; h is the depth of coal seam, m; P_i is support resistance, MPa; a is the equivalent radius of the roadway, the value can be obtained by the circumcircle of

the roadway, m; C is cohesion, MPa; φ is the internal friction angle, °; K_2 is the correction coefficient of mechanical parameters of coal and rock mass.

After calculation, the plastic radius of the 29204 track trough is 3.44 m. Considering the roof lithology characteristics, the length of the grouting anchor cable is finally determined to be 4.3 m.

4.2 Determination of support scheme

The determination of support scheme should be based on field engineering practice. At the same time, the characteristics of coal and rock strata, the adaptability of support control technology and the structural coordination of support conditions should be analyzed. Reasonable design should be carried out for the row spacing between anchor cables, the position of anchor cables, the arrangement of anchor cables, the grouting method and sequence.

In view of the problems existing in the track groove of 29204 working face in Dongqu Coal Mine, the preliminary design scheme of field support is as follows: two hollow grouting anchor cables are arranged in each row at the top of the roadway, 1 000 mm apart from the two sides, 1 600 mm apart and 2 000 mm apart. The anchorage force is not less than 200 kN, and the bearing capacity is not less than 350 kN by using 250 mm×250 mm×17 mm high strength bracket and supporting special lock. The anchor cables are all arranged vertically to the rock surface. The interval grouting method is adopted. One row of observation anchor cables is set in each two rows. The grouting time of observation anchor cables is determined according to the deformation of the roadway in the advance section. If the roof in the advance section is reliable and without large deformation, in order to ensure the timely collapse of the working face corner, the observation anchor cables are not grouted. The support scheme is carried out on the basis of the original support.

4.3 Determination of grouting pressure and time

4.3.1 Model establishment and scheme.

This paper uses COMSOL numerical simulation software to study and analyze the grouting pressure and time. The model size is set to 20 m×20 m, and a grouting hole is arranged in the middle part. Darcy 's law is used to solve the model. The grouting pressure and time range are obtained according to the field experience, and the specific simulation scheme is shown in Table 2. The mesh of the model is shown in Fig. 2, and the model parameters are shown in Table 3.

Table 2. Scheme of numerical simulation

Grouting parameters	Simulation scheme									
Grouting pressure/MPa	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Grouting time/min	1	2	3	4	5	6	7	8	9	10

Table 3. The parameter of the model

Name	slurry viscosity/Pa·s	slurry density /kg/m^3	Permeability of surrounding rock/m^2	Gap width /mm	Porosity
Grouting parameters	19.57	5671	4.48	0.5	0.012

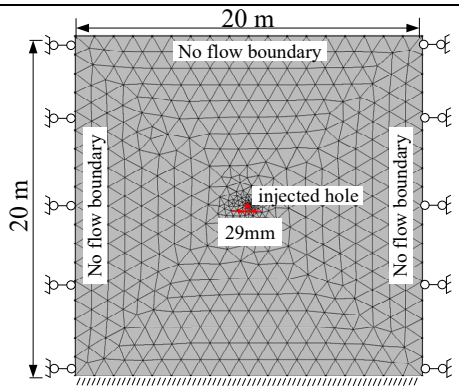
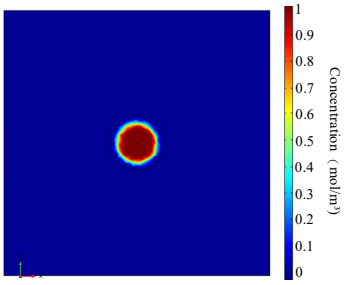


Figure 2. Model mesh generation and boundary conditions

4.3.2 Analysis of simulation results

(1) Grouting pressure

Fixed slurry diffusion time is 10 min, according to the grouting pressure simulation scheme shown in Table 2. The simulation results are selected when the grouting pressure is 1 MPa, 2 MPa, 3 MPa, 4 MPa and 5 MPa, as shown in Fig. 3. As can be seen from Fig. 3, under the same grouting time, the slurry diffusion area increases with the increase of grouting pressure. In order to study its evolution law more carefully, the slurry diffusion area is quantitatively analyzed, and the results are shown in Fig. 4. It can be seen from the figure that at the moment of grouting, the diffusion range of slurry increases significantly, by about 63% compared with that without grouting, considering the breakage of lower coal roof strata caused by upper coal mining. But the growth ratio generally increases first and then decreases. When the grouting pressure is less than 4 MPa, the growth ratio of the slurry diffusion range is greater than 10%. After more than 4 MPa, the slurry diffusion range basically does not increase, the growth rate is less than 10%. Considering that when the grouting pressure is too large, the integrity of the surrounding rock will be further reduced, so the appropriate grouting pressure is determined to be 4 MPa.



（a）Grouting pressure is 1 MPa

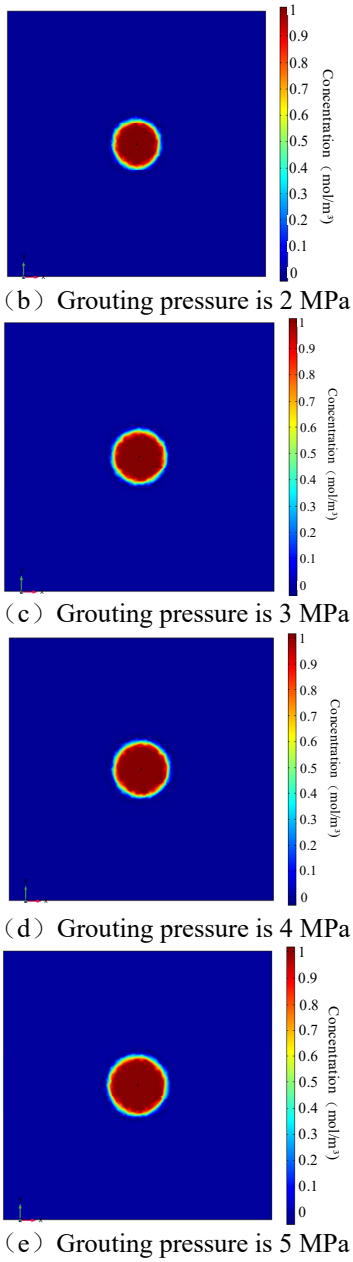


Figure 3. Partial simulation results

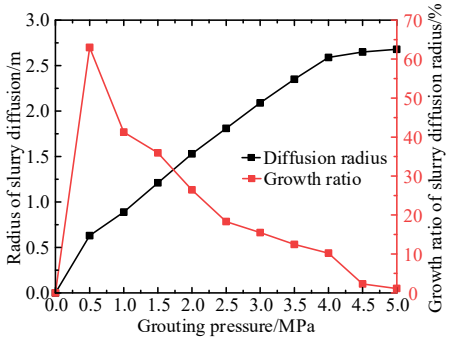


Figure 4. Slurry diffusion effect at different grouting pressure

(2) grouting time

Based on the above analysis of grouting pressure, the fixed grouting pressure is 4 MPa, and the simulation analysis is carried out according to the grouting time simulation scheme shown in Table 2. The results are shown in Fig. 5.

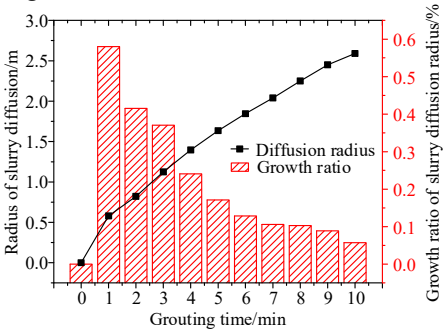


Figure 5. Slurry diffusion effect at different grouting time

It can be seen from the diagram that under the action of grouting pressure, the slurry diffusion radius increases gradually, but it also shows a trend of increasing first and then decreasing. When the grouting time is less than 8 min, the growth rate of slurry diffusion radius is more than 10%, but the overall growth rate decreases gradually. When the grouting time was more than 8 min, the growth rate was less than 10%, showing a rapid downward trend, and the diffusion effect was poor. So the best grouting time is 8 min.

4.4 Time of grouting

Pulverized coal detection was carried out at 6 m, 20 m, 28 m, 41 m, 60 m, 82 m and 105 m ahead of the working face in the track trough of 29204 working face. Taking into account the length of the hollow grouting anchor cable, the average amount of coal powder in the 1~5 m drilling range of different distances in the advanced working face is selected for monitoring and analysis, as shown in Fig. 6.

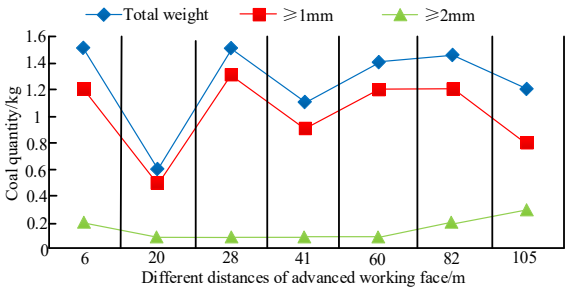


Figure 6. Statistical curve of average coal powder quantity

The amount of coal powder in different drilling depth ranges from 20 m to 28 m in advance working face generally increases, and some boreholes appear stuck drilling and drilling difficulties, indicating that the pressure in this area increases, which may have a greater damage to surrounding rock. At the same time, considering the advancing speed of the working face, the convenience of grouting construction and the solidification time of grouting slurry, it is suggested that the grouting reinforcement time should be selected at about 20 m ahead of the working face.

5. Construction Technology Design and Monitoring Effect Analysis

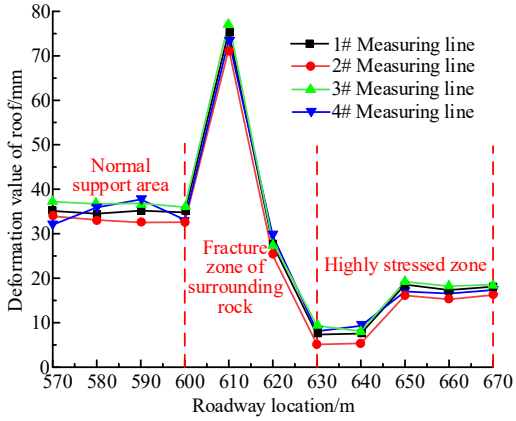
5.1 Site Construction Technology and Design Supervision

The range of 570~670 m in advance working face is selected as the field construction test area based on the analysis of the current roadway stress in the track roadway of 29204 working face. A station is set every 10 m to ensure the correctness of the monitoring data.

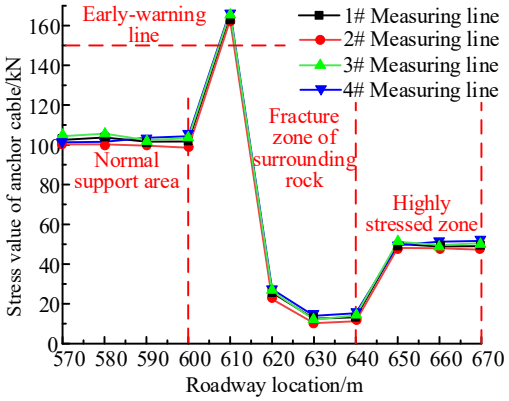
In the field construction, the anchor hole position is determined according to the design and layout requirements of the grouting anchor cable, and the drilling bit with a diameter of 29 mm is used for drilling. Then the grouting anchor cable is pushed into the fundus, and the drug roll is stirred for not less than 10 s after the push. After the stirring is completed, the bolt machine should maintain the thrust of not less than 2 min to ensure the grouting effect. When grouting, using from inside to outside grouting sequence, the speed is slow. After the grouting is filled, the grouting pump can be closed, and the grouting waits for 2~3 min until the grouting is filled again, and the grouting mouth is blocked with screws in time to prevent the slurry from flowing out. In the process of grouting, grouting pressure should be observed at all times to prevent leakage and running.

5.2 Site supervision and monitoring

From Fig. 7, it can be seen that the deformation of surrounding rock and the stress of anchor cable in 570~600 m roadway are relatively stable, indicating that the support effect is better. However, the deformation of the roadway is suddenly too fast between 600~610 m, and the stress of the anchor cable is suddenly increased, and exceeds the warning value set by the mine, indicating that the original support scheme cannot effectively control the deformation of the surrounding rock of roadway. The field analysis shows that the surrounding rock of roadway in this area is broken and belongs to the broken area of the surrounding rock, so it is necessary to adjust the support scheme. Combined with the intelligent evaluation platform of anchor grouting support, the original support scheme is analyzed and predicted. The anchor cable row spacing is changed to 1 000 mm, and the grouting method is used in each row in turn.



(a) Deformation value of Roof



(b) Stress value of anchor cable

Figure 7. Monitoring results and scheme optimization

It can be seen from Fig. 11 that the deformation of the roadway decreases rapidly, and the stress value of the anchor cable is also reduced to below the warning value, and tends to be stable. With the continuous advancement of the working face, within the range of 630m-640m, it is found that the roof of the roadway has no subsidence, and the suspended roof greater than 5m appears after the mining of the working face, which affects the safety production of the working face. The field analysis shows that the surrounding rock of the roadway in this area belongs to high stress area, so it is necessary to adjust the support scheme appropriately. Combined with the intelligent evaluation platform of anchor grouting support, the support scheme is analyzed and predicted, and the grouting sequence is changed to interval grouting.

After the optimization of the support scheme, it can be seen from Fig. 7 that the deformation of the roadway increases slightly, but finally tends to be stable. The stress value of the anchor cable also shows the same trend, and the final values of the two also meet the requirements of safe production of working face.

Compared with the original support scheme, the overall field implementation shows that the maximum subsidence of the roof is reduced by 73.48% and the maximum stress of anchor cable is reduced by 50.68% compared with the original support scheme, and the support effect is improved significantly. It can be seen that the intelligent evaluation platform of anchor-grouting support proposed in this paper can accurately optimize the design of support scheme, so as to achieve good field application effect.

6. Conclusion

This paper puts forward a kind of advanced bolting and grouting support system, and carries out engineering application of the working face track channel, and achieves the following results:

1) An advanced bolting and grouting support system and intelligent evaluation of bolting and grouting is proposed. The system can effectively solve the problem of roadway support from the design system, construction system and monitoring and evaluation system.

2) Aiming at the track trough of 29204 working face in Dongqu Coal Mine, the grouting pressure, time and opportunity in the grouting construction technology were

studied and analyzed, respectively. By detecting the amount of pulverized coal in the same drilling depth in different distance boreholes ahead of the working face, the grouting opportunity was determined to be 20m.
3) The results show that the maximum subsidence of roof in the test section is reduced by 73.48% compared with the original support scheme, and the maximum stress of anchor cable is reduced by 50.68%, indicating that the design of support system can effectively improve the support effect of roadway surrounding rock.

Acknowledgments

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