Research on the influence of bottom expanding and filling on bolt sliding instability and supporting effect

Jinrui Wang *, Hua Nan and Shuai Wang
School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo 454000, China
*Corresponding author’s e-mail: 212002020060@home.hpu.edu.cn

Abstract: Aiming at the problems of soft coal roadway, such as low hardness, fracture development, poor bonding ability between anchoring agent and surrounding rock of borehole, weak shear resistance, which easily lead to resin bolt sliding instability in coal roadway. To effectively support soft coal roadway, the method of bottom expanding and filling is adopted. This method expands the hole at the bottom of the borehole and replaces the soft coal with high-strength material to achieve the same position modification of the soft coal body at the bottom of the borehole and improve the anchoring performance of bolt support. Through laboratory tests and numerical simulations, the sliding instability of the bottom reamed bolt is evaluated. The results show that, with the increase of the reaming times, the anchoring force changes in direct proportion to the reaming times, except single of the reaming times, the anchoring force increases fast under quintuple of the reaming times, and increases slowly over quintuple of the reaming times, so it is considered that quintuple reaming is the most appropriate.

1.Introduction
As the most basic component of roadway support, bolt plays a preventive role in the separation, sliding, and crack expansion of surrounding rock in Anchorage Zone, and avoids deformation, tension and shear damage of surrounding rock under pressure[1]. Compared with ordinary rock roadway, soft rock coal roadway has the characteristics of large deformation range, fast deformation speed and long deformation duration due to its low strength. The low anchoring force increases the difficulty of coal mine maintenance in the excavation and support period, and the resin bolt sliding damage is serious. According to statistics, 12000 km of new roadways are excavated every year in China's coal mines[2], and the annual renovation rate of soft rock roadways is as high as 70%, therefore, the support theory and technology of soft rock roadways has always been one of the core research contents of coal mine strata control[3-6].

The main improvement to increase the anchoring force of soft coal is to increase the anchoring force. He ManChao developed a constant resistance large deformation bolt, which can absorb dynamic impact energy and adapt to dynamic impact environment[7]. Wang Weijun pointed out that bolt support can effectively control the discontinuous deformation of the broken surrounding rock, improve the continuity and overall stability of surrounding rock of deep roadway[8]. Wang Hongtao and other researchers believe that in the range of one-third of the end of the anchor section, the stress of the anchor is the most concentrated, especially in the soft rock coal roadway[9]. Cheng Lixing studied the supporting method of the reamed bolt in soft rock coal body, and found that the supporting force of reamed bolt was significantly higher than that of normal anchoring[10]. Li Chao pointed out that the soft surrounding rock and insufficient anchoring force of anchorage body are the most fundamental
reasons for roadway instability[11]. Wang Zhi thought that with the increase of reaming diameter, the extrusion resistance increased obviously[12]. Zhang Hui studied the influence of bolt reaming shape on the stability of the anchorage system, and compared the influence of different reaming shapes on the anchorage force, the results show that the inverted wedge reaming bolt can significantly improve the ability of the anchorage system[13].

This paper is to study how to improve the anchoring performance of bolts in soft coal roadway, proposed a method of bottom expanding and filling. This method can improve the surrounding rock properties of the bolt hole anchoring section, increase the bonding force between the anchoring agent and surrounding rock, improve the stability of the anchoring system, and reduce the slip damage of resin bolt support in soft coal roadway. Through the laboratory test and numerical simulation, the anchorage performance of normal anchorage and bottom reinforcement anchorage is compared, and the influence of reaming ratio of hole enlargement on the anchorage effect is more significant.

2. Laboratory test

2.1. Material ratio test

To simulate the situation of the coal body, the surrounding rock adopts a similar material ratio test. A similar material aggregate in this test is coal particles with particle size less than 5 mm, and the cement is ordinary Portland 325 cement. Similar material ratio is 1:0.2, 1:0.3, 1:0.4, 1:0.5, 1:0.6, water-cement ratio is 1:4. Using the RMT-150C rock mechanics experimental system, the average uniaxial compressive strength of different ratios respectively are 3.20 MPa, 6.49 MPa, 9.7 MPa, 13.0 MPa, and 16.6 MPa. According to the characteristic parameters of upper roadway surrounding rock of 1502 working face in 1# well of Hongni Mining Co., Ltd., the uniaxial compressive strength of similar materials is about 3.20 MPa, so triaxial compression test is carried out on the similar material ratio of 1:0.2 group. After experimental comparison, the final decision was the ratio of aggregate and cement is determined to be 1:0.2, and the water-cement ratio is 1:4.

2.2. Test scheme

The pull-out test was carried out in the laboratory. The normal anchoring group was set as the reference group, and the bottom expanding and filling anchoring group was set as the experimental group. The hole expanding diameter was 1 to 5 times the bolt diameter respectively. The anchorage form of the experimental group and the reference group is end anchorage, the anchorage length is 350 mm, the diameter of the reaming is 30 mm, the diameter of the bolt is 20 mm, the length is 1.2 m, the type of the anchorage agent is K2335, and the size of the surrounding rock Φ 500 mm * 1000 mm.

The air drill is used to drill the surrounding rock after maintenance and drying. The self-made double-wing reaming device is used to enlarge the hole in the bottom expanding and filling group, then the manual hydraulic pump and grouting pipe are used to fill the hole, the grouting pipe is pulled out after the filling body solidifies. At this time, the anchoring agent is filled in the normal anchoring and bottom expanding and filling anchoring group, and then the anchor rod is installed, the anchor rod is pulled out by the anchor rod drawing instrument, the load is extracted by the anchor (cable) dynamometer, and the displacement is monitored by a micrometer.

2.3. Results analysis

Pull-out tests were carried out on one group of normal anchorage and five groups of bottom expansion anchorage with different reaming ratios. The results show that there are obvious differences in anchorage force with different reaming ratios. See table 1 for details. Among them, the maximum anchoring force (17.41 KN and 19.56 KN respectively) is not significantly different from the normal anchoring force (18.70 KN), the maximum anchoring force (52.10 KN) is 5 times of the bottom expansion, which is 2.79 times of the normal anchoring.
Table 1. Anchoring force of different reaming times.

| Group            | Normal anchorage | One time reaming | Double reaming | Triple reaming | Quadruple reaming | Quintuple reaming |
|------------------|------------------|------------------|----------------|----------------|-------------------|------------------|
| Anchoring force  | 18.7             | 17.41            | 19.56          | 35.10          | 43.47             | 52.10            |
| Growth rate      | 0                | -6.9%            | 4.6%           | 87.7%          | 132.5%            | 178.6%           |

Figure 1. Comparison of axial load between normal anchorage and reverse filling anchorage at different expansion multiples.

Figure 1 shows the variation curve of the bolt pull-out test data under six anchoring states. The ultimate bearing capacity of the double bottom expanding and filling anchorage system is roughly the same as that of the normal anchorage system, and the variation trend and increasing speed of the pull-out force curve are similar. However, the increase of ultimate bearing capacity and pull-out force of triple, quadruple and quintuple bottom expansion anchorage is significantly greater than that of normal anchorage, and quintuple bottom expansion anchorage has the largest ultimate bearing capacity and the fastest increase of pull-out force.

With the increase of the maximum reaming diameter, the increase of the ultimate bearing capacity of the anchoring system tends to be gentle. After the damage of the anchorage system, the residual anchoring force of the quintuple bottom expansion anchorage is the largest. The reason is that after quintuple of bottom expansion, the filling can quickly reach the ultimate bearing capacity of the anchorage system in the shortest distance, and quickly play the role of resin bolt support, which makes the effect of maintaining the integrity of surrounding rock and resisting the deformation of surrounding rock better than normal anchorage. At the same time, the backfill indirectly acts as an effective cushion between the anchorage agent and the surrounding rock of the borehole. The bearing capacity of the anchorage acceptor is strengthened, and the stability of the anchorage system is better under the same external load.

3. Numerical simulation
The laboratory test results show that the anchoring force of resin bolt increases with the increase of reaming diameter, but due to the limitation of reaming conditions, it is impossible to carry out larger reaming, and the anchoring effect of more than a quintuple of reaming is unknown. Therefore, ABAQUS/CAE software is used to carry out numerical simulation experiments for more than Quintuple reaming, and six groups of indoor tests are carried out to simulate the tensile stress of each part Details of displacement changes. Through comparative and comprehensive analysis, the best reaming ratio is determined to make sufficient preparation for a field test.
3.1. Parameter setting of numerical simulation

A simulation test is a group of normal anchorage and single, double, triple, fourfold, quintuple, six times, eight times, and ten times of bottom expansion anchorage. The normal anchoring model includes three parts: surrounding rock, anchor rod, and anchoring agent, as shown in figure 2 (a). In addition to the above components, the bottom expanding and filling anchorage model also includes the filling body components, as shown in figure 2 (b). The positive direction of the path selection for extracting data is from the free segment of the anchor to the anchorage segment, as shown in figure 2 (c). The simulation condition is based on the mechanical condition of the surrounding rock of the roadway on the 1502 working face. The axial load of 150 KN is applied at the free end of the bolt. The bolt is pulled out by numerical simulation. After the damage of anchoring between the anchoring agent and the borehole wall, a comprehensive analysis is made, the results show that the distribution of displacement and tensile stress of anchor and the change of anchoring force in the process of bolt instability.

3.2. Numerical simulation results

In the numerical simulation experiments, 150 KN axial tension was applied to the free end of the anchor rod for both the conventional anchoring state and the bottom expanding and filling anchoring state. It can be seen from figure 3 that with the increase of the maximum diameter of the reaming hole, the stress of the hole wall and the stress of the anchoring agent increase significantly, and the anchoring ability of the bottom expanding and filling anchoring system increases significantly.

During normal anchoring, the maximum tensile stress of the borehole surrounding rock is 49.69 MPa, and the maximum tensile stress of the anchoring agent is 68 MPa. When quintuple of bottom expanding and filling anchorage, the maximum tensile stress of surrounding rock is 190 MPa, increasing by 187.78%, the maximum tensile stress of anchorage agent is 142 MPa, increasing by 179.41%. When six times of bottom expanding and filling anchorage, the maximum tensile stress of surrounding rock is 194 MPa, increasing by 199.8%, and the maximum tensile stress of anchorage agent is 149 MPa, increasing by 185.29%. When eight times of bottom expanding and filling anchorage, the maximum tensile stress of surrounding rock is 197 MPa, increasing by 205.9%, and the maximum tensile stress of anchorage agent is 152 MPa, increasing by 189.70%. When ten times of bottom expanding and filling anchorage, the maximum tensile stress of surrounding rock is 199 MPa, increasing by 207.9%, and the maximum tensile stress of anchorage agent is 153 MPa, increasing by 192.79%.
Table 2. Displacement values of components with different reaming times.

| Reaming times | Filling body displacement (mm) | Anchoring agent displacement (mm) | Surrounding rock displacement (mm) |
|---------------|-------------------------------|----------------------------------|----------------------------------|
| 1             | 2.447                         | 2.280                            | 2.205                            |
| 2             | 1.153                         | 1.910                            | 1.000                            |
| 3             | 1.030                         | 1.850                            | 0.386                            |
| 4             | 0.396                         | 0.696                            | 0.262                            |
| 5             | 0.280                         | 0.622                            | 0.231                            |
| 6             | 0.251                         | 0.612                            | 0.200                            |
| 8             | 0.225                         | 0.585                            | 0.190                            |
| 10            | 0.198                         | 0.555                            | 0.190                            |

The displacement values of various components with different reaming times are shown in table 2. The displacement of conventional anchorage filling body is 12.36 times that of ten times reaming filling body, the displacement of anchorage agent is 4.12 times that of ten times reaming filling body, and the displacement of surrounding rock is 11.61 times that of ten times reaming filling body. The difference between the axial stabilization force of quintuple reaming anchorage, six times reaming anchorage and eight times reaming anchorage and ten times reaming anchorage is small, and the displacement difference is small. Although the displacement of each component of fourfold reaming has improved significantly compared with that of lower fourfold reaming, the effect of quintuple reaming is still greater than that of fourfold reaming compared with the difference of displacement of each component of six, eight and ten times reaming. The reason why the anchoring effect of quintuple or more reaming is the same is that the force between the filling body and the surrounding rock in the quintuple bottom reaming is enough to bear the ultimate bond strength between the anchoring agent and the surrounding rock of the borehole with an anchoring length of 350 mm, and increasing the reaming multiplier does not improve the bond strength between the surrounding rock of the borehole and the anchoring any more.

In the field experiment, the higher the reaming ratio is, the greater the workload of reaming is. Although the anchoring effect of ten times of reaming is slightly better than that of quintuple of reaming, the diameter of reaming is twice that of quintuple reaming. Quintuple of bottom expansion is the most suitable expansion ratio to prevent bolt sliding and instability.

3.3. Simulation comparison results of quintuple enlarged bottom filling anchorage and normal anchorage

Axial loads of 30 KN, 60 KN, 90 KN, 120 KN, and 150 KN were applied to the free end of the anchor rod, and it was assumed that the anchorants were all in uniform contact with the surrounding rock to compare the effect of normal anchoring with that of five times expanded bottom fill anchoring.

It can be seen from figure 4, when the bolt is subjected to axial force, the surrounding rock at the starting point compresses the surrounding rock of the borehole due to the stress of the bolt, which makes the tensile stress distribution curve of the surrounding rock have a rising stage. The tensile stress concentration and maximum value appear on the surface of the borehole surrounding the rock. With the increase of the load, the range of the tensile stress concentration increases, and the maximum value of the tensile stress of the borehole surrounding rock also increases from 11.28 Mpa to 49.69 Mpa, so that the borehole surrounding rock at the boundary between the anchored and unanchored sections is the first to show the phenomenon of tensile stress concentration, and the range of stress concentration expands gradually to both ends with the increase of load.

It can be seen from figure 5 that under the state of quintuple bottom expansion, with the increase of axial load, the tensile stress concentration of surrounding rock increases from 32.7 Mpa to 143 MPa. The tensile stress concentration starts from the minimum diameter of the reaming hole and then extends to both ends. With the increase of axial load, the extension range to both ends is larger. This indicates
that the physical and mechanical properties of the surrounding rock of the anchorage section are improved, and the bearing capacity of the anchorage section is improved. The bonding force between the anchorage agent and the filling body is greater than that between the anchorage agents, which makes the filling body and the anchorage system almost move synchronously in the initial stage of stress. With the increase of load, the range of stress concentration to both ends gradually increases, but the range and speed to the positive direction of the path is greater than that of the other end, the range of expansion is less than that of the normal anchorage, and the peak value of stress concentration is far greater than that of the normal anchorage.

Figure 4. Tensile stress cloud diagram of normal anchorage surrounding rock.

Figure 5. Tensile stress cloud diagram of quintuple reaming surrounding rock.

4. Conclusion
Based on the field research, this paper systematically investigates the mechanism and effect of expanding bottom and filling anchorage on preventing the slippage of resin anchors in coal roadway, using laboratory tests and numerical simulations, and draws the following main conclusions.

(1) In view of the main factors of resin bolt sliding damage in coal roadway and the physical and mechanical characteristics of surrounding rock of borehole, the basic idea of bottom expanding and filling anchoring is put forward, and the mechanical model of surrounding rock during hole expanding is established. Through the theoretical calculation of the anchorage system, the feasibility of the anchorage system is determined.

(2) Laboratory tests were conducted by comparing normal anchorage with five different types of bottom-reinforced anchorage with different reaming diameters, and the test results showed that the
ultimate bearing capacity of normal anchorage was 18.7 KN, the ultimate bearing capacity of one time bottom-reinforced anchorage was 17.41 KN, an increase of -6.9%, the ultimate bearing capacity of double bottom expansion anchorage was 19.56 KN, an increase of 4.6%, and the ultimate bearing capacity of triple bottom expansion anchorage was 35.1 KN, an increase of 87.7%, the ultimate bearing capacity of quadruple bottom expansion fill is 43.47 KN, an increase of 132.5%, and the ultimate bearing capacity of quadruple expansion anchorage was 52.1 KN, an increase of 178%.

(3) Using ABAQUS / CAE software for numerical simulation test, it is concluded that the displacement of anchorage agent, filling body and surrounding rock in the bottom expanding and filling anchorage section is obviously less than that in the normal anchorage section and drilling surrounding rock.

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