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Directional Drainage Grouting Technology of Coal Mine Water Damage Treatment

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Abstract

Grouting has become an important and effective means of prevention and treatment to mine water disaster. Explore the rapid and efficient mechanism and grouting technology for coal mine water control work has great significance. This paper proposed directional drainage grouting based on Grouting mechanism and practice experience. It could be used for tunnel closure, collapse column water inrush and "four-fuzziness" (measurements are not allowed, water inrush source uncertainty, water inrush location is unknown and leading water channels is unclear) mines. And the water grouting mechanism and key techniques are discussed in detail. The water disasters treatment of Renlou coal mine and Tianhe coal mine showed that directional drainage grouting have high efficiency, save materials, large safety factor and so on. It has broad application prospects.

1. Introduction

With the increased depth of coal mining, changes in mining methods, working face and the spatial scale significantly improved degree of mechanization, the production conditions of water damage, water damage level of threat and great changes have taken place in the formation mechanism. Grouting predecessors in theory, materials, equipment and construction technology has been done a lot of work, but...
failed to achieve rapid recovery of the mine on theory of the key technologies and systematic, much-needed breakthrough in water control by experience\textsuperscript{[9-16]}. Exploration, mining and applications adapt to new conditions to promote the mine water damage control mechanism and method to achieve rapid recovery after the mine flood control is the current important and urgent task. The author proposed rapid Grouting technology based on the recent research and practice, it has great practical and long-term significance to safety production of coal enterprises.

2. Mechanism of directional drainage grouting

After finding out water inrush points, inrush water source and channels of coal mine, then can construct conventional grouting. It is that inject the preparative grout and aggregate rock through the bores into the rock voids, cracks or roadway, force it diffuse and consolidate, so that the rock have a high strength, compactness and impermeability to achieve cut off water supply and reinforce the impermeable layer. The directional drainage grouting based on conventional ground grouting, during the grouting process, when a certain amount of aggregate and grout had been injected, the main channels and fissures have been basically filled with grout, but there are still individual large cracks and a considerable number of small fissures or the narrow weak zones. If continue to increase the pump pressure grouting, grout or cracks spread along the channels far, result in a waste grout, or along small cracks or weak zones bring new fissures, so that the original confining effect is damage. If drainage from the main and auxiliary shaft or near the water inrush point, change hydrostatic conditions into micro-hydrodynamic conditions, fine aggregate and grout can slow flow through the water channels, and gradually block the channels in order to achieve grouting and blocking water. This is called directional drainage grouting.

3. Types of water damage and treatment mechanism

3.1. Roadway closure

When coal mine occur water damage flooding shaft impact of normal production, the first should be selected near the working face or roadway of the water burst to achieve interception, so that form the confined space near water burst points, then drainage in other regions, restore normal production work in the other range of mine. In the process of achieving closure, must pitch aggregate through bores after hitting the roadway. Before grouting change the pipe flow of the roadway into penetration flow, increase the flow resistance. Groundwater flow will produce a pressure head loss because fluid properties and flow environment, the value can gain from the modified Darcy-Weiss Bach formula:

\[ h_f = \frac{\lambda L v^2}{2 D g}, \quad \lambda = 0.1 \left( \frac{68 \mu}{v D} + \frac{k}{D} \right)^{0.25} \]  

\( h_f \) is the fluid pressure head loss, \( \lambda \) is the fluid friction coefficient, \( L \) is the length of roadway (crack), \( v \) is velocity of flow, \( D \) is width of the roadway (crack), \( \mu \) is kinematic viscosity, \( k \) is absolute rough degree of channel, \( g \) is acceleration due to gravity.

The above formula indicates that the wider of roadway (fracture), the smaller of fluid pressure head loss. When not pitch the aggregate, \( h_f \) value is approximately zero, the grout immediately washed away by water not yet solidified. Only to pitch a lot of aggregate in the roadway (fracture), turn the roadway (crack) narrowed, lengthened the water flow, the value of pressure head loss increases, the density and dynamic
viscosity coefficient of grout are larger than water, the value of the pressure head loss is greater, grout will fill the gap in the aggregate and turn solidification to form a trend of closure.

According to aggregate in the borehole can be regarded as free-fall deposits on the roadway floor, it can be theoretically calculated the required amount of aggregate as formula.

\[
V = k \left( \frac{Pbh}{T_s} + \frac{b^2h}{\tan \theta} \right)
\]  

Where \( V \) is the required amount of aggregate, m\(^3\). \( P \) is the tunnel water pressure, Mpa. \( T_s \) is the critical coefficient of water inrush, generally 0.06~0.1 Mpa/m. \( b \) is the section width of roadway, m. \( h \) is the section height of roadway, M. \( \theta \) is natural deposit angle of aggregate, generally 30°~39°. \( k \) is an empirical coefficient, typically take 5~10.

The injection grout is driven by the pressure difference, fill cracks between aggregate and small channels after aggregate has been pitched, the roadway and the top floor reinforced as a whole to achieve the purpose of closure. After pitching aggregate and grouting, the water level of long view water bores and roadway are significant changes, but not be succeed in closure at this time. As surviving small capillary cracks or weak areas formed by solidified of cement damming, expected rate is about 80%, there is infiltration of water, greater security risks. Therefore should drainage water at back side of the inrush point in the tunnel, an artificial flow field is established, and guide grout filling along small channels farther in the damming. So that the original closure damming body fully reinforced to ensure the security and water shut closure effect. As shown in Fig. 1.

![Directional drainage grouting reinforce closure damming object schematic diagram](image)

**Fig. 1** Directional drainage grouting reinforce closure damming object schematic diagram

### 3.2 Water inrush of collapse column

Water inrush from collapse columns have frequently occurred in past years. As large scale caves are gradually formed by the dissoluble thick stratum and favorable hydrodynamic conditions. Top stratum collapsed under gravity to form collapse columns. There is greater water vertical guide channel cross-section. Often connect with strong water-filled karst aquifer. Therefore, tend to have high conductivity and abundant supply water. If collapse columns connect with aquifer result in water inrush, often lead to full mine production stopping or submergence accident. This paper presents an approach form "sealing plug" block the water channels by directional drainage grouting to treat water damage. Firstly, at the root of its appropriate layer (at least below coal seam) pitch a certain amount of aggregate to plug the large water channels, then grouting establish artificial "sealing plug". At this time the water level should be reflected, but the irregular edges of collapse columns and the sealing plug remains small cracks and weak
ring. This need to create artificial drainage in the roadway, force the grout along the water channels to fill the fractures and to enhance "sealing plug". Reinforce the cement and surrounding rock mass to achieve complete sealing. To increase safety and successfully passed the collapse columns, should pitch aggregate and grouting under the "sealing plug", change the original aquifer into impermeable layer possibly.

(1) Establish "sealing plug"

The most important issue of directional drainage grouting is the "sealing plug" establishment. The strong and effective sealing plug can block the limestone water of lower part coal seam. Specifically relate to "sealing plug" layer select, the thickness of sealing plug and establish procedure.

- Layer choice.

Firstly, the "sealing plug" should be built below the planned mining coal seam floor, and ensure excavating the upper coal seam not to destruct it, ensure its integrity, strong and watertight effect. Secondly, the "sealing plug" should be built in which integrity, high hardness, and has a relatively watertight effect sandstone layers, can ensure bond quality between "sealing plug" and the rock. Prevent high-pressure water flow around it and the surrounding rock ring band, erode "sealing plug" that lead its floating up and down, damage sealing effect, and occur secondary disaster.

- Identify the length of "sealing plug".

"Sealing plug" is a barrier between coal seam and the high pressure limestone water, so the thickness of the "sealing plug" decided by pressure of limestone water. The thickness can be obtained from the water inrush coefficient formula:

\[ M = \frac{kP}{T_s} \]  

(3)

\( M \) is thickness of "sealing plug", m. \( T_s \) is the water inrush coefficient, MPa/m. \( P \) is received water pressure of "sealing plug", MPa. \( k \) is an empirical coefficient, generally take 2 to 3.

- Establish procedure

First, bores construction. When drilling can not according to design produce new bores all right in collapse column, because it is often full of chaotic broken rocks and caves, so that collapse hole bury drill and sticking accidents occur frequently. To reduce treat water damage time and accelerate grouting progress, it should not directly drill in the collapse columns. Grouting bores should be complete in whole stratum around the collapse column, after drilling to scheduled depth ramp into it at about 10 m above "sealing plug". Second, pitch aggregate. Grouting bores in the "sealing plug" position pitch aggregate to fill the larger space of collapse column. Finally, grouting change into plug. After pitching aggregate, adopt the three-stage plug technology, which fill the upper section, reinforce middle section and fill the lower section. The upper and lower section adopt downwards non-pressure intermittently grouting, the middle section adopt large pulp downwards non-pressure continuously grouting. When anticipate "sealing plug" section basically complete, use downwards grouting reinforce middle section again. At this point, "sealing plug" own a cover and bottom, can prevent grout huge loss, also pressurized grouting and rapid form a dense and solid "sealing plug." As shown in Fig. 2.

(2) Directional drainage grouting reinforce "sealing plug"

The joint of "sealing plug" and surrounding rock and the fracture zone around collapse column exists weak part affected by the number of grouting holes, grouting process, bond quality, hydrodynamic conditions (especially hydrostatic conditions) and other complex factors. Therefore, it is necessary to strengthen it. Directional drainage grouting can quickly and efficiently improve and reinforce the "sealing plug". Through the drainage from mine, increase the water level difference between upside and underside of the "sealing plug", use the bores transport the grout to water channels of "sealing plug" to improve the sealing quality. Save a lot of grouting bores and accelerate the rate of re-mining.
3.3. "Four-fuzziness" Water Damages

In past years, water inrush accidents of small coal mines occurred endlessly, however small coal mines often because management is not strict, result in incomplete data, difficult quickly to treat water disaster. In this paper, directional drainage grouting can treat "four-fuzziness" water damage which measurements are not allowed, water source is uncertain, water inrush location is unknown, water channels are unclear.

A small amount of bores is difficult to hit the water channels to the "four-fuzziness" water damage, so it is not an accurate bore plug them, a low utilization rate of drilling, cost large engineering and the effect is difficult to guarantee. In order to make the grout into the aggregate and reach the water points through long-distance migration and block off the water channels. Find out water sources by connectivity test in the bores with tracer reagent. Pitch aggregate attenuate pipe flow to penetration flow. Create artificial flow by change of pump output according to design migrate distance of aggregate and grout, injection amount and shape of water channels. Adopt directional drainage grouting and use the specific role of water channels, guide aggregate and grout flow along the channels to water inrush points, and gradually achieve plugging, reduce the amount of drilling and grouting. As shown in Fig. 3.
4. Applications

(1) 7222 working face occurred water inrush accident in first coal mining area of Renlou mine in March 4, 1996. The water source was deep limestone water of Ordovician, maximum water inrush 34570 m³/h, and far more than 1200 m³/h of mine's largest integrated drainage capacity result in submerging. Used directional drainage grouting to establish "sealing plug", constructed a total of 13 bores, drilling 5542.87 m, injected into a variety of grout 15032 t, high standard built "sealing plug" in collapse column. Complex stability water inflow was 240 m³/h of the total mine after grouting, while the originally stable water inflow was 270 m³/h of the total mine. Not only 100% completely plugged the 11854~34570 m³/h water inrush, but also additionally reduced original part of the normal water inflow of the mine.

(2) 8061 working face occurred lag water inrush accident of Tianhe mine in May 22, 2000. The maximum water inrush amount was about 800 m³/h, it was lack of drainage capacity result in submerging. This project is under the "four-fuzziness" conditions, which measurements are not allowed, water source is uncertain, water inrush location is unknown, water channels are unclear. Used directional drainage, make full use of available condition that bores connect to water inrush point. Artificial directional flow field was created. It was successfully completed with two bores, injection aggregate 1395 m³, cement 2006.25 t and 80 days and water shut off rate 98%.

5. Conclusions

Directional drainage grouting is based on directional drainage to create artificial flow field, lead fine aggregate and grout slow to flow through the water channels, gradually to plug and reinforce works to completely achieve grouting. Mainly used in tunnel closure, establish a "sealing plug" in collapse column and "four-fuzziness" water damage of small coal mines. There are better treatment effect, economic benefit and prominent social significance.

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