Bolting United with Grouting for Reinforcement of Roadway Surrounding Rock

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Abstract: A joint technique, the combination of bolting and grouting, devised to control the stability of underground roadway within weak strata or under high ground pressure is introduced in this paper. Prescribed concurrently are the sealing technique of grouting hole in relation to this unique joint technique. Having been used extensively in coal mines in China, such a new type of bolting and grouting technique has shown its exceptional advantages in enhancing the strength and integrity of surrounding rock and the promotion of bolting effectiveness in this kind of surrounding rock.

Key Words: bolt, grout, roadway, stability control, weak rock

1 Introduction

Bolting, cable bolting and their variants have been developed extensively and widely brought into use in the world for the control of underground roadway stability. Great benefits have been obtained both technically and economically in some specific geotechnical circumstance. However their application to the control of the stability of roadway in weak strata or seriously affected by the active abutment pressure caused by mining activity seldom proves effective. This results from the following two reasons:

- The tremendous deformation of the roadway surrounding rock caused either by the weakness of the surrounding rock or by the big ratio of ground pressure to rock strength together with the great force applied on the bolt being excessive of its capability to keep the roadway in good condition.

- The weakness of the surrounding rock reduces the anchoring effectiveness of the bolt installed in it and makes it impossible for the bolt to bring its potential role into full play.

Therefore, the radical approach to enhance the applicability of bolt and its effectiveness in the control of weak rock is to improve the properties of the roadway surrounding rock in advance which the bolt is to be installed in and work with. It is known publicly that grouting into the fissure and crack in the surrounding rock of the roadway is a very practicable way for this purpose. The combination of the bolting and grouting is especially designed to control the roadways under this kind of circumstance. Applications carried out in underground roadway in different coal mines and field investigation of development of the stability of these roadways showed the fantastic results of roadway stability maintenance on the grounds of the promotion of the properties of the surrounding rock after being bolted and grouted.
2 The structure of grouting bolt and its working mechanism
The special characteristic of the combination of bolting and grouting is to use the bolt as packer pipe and injection pipe concurrently, use the same borehole for both the installation of bolt and performance of grouting. This bolt is therefore called grouting bolt. Grouting bolt can be made of standard thick wall seamless steel pipe or particularly designed steel pipe. The determination of its size depends on geotechnical conditions such as the dimension of the roadway, the width of the broken zone and the properties of surrounding rock with which the bolt is to work, the ground pressure, and so on. Generally, the outer diameter of the bolt ranges from 20 to 30 mm, the inner diameter is about 6 to 8 mm and the length varies from 2.5 to 3.5 m. As shown in Fig. 1, one end of the grouting bolt in the toe of the borehole is the grouting sector with several holes of 4 mm in diameter and a fixed friction ring on it. The other end of the grouting bolt is the thread sector for the installation of back-up plate and nut. This thread is also used to link the couple, cock and grouting slurry intake.

![Figure 1 The structure of the grouting bolt](image)

1-Grouting bolt; 2-Back-up plate; 3-Nut; 4-Obturators; 5-Grouting outlet; 6-Surrounding rock of the borehole; 7-Friction ring

The obturator used to seal the borehole is a specially designed roll made from Rapidly Hardening and Swelling Cement (RHSC). Its outer and inner diameters are dominated by the selected diameters of borehole and the outer diameter of grouting bolt. Its length is normally 250 mm. Two to four RHSC rolls are employed depending upon the degree to which the surrounding rock of the roadway cracked, the value of the grouting pressure and other grouting parameter such as the viscosity or density of the grouting slurry.

The distribution of grouting bolts depends upon the degree of the jointing in the rock, the length of the bolt, the selected grouting pressure, the permeability of the rock and the characteristics of grouting slurry. The spacing of the individual borehole fans usually ranges from 1.0 to 1.5 m. In each fan, the boreholes are 0.8 to 1.2 m apart on the surface of surrounding rock of the roadway and 2.0 to 2.5 m apart on the circumference. Boreholes in the neighbouring fans are staggered.

This specially designed bolt can work in the same way as normal fully grouted bolt after the completion of grouting through the bolt itself. The combination of bolting and grouting can make the structure of the loose surrounding rock more integral, enhance its strength, Cohesion and Friction Angle, increase its capability of resisting water erosion especially for the weak rock being prone to be weakened and promote the stability of rock structure.

3 The operating procedure of grouting-bolting technique
The whole procedure of the grouting-bolting technique comprises of four steps as shown in Figure 2.

![Operating procedure of the combination of bolting and grouting](Image)

(a) Drilling borehole; (b) Installing grouting bolt along with obturators; (c) Grouting

3.1 Sealing the surface of surrounding rock

The surface of the roadway surrounding rock is the most jointedly developed part of the surrounding rock and must be sealed properly around one week in advance before the implementation of grouting. Otherwise, the grouting slurry will flow into the roadway instead of penetrating into the joints of the broken surrounding rock because the closer to the surface of the surrounding rock, the easier for the grouting slurry to get through. Shotcrete is therefore usually employed for this purpose. Its thickness is 30 to 50 mm.

3.2 Drilling and flushing the borehole

Borehole can be made by rotary plain-hole drilling or rotary percussive drilling depending on the hardness of the rock. Its diameter and depth are separately dictated by the outer diameter of the RHSC roll and bolt length. Water flushing or gas flushing has to be conducted to flush all the drillings out of the borehole so that the grouting efficiency and adhesive force among bolt, cement and the wall of borehole can be achieved to their best.

3.3 Installing of bolt and obturators

Two to four RHSC rolls to be used as obturators need to be soaked in water for about half minute before being put on the bolt one close to another. Then, the bolt is put into the flushed borehole with the soaked RHSC being located as close to the hole collar as possible. The good match among the diameters of bolt, RHSC roll and borehole along with the rapid expansion and hardening of RHSC rolls make the bolt fixed immediately and firmly.

3.4 Grouting implementation

Grouting commences immediately after the grouting bolts, cocks, manometers, grouting slurry delivery pipe and pump have been well connected. As shown in Figure 2(c), grouting can be implemented simultaneously on multiple grouting bolts with each grouting bolt being controlled individually by its own manometer.
4 Case study

The united technique of grouting and bolting has shown its exceptional advantages in the control of roadway either within weak surrounding rock or suffering high active abutment pressure caused by mining activities. The following case prescribes briefly its successful practices in China coal mining industry.

4.1 Basic information about the applied roadway

The main haulage roadway excavated in sandy shale in Qisan Colliery is situated at the depth of 600 m. It had a designed cross section area of 11.08 m² and initially supported by slotted bolt and shotcrete. This roadway was kept in good condition and had served the transportation of about 0.5 mt coal per year for more than one decade before it started to suffer the active abutment pressure arisen by the mining activity of the longwall faces vertically 25 m above in the upper seam. These longwall faces advanced in the direction perpendicular to the roadway (see Figure 3). The influence of the abutment pressure on the behavior of the roadway surrounding rock started noticeably when the longwall face was sitting 150m prior to the roadway and disappeared gradually after it left the roadway 100 m away.

Framed steel support set was used as an expedient measure to maintain the safe use of this roadway when it experienced the impact of the first longwall face above (Longwall face No 1 in Figure 3). Unfortunately, this temporary support was not adequate to resist the huge abutment pressure and a large amount of deformation of surrounding rock. Consequently, damage of support sets occurred and frequently short cease of coal transportation became inevitable during the period of roadway rehabilitation. Additionally, the installation of the framed set in the roadway reduced its effective cross section area and lead the excessive speed of the wind in it. The condition of roadway maintenance and deformation during the course of the longwall face No 1 advancing from the right side of the roadway to its left side was shown in Figure 4 and 5. It can be seen from Figure 4 that the closure speed of the two roadway walls increased evidently when the roadway was on the right side of the roadway 60 m horizontally prior to the longwall face No 1 above. The total wall-to-wall closure of 80 mm was accumulated during the course of longwall face No 1 approaching the roadway from its right side 60 m away until 5 m away where the roadway reached its peak deformation speed of 6 mm/day. Figure 5 reflects the serious roof scaling along with big reduction of roadway cross section area taking place as a result of the tremendous deformation of roadway surrounding rock during the impacting period of active abutment pressure.

![Figure 3 Geometrical relation between the roadway and the longwall faces above](image-url)
Figure 4 Deformation of the surrounding rock

- ■ - Wall-to-wall closure amount and speed at the steel set additionally supported section;
- • X - Wall-to-wall closure amount and speed at the bolting and grouting reinforced section;

(a)
(b)

Figure 5 The roadway condition at different section

(a)-Roadway additionally supported by steel set; (b)-Roadway reinforced by grouting bolt

In this case, grouting and bolting united technique was applied to the vicinity of the roadway which is to suffer the impact of the active abutment pressure caused by longwall face No 2. Borehole with 42 mm in diameter and 2.5 m long was drilled with the fan spacing of 1.5 m and 1.0 m apart between the two boreholes in the fan 10 days after 50 mm shotcrete had been sprayed to seal the surface of the surrounding rock. Four RHSC rolls were employed to seal the borehole and fixed the grouting bolt as well. The grouting material used was Portland Cement with a small amount of additives. Four grouting bolts were grouted simultaneously by the same pump (see Figure 2c). The designed grouting pressure was 4 MPa which was monitored by the exclusive manometer of each grouting bolt.

4.2 The behaviour of the grouted and bolted surrounding rock of roadway

Deformation of the roadway surrounding rock was measured and presented in Figure 4. It can be found that, in contrast with the situation of the framed steel set supported section, the grouted and bolted section was maintained in extremely good condition (see Figure 5(b)) with its highest wall-to-wall closure rate of 1.25 mm/day occurring when the work face above was sitting 5 m horizontally prior to it. The totally accumulative wall-to-wall closure is only 20 mm during the course of the longwall face No 2 approaching the roadway from its right side 60 m away till 5 m away. The wall-to-wall closure taking place while the longwall face No 2 started to leave the roadway to 100 m away is also only 25% of the section supported by steel set.
4.3 The reinforcing effect of bolting united grouting on the surrounding rock

Drill cores were collected before and after the performance of bolted grouting. Properties of the core sample and the results of supersonic test carried out in the core holes are listed in Table 1. It indicates that the mechanical properties of surrounding rock after bolted grouting were greatly improved. The enhancement of supersonic speed reveals that the integrity of the surrounding rock was upgraded greatly. That is why the bolted and grouted section of the roadway was kept in much better condition than the steel set supported section.

<table>
<thead>
<tr>
<th>items</th>
<th>Steel set supported section</th>
<th>Bolted and grouted section</th>
<th>Increase percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCS (MPa)</td>
<td>29.8</td>
<td>69.7</td>
<td>134</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>1.83</td>
<td>2.38</td>
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<td>Cohesion (MPa)</td>
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<tr>
<td>Friction angle(°)</td>
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<td>Elastic modulus (MPa)</td>
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<tr>
<td>Poisson's ratio</td>
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<td>0.2</td>
<td>-23</td>
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<td>Sound wave speed(m/s)</td>
<td>Depth 0.7–1.1m</td>
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<td>4587</td>
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<tr>
<td></td>
<td>Depth 0.5–1.7m</td>
<td>3547</td>
<td>4441</td>
</tr>
</tbody>
</table>

5 Conclusion

It is known publicly that the active abutment pressure caused by the advance of longwall face is usually 3 times the normal static pressure of the overburden. It is inevitable for the roadway to be damaged somewhat under the effect of this huge pressure if no appropriate measures was taken. The integration of bolting and grouting provides an unique method for the purpose of reinforcement of roadway under this situation. With the increase of the depth of mining level, this special method will find its way widely in ground stability control and roadway maintenance both in coal mines and in metal mines.

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Reference

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