Integrated Study on the Grouting Effect Testing Method for Fully-mechanized Caving Face Based on Highly Confined Water

Xun Chen¹,², Meng Xu¹,*, Lisheng Xu¹, Longfei Wang¹

1 School of Geosciences and Info-Physics, Central South University, Changsha, Hunan, 410083, China
2 Changsha Aeronautical Vocational and Technical College, Changsha, Hunan, 410124, China

Email: sky1125baby@163.com

Abstract — The grouting technology has been widely applied in various underground engineering, and its effect reflects the quality of the project due to the concealable nature of the grouting engineering. As an important accessorius method for underground engineering, the grouting technology plays a vital role in the transformation of the mining floor over highly confined water, the water blockage by grouting for the fault, the reinforcement of the loose floor and crushed zone, the subsidence control, and so on. In addition, the grouting effect testing technology is of great significance to the grouting quality. This paper will take Baishaoping mine of Hunan Coal Industry Group as the test base and adopt the P-Q-t curve method during grouting, sampling by excavation method, digital drill hole TV technology, geophysical prospecting technology and inspection hole permeability coefficient testing method to examine the grouting effect of the caving face floor and monitor the water inflow of the caving face. According to the testing and monitoring results, the water-rich area disappears and the stratum’s electrical resistivity increases after the grouting. The floor stratum is more integrated and the drill hole inflow drops by 93.3% after the grouting. The stratum’s permeability coefficient is between 1.62×10⁻⁵ and 1.74×10⁻⁵ cm/s after the grouting. The number of fractures decreases by 35 and the fractures are much narrower after the grouting. The P-Q-t curve method is based on constant pressure and quantity, and the grouting will be completed when the grouting pressure reaches the preset one and the grouting speed remains less than 5L/min for over 30 minutes. The safe mining can be achieved when the water inflow during the stoping of the caving face remains below 60m³/h and the discharge capacity of the caving face.

Keywords - Grouting effect; testing method; highly confined water

I. INTRODUCTION

The grouting technology has been widely used in water blockage and stratum improvement since it was invented by French engineer Charles Berigny in 1802. At present, the grouting technology has been extended to various industries such as coal, mining, hydropower, municipal construction, railway and military industry as well as all aspects of underground engineering. Moreover, the grouting technology plays a vital role in the foundation reinforcement, water blockage by grouting, backfilling and settling prevention, deviation rectification for housing, landslide prevention and control, deformation control, collapse treatment, interception curtain, subsidence control, leakage control, seepage prevention of dam foundation, gas overflow control, protection of old structures, crack repair, and so on. For the underground engineering, with the continuous stopping of coal resources, the shallow coal seam is nearly exhausted [1] and the mining has to be extended to the deeper stratum thus leading to risks from the floor confined water [2, 3]. One of the key technical issues for safe production is to reinforce and reconstruct the stopping face floor under risks arising from the confined water by grouting [4]. However, as the grouting works is concealed, the existing testing method for grouting effect is limited [5, 6] and not mature. The testing has always been a weak link in the grouting construction procedures and no consummate standard can be referred to[7]. The common testing methods include inspection hole method, analytical method, geophysical prospecting technology and sampling by excavation method[8-10].

Regarding the study on the grouting effect testing, CHEN Ming [11] et al used the direct current electric method to test the floor before and after mining and analyze the grouting effect by comparing the resistance values before and after mining. Wu Huozhen [12] et al proposed to use the geological radar oscillogram to test the grouting effect by combining the propagation characteristics of electromagnetic wave in multiple media. Xue Zongjian [13] utilized the water inflow during drilling to judge the existence of any obvious geologic structural fracture in front of the tunnel. LIU Zhigu [14] adopted the secondary electrical method to detect any electrical resistivity abnormality and rock core verification and grouting filling method to assess the grouting effect. XU Yanchun [15] employed the grouting hole testing method to study the grouting effect of the floor and based on the study results, the reinforcement effect by grouting can be assessed and the grout concentration can be selected later. Wang Dequan [16] et al adopted the mine transient electromagnetic method (TDM) to test the water hazard position of the caving face floor and found that the floor stratum was effectively reinforced after the grouting as its resistance was increased significantly. HUANG Xiaoguang [17] et al evaluated the floor grouting effect based on the occurrence of any water bursting accident.

For those above studies, only one method can be generally utilized to evaluate the grouting effect but the results are independent and not correlative thus lowering the...
accuracy significantly. In this paper, the first mining face of Baishanping mine is taken as the test face and the testing methods of P-Q-t curve method during grouting, sampling by excavation method, digital drill hole TV technology, geophysical prospecting technology and inspection hole permeability coefficient testing method are used collectively to assess the floor grouting effect of the first mining face in a macroscopic manner and the results can be used as reference for other similar works.

II. PROJECT PROFILE

Baishanping mine of Baisha Coal and Power Group has been designed with a capacity of 1.2Mt/a. The caving face for this test is face 5-101 and has a floor elevation of +1230~+1300 m ASL, a strike length of 585 m and an inclined length of 105 m. The main mining coal seam is 5#, with an average thickness of 10.3 m and a dip angle of 35°. The full-mechanized caving mining technology is used. The coal seam roof is mainly composed of carbonates of medium-hard rocks with high strength and blocky structure therefore is very stable. The floor is mainly comprised of soft rocks and the surrounding rocks are of poor quality and stability.

According to the transient electromagnetic and omnibearing wireless wave prospecting results, there are 8 faults (normal faults) on the caving face, with the maximum drop of 20m. An Ordovician limestone water aquifer exists 73m from the floor, with a water pressure up to 4MPa and water bursting coefficient of 0.05~0.065MPa/m, less than 0.1MPa/m. Once the floor is intact, the Ordovician limestone water aquifer usually will not threaten the coal mining. However, the soft or broken surrounding rocks, the existence of structures and the occurrence of water burst accidents of nearby mines (water bursting coefficient: 0.015~0.059MPa/m) would increase the probability of water burst accidents of this caving face and therefore urging proper measures.

Crushed zones are developed in the floor, especially in the section of 110~550m, which has serious effects on the rock mass and damages the stratum integrity. The impervious performance is poor and even seepage deformation and fracture occur in case of any deformation of the surrounding rocks. If the caving face stoping is through the structures or crushed zones, proper reinforcement and reconstruction by grouting measures can be taken to control the safety risks in an effective manner.

The whole-floor grouting scheme is put forward based on the actual geological conditions to ensure the stoping safety of the caving face. The depth of the grouting drill hole finished is 20m from the surface of the Ordovician limestone water aquifer, with the maximum drilling depth of 215m, minimum drilling depth of 96m, total grouting quantity of 20,469m³ and average grouting quantity of 2.03m³/m.

III. METHODS

In the grouting, the P-Q-t curve method during grouting, sampling by excavation method, digital drill hole TV technology, geophysical prospecting technology and inspection hole permeability coefficient testing method are employed to test the grouting effect comprehensively. If the grouting fails to meet the stopping requirement, supplemental grouting should be performed locally until the grouting effect is acceptable. The comprehensive testing method system for reinforcement by grouting of the coal seam floor is shown in Figure 1 and Table I.

TABLE I. COMPREHENSIVE TESTING METHOD SYSTEM FOR REINFORCEMENT BY GROUTING OF THE COAL SEAM FLOOR

<table>
<thead>
<tr>
<th>Method</th>
<th>Performance index</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-Q-t Curve Method</td>
<td>Grouting pressure</td>
</tr>
<tr>
<td>Sampling by excavation Method</td>
<td>Water inflow</td>
</tr>
<tr>
<td>Digital Drill Hole TV Technology</td>
<td>Fracture filling</td>
</tr>
<tr>
<td>Geophysical Prospecting Technology</td>
<td>Electrical resistivity characteristics</td>
</tr>
<tr>
<td>Inspection Hole Permeability Coefficient Testing Method</td>
<td>Permeability coefficient</td>
</tr>
</tbody>
</table>

A. P-Q-t Curve Method During Grouting

The P-Q-t curve method during grouting refers to the piloting of pressure-time and grouting quantity-time curves based on the pressure and grouting quantity recording in the grouting process and the analysis of the grouting effect based on the geologic features, grouting process, status of equipment and P-Q-t curve and the grouting effect elevation is very effective.

The grouting is compaction grouting in which the pressure is controlled to limit the grouting quantity and a grouting parameter recorder is used for automatic recording. The grouting data is shown in Figure 2 and 3.
pressure is limited to 4~5MPa and the completion of each circulating grouting for a single hole depends on the main controlled grouting pressure and flow.

On the basis of the constant pressure and quantity, the grouting can be considered to be completed once the grouting pressure reaches the preset one and the grouting speed remains less than 5L/min for over 30 minutes. If the grouting pressure remains not rising for a long time and the grouting quantity reaches the preset one, the grout condensation time should be reduced and the corresponding measures should be taken to control the quantity. Once the grouting hole meets the preset standard, the grouting can be stopped.

**B. Grouting Effect Testing with Sampling by excavation Method**

The sampling by excavation method refers to the method with which the grouting effect is assessed by comparing the mechanical parameters of the rock core before and after grouting (such as compressive strength and water content) or the water inflow of the drill hole before and after grouting. This method is necessary to the water blockage by grouting works. The rock sample is shown in Figure 3, the comparison of mechanical parameters before and after grouting is shown in Table I and the water inflow before and after grouting is displayed in Table II.

According to the mechanical parameters before and after grouting as shown in Table II, the compressive strength of the stratum before grouting is 13.2MPa and rises to 20.5MPa after three days and to 24.3MPa after ten days. The water content after grouting drops to 45.3% from 98.2%, the porosity decreases from 82.6% to 17.2% and the density increases from 1.46 to 1.62. All the mechanics indexes have changed dramatically after grouting and the grouting effect is significant according to the comprehensive analysis results.

<table>
<thead>
<tr>
<th>Hole Number</th>
<th>water inflow(before grouting),M3/H</th>
<th>water inflow(after grouting),M3/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>JC1</td>
<td>31.2</td>
<td>1.4</td>
</tr>
<tr>
<td>JC2</td>
<td>42.7</td>
<td>2.5</td>
</tr>
<tr>
<td>JC3</td>
<td>34.5</td>
<td>2.8</td>
</tr>
<tr>
<td>JC4</td>
<td>40.1</td>
<td>3.1</td>
</tr>
<tr>
<td>JC5</td>
<td>43.9</td>
<td>3.0</td>
</tr>
<tr>
<td>JC6</td>
<td>50.2</td>
<td>1.9</td>
</tr>
<tr>
<td>JC7</td>
<td>35.6</td>
<td>2.7</td>
</tr>
<tr>
<td>JC8</td>
<td>30.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>
In accordance with the water inflow data of the drill hole before and after grouting in Figure 4, the water inflow before grouting ranges between 30 and 55 m³/h and it drops below 2 m³/h after grouting, which means that the initial fracture and water-rich area are almost fully covered after grouting thus leading to smaller water inflow. These results suggest that the grouting effect is significant.

C. Grouting Effect Testing with Digital Drill Hole TV Technology

The internal rock core image of the drill hole can be obtained by using the digital drill hole and can truly reflect the rock mass characteristics of the stratum and generate the stratum attitude image by digital processing of the information collected by the drill. Utilizing this technology, not only the geologic phenomena can be observed, but also data processing can be achieved and technical support can be provided for obtaining accurate stratum information. The grouting effect can then be evaluated based on the fracture filling after the grouting. The drill hole TV system is shown in Figure 6, the image processing system is displayed in Figure 7 and the fracture filling after the grouting is demonstrated in Figure 5.

Based on the fracture statistics of the rock core image obtained by the drill hole TV before and after grouting, there are 48 fractures before grouting, among which 6 have a length of more than 5 mm, 6 have a length of 4~5 mm, 12 of 3~4 mm, 9 of 2~3 mm, 10 of 1~2 mm and 5 of 0~1 mm. There are 13 fractures after grouting, among which only one has a length of 1~2 mm and the other 12 have a length of 0~1 mm. The distribution of these fractures is shown in Table IV.

### TABLE III  TABLE OF MECHANICAL PARAMETERS

<table>
<thead>
<tr>
<th>Mechanics Indexes</th>
<th>Compressive strength /MPa</th>
<th>Flexural strength /MPa</th>
<th>Tensile strength /MPa</th>
<th>Water content /%</th>
<th>Density /g·cm⁻³</th>
<th>Porosity /%</th>
<th>Saturation /%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before grouting</td>
<td>13.1</td>
<td>1.2</td>
<td>0.5</td>
<td>98.5</td>
<td>1.46</td>
<td>82.9</td>
<td>100</td>
</tr>
<tr>
<td>after grouting</td>
<td>20.4</td>
<td>3.4</td>
<td>1.6</td>
<td>45.3</td>
<td>1.62</td>
<td>17.2</td>
<td>95.4</td>
</tr>
<tr>
<td>(4d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after grouting</td>
<td>24.5</td>
<td>4.3</td>
<td>2.6</td>
<td>42.1</td>
<td>1.68</td>
<td>16.8</td>
<td>94.7</td>
</tr>
<tr>
<td>(8d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In accordance with the water inflow data of the drill hole before and after grouting in Figure 4, the water inflow before grouting ranges between 30 and 55 m³/h and it drops below 2 m³/h after grouting, which means that the initial fracture and water-rich area are almost fully covered after grouting thus leading to smaller water inflow. These results suggest that the grouting effect is significant.

Based on the fracture statistics of the rock core image obtained by the drill hole TV before and after grouting, there are 48 fractures before grouting, among which 6 have a length of more than 5 mm, 6 have a length of 4~5 mm, 12 of 3~4 mm, 9 of 2~3 mm, 10 of 1~2 mm and 5 of 0~1 mm. There are 13 fractures after grouting, among which only one has a length of 1~2 mm and the other 12 have a length of 0~1 mm. The distribution of these fractures is shown in Table IV.

### TABLE IV  DISTRIBUTION CHART OF FRACTURES

<table>
<thead>
<tr>
<th>Fracture Width mm</th>
<th>0-1</th>
<th>1-2</th>
<th>2-3</th>
<th>3-4</th>
<th>4-5</th>
<th>5-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture number (before grouting)</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Fracture number (after grouting)</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 4. Drill hole TV instrument

Figure 5. Fracture filling after grouting.
The fractures after grouting are much narrower, and their width is primarily between 0 and 1mm with most less than 0.15mm. Based on the analysis results, ordinary Portland cement grout is hard to permeate fractures with a length of 0.15mm and therefore, these fractures are not filled with grout. However, as larger fractures are not completely filled with grout thus leading to smaller fractures, the number of fractures with a length of 0~1mm increases. The grouting effect therefore is significant according to the comprehensive analysis results.

D. Grouting Effect Testing with Geophysical Prospecting Technology

The geophysical prospecting technology is used to evaluate the grouting effect by comparing the stratum’s electrical resistivity or electromagnetic characteristics before and after grouting. The electrical resistivity characteristics before and after grouting are shown in Figure 6.

E. Grouting Effect Testing with Inspection Hole Permeability Coefficient Testing Method

The permeability coefficient testing method is a method with which the stratum is tested before and after grouting by water injection test (the system is as shown in Figure 7) and then the permeability coefficient is obtained using the following formula (see formula 1). For water lockage by grouting works, especially for the grouting interception curtain, this method is the most important and reliable one for testing the grouting effect.
\[
k = \frac{0.366Q}{ls} \log \frac{2l}{r}
\]

Where: \(k\) : permeability coefficient \((m/d)\), \(Q\): stable water injection quantity of the drill hole \((m^3)\), \(l\): length of the test section \((m)\), \(s\): head height of the drill hole \((m)\), \(r\): radius of the drill hole \((m)\).

In this test, the water injection pressure is 5Mpa. The test is performed for each section for three times and the test results of each section are the mean, and the results of all sections of the whole hole are averaged. The water injection after grouting is shown in Table II.

According to the results calculated using Formula 1, the permeability coefficient of the stratum after grouting is \(1.62\times10^{-5}~1.74\times10^{-5} /cm \cdot s\), which meets the requirement of safe mining for the caving face in theory. Therefore, the reinforcement and reconstruction by grouting has been achieved.

### IV. RESULTS AND DISCUSSION

Stopping is performed for the caving face after grouting and the water inflow of the caving face is monitored throughout the whole stopping process and the inflow curve is shown in Figure 8.

As shown in Figure 8, for the caving face during the stopping, the water inflow in the first 50m is increasing with the increase of the stopping distance and that from 50 to 275m is generally slightly decreasing and that after 275m almost remains the same. Throughout the stopping, the maximum water inflow is smaller than the discharge capacity of the caving face \((60m^3/h)\), thus satisfying the requirement of safe stopping.

### V. CONCLUSIONS

The following conclusions can be drawn after the P-Q-t curve method during grouting, sampling by excavation method, digital drill hole TV technology, geophysical prospecting technology and inspection hole permeability coefficient testing method are used to assess the reinforcement and reconstruction effect by grouting for the 5-101 caving face of Baishanping mine of Baisha Coal and Power Group and the water inflow is monitored and tested for the caving face stopping:

(a) The P-Q-t curve method takes the constant pressure and quantity to monitor the completion of the grouting. When the grouting pressure reaches the preset one and the grouting speed remains less than 5L/min for over 30 minutes, the grouting can be considered to completed. It is an effective way for improving the grouting effect to control the grouting based on the standard during the grouting process.

(b) The sampling by excavation method is used to analyze the mechanical parameters of the rock sample and the water inflow of the drill hole before and after grouting. According to the analysis results, the floor stratum is more integrated, the compressive strength increases by 11.1MPa, the flexural strength rises by 2.9MPa and the tensile strength increases by 1.9MPa after grouting. In addition, after grouting, the water content decreases from 98.2% to 45.3%, the porosity drops from 82.6 to 17.2%, the dense increases from 1.46 to 1.62 and the water inflow of the drill hole decreases by 93.3%.

(c) According to the rock core image generated using the drill hole TV technology, the number of fractures after grouting drops by 35 and the width is significantly narrowed. Meanwhile, when the fractures with a width of over 0.15mm are completely filled with grout, the stratum is filled compactly.

(d) The geophysical prospecting technology is applied to test the stratum’s electrical resistivity before and after grouting. A large water-rich area XC1 lies under the caving face before grouting and disappears and the stratum’s electrical resistivity increases after grouting.

(e) The permeability coefficient testing method is used to test the permeability coefficient of the rock mass before and after grouting. As shown by the testing results, the permeability coefficient of the drill hole stratum after grouting is \(1.62\times10^{-5}~1.74\times10^{-5}\), and in theory it meets the requirement of safe mining. Therefore, the reinforcement and reconstruction by grouting has been realized.

### ACKNOWLEDGEMENT

National Natural Science Youth Fund: Method research of Dynamic slurry density detection based on the self circulating differential pressure method for grouting (No. 51208514).

### REFERENCE

[1] CHENG Aiping, GAO Yongtao, LIANG Xingwang et al, “Dynamic forecasting of mining-induced failure depth of floor based on...
XUN CHEN et al: INTEGRATED STUDY ON THE GROUTING EFFECT TESTING METHOD FOR . . .


