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Rapid development of coalmine bolting in China

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Abstract

Despite a slow beginning, coalmine bolting in China has got a rapid development in the past twenty years for pressing demand of deep mining, which has provided a sound technical support for safe and efficient coal production. In terms of technical characteristics, this process can be divided into three stages: “one-high” stage (high strength bolting), “two-high” stage (high strength and high pretension force bolting) and “three-high” stage (combination of high strength, high pretension force and high system stiffness bolting). Studies show that rational match of the “three-high” is safeguard to deal with the increasingly complicated deep mining situation. A whole set of strengthening bolting technology based on the “three-high” is put forward. The feasibility of its application under the most support-challenging condition-retained roadways is well tested by a typical engineering case.

Keywords: bolting; high strength; high pretension force; high system stiffness; retained roadway

1. Introduction

Compared with other major coal mining countries, China has only a few resources for open-pit mining. With the exception of certain western coalfields, coal mining conditions are highly complicated nationwide. Particularly, the fact that most eastern mining fields have entered the deep mining stage, leading to more severe challenges for safe and efficient coal production. All of these objectively decide that China's coal mining must take the road of independent innovation. Ever since the late 1990s, China’s coal industry has energetically implemented plans of tackling the scientific and technological problems in coal roadway bolting. Great progress has been made to allow adoption of this safe and economic support system even in conditions unthinkable just 20 years ago. A number of recently finished developments are described such as concept of “three-high” bolting and analysis of strengthening initial bearing capacity of bolts. A typical engineering case in a deep large cross sectional retained goaf edge roadway in Huainan Mining Bureau is presented to illustrate the technology.

2. Development of bolting technology in China

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2.1. “One-high” stage (high strength bolting)

Bolting support was first introduced into China coalfields in 1950s. At that time most mining activities took place at a rather shallow depth. Even mechanical bolts were standard. Before and during this stage, wide domestic use was metal bolts made of low carbon Q235 steel with a yield strength of 235MPa and 14 ~ 18 mm in diameter. As the cross-sectional area of the screw thread end was 5~15% smaller than that of the rod body, it was subject to break even with rather low breaking power. So it failed to provide the required capacity due to increasing stress from severe mining conditions.

During the late 1990s, through learning advanced technologies from foreign countries such as Australia and the USA, the high-strength rebar resin bolting technology were integrated and innovated with emphasis on high strength bolt and resin anchoring manner. The key step is the substitution of Q235 steel by 20SiMn (Grade II, yield strength \( \geq 340\text{MPa} \)) left-hand twist thread steel to achieve high strength of bolts. Also, rational match of drill-hole, bolt and resin diameters are stressed[1, 2]. The technical performance index of bolt materials is shown in Table 1.

Table 1. Technical performance indexes of bolt materials

<table>
<thead>
<tr>
<th>Bolt material</th>
<th>Index (mm)</th>
<th>Diameter (mm)</th>
<th>Yield strength (MPa)</th>
<th>Ultimate strength (MPa)</th>
<th>Yield load (kN)</th>
<th>Ultimate load (kN)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q235 round steel</td>
<td>16</td>
<td>16</td>
<td>240</td>
<td>410</td>
<td>48</td>
<td>82</td>
<td>26</td>
</tr>
<tr>
<td>Grade II thread steel</td>
<td>22</td>
<td>22</td>
<td>410</td>
<td>600</td>
<td>156</td>
<td>228</td>
<td>17</td>
</tr>
<tr>
<td>Grade III thread steel</td>
<td>22</td>
<td>22</td>
<td>650</td>
<td>900</td>
<td>247</td>
<td>342</td>
<td>17</td>
</tr>
</tbody>
</table>

Anchorage agent is the essential part of bolting, which is rapidly developed. Starting from total import of equipment and technology from foreign countries, Synthetic Material Plant of Huainan Mining Bureau produced the first batch of resin anchorage agent in China. Soon simpler production technology was developed and widely applied by other mining bureaus to achieve self-sufficiency. Variety in agent diameter and setting time allows for flexible choice for practical use according to technological and conducting requirements.

However in deep mines with complicated roof strata, use of the above technology is greatly limited. The conventional yieldable U-steel support is in dominant use for a long time but always facing the following big challenge. Usually there is a 500-to-800mm convergence deformation of surrounding rock in the digging stage and additional 800-to-1000mm deformation during the mining stage. Thus the cumulative deformation could be from 1500 to 2000 mm. Especially when the roadway is close to the working face end, the U-steel set is often badly deformed and its bearing capacity basically lost. For example, the fully mechanized coal face No. 1262(1) in Dingji mine of Huainan Mining Bureau was supported by yieldable U36-steel support. When the face was being mined, deformation of the roadway was so large that the section of the gob-side entry retained decreased by 50% of its original scale and the roadway had to be abandoned at last (Fig. 1). Practice has proven that even the high density U-steel sets could not meet the support requirements of gob-side retained entries under similar conditions.

![Fig. 1. Large deformation of U-steel support in deep mine](image-url)
This stage was highlighted by the "one high" technology feature of high-strength. Breakthroughs in machinery and technology were also made. By the end of 2000, the percentage of bolting support had reached more than 30%.

2.2. “Two-high” stage (high strength and high pretension force bolting)

In reaction to the low performance of bolting support in “one-high” stage, great efforts were put into finding effective ways adapted to China regulations and conditions. Combination of high-strength and high pre-tension technology was proposed with emphasis on fine machining and installation. Works mainly done in this stage were as follows:

- To list all the defects and problems related to structure, processing and application of the present bolts;
- To propose Chinese specific concept of high capacity bolts;
- To explore structure and property requirements of new type of bolts from aspects like material selection, rapid installation and thread machining;
- To get pretension force as great as possible;
- To clarify and standardize the technological properties and processing requirements of the new type of bolts.

This new type of bolts has shown several technical advantages: mechanical installation with the use of torque nuts, high reliability, massive early anchoring force, direct display of installation quality by annex, and so on. The pretension force of a single set can be up to 20 ~ 30 kN with the initial support strength being up to 30 ~ 45 kN/m². Innovative structure, easy processing, good quality, and low price make it the first of its kind nationwide.

Besides, M-steel strip (Table 2), T-steel strip (Table 3), and Π-steel strip were developed. With asymmetric bending performance, these products could easily cling to the surrounding rock and adapt to the crushing and unevenness of coal roadway. They have several advantages over the W-steel strip, for example great stiffness, high strength, anti-rupture, and full utilization of section.

Combination of the new type of bolts and steel strips was used as primary support in many complex conditions with sound effect. Under simple conditions, the spacing and distance between two rows could even be 1.0~1.2m with over 1000m per month advance rate.

Table 2. Technical performance index of M-steel strip

<table>
<thead>
<tr>
<th>Type</th>
<th>Broadening (mm)</th>
<th>Thickness (mm)</th>
<th>Weight (kg/m)</th>
<th>Yield load (kN)</th>
<th>Rupture load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRT-M3</td>
<td>173</td>
<td>3</td>
<td>4.05</td>
<td>124.56</td>
<td>197.22</td>
</tr>
<tr>
<td>GRT-M4</td>
<td>173</td>
<td>4</td>
<td>5.40</td>
<td>166.08</td>
<td>262.96</td>
</tr>
<tr>
<td>GRT-M5</td>
<td>173</td>
<td>5</td>
<td>6.75</td>
<td>207.6</td>
<td>328.70</td>
</tr>
<tr>
<td>GRT-M6</td>
<td>173</td>
<td>6</td>
<td>8.09</td>
<td>249.12</td>
<td>394.44</td>
</tr>
</tbody>
</table>

Note: A3 steel, $\sigma_s = 200$MPa, $\sigma_b = 340$MPa

Table 3. Technical performance index of T-steel strip

<table>
<thead>
<tr>
<th>Type</th>
<th>Broadening (mm)</th>
<th>Average thickness of the middle (mm)</th>
<th>Weight (kg/m)</th>
<th>Yield load (kN)</th>
<th>Rupture load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1</td>
<td>100</td>
<td>12</td>
<td>7.2</td>
<td>255.5</td>
<td>401.4</td>
</tr>
<tr>
<td>T-2</td>
<td>140</td>
<td>12</td>
<td>8.9</td>
<td>315.4</td>
<td>496.2</td>
</tr>
</tbody>
</table>

Note: 20SiMn steel, $\sigma_s = 340$MPa, $\sigma_b = 490$MPa

This stage was highlighted by the “two-high” technology features of high-strength bolt and high pre-tension force. Therefore bolting application range was greatly enlarged. The percentage of bolting support had been over 60% by the end of 2005.

2.3. “Three-high” stage (combination of high strength, high pretension force and high system stiffness bolting)

In recent years, facing the support challenge of extremely bed separating prone weak roof, Huainan mining area
has tried the pretension control technology\cite{4,5} and put it into wide use in areas with burial depth deeper than 700 m. However when it was used in deep coal seams, deformation changed from 300mm to 500 mm in the digging stage, while the anchoring force decreased by 50% to 80%, the resin anchoring system failed to work during the mining period. How to solve support problems of mining area with high ground stress under deep burial condition has become a hot topic.

Research shows that when the initial strength of bolt support is less than 0.1 MPa, loose deformation decreases greatly as initial support strength increases; when the initial support strength is between 0.1 and 0.3 MPa, the deformation decreases slowly; when the initial support strength is over 0.3 MPa, the deformation becomes very small. Therefore, the initial support strength for surrounding rock should be 0.3 MPa. According to current bolt layout, pretension force of each bolt should be about 100 KN. However, in most cases, bolt pretension force is only between 20 and 30 kN, which is far from enough. When the initial support strength is too low, roadway deformation is between 400 and 500 mm for coal roadway in deep mine after digging. This makes roadway very difficult to be retained. Absence of proper support will lead to two types of roadway deformation: structural deformation and expansion deformation. And the deformation will rapidly develop and result in collapse of the roadway. Therefore, bolting support characteristics, condition of surrounding rock and their interactions must be fully considered. Only when the initial support strength increases, can the deformation be controlled effectively.

The general support-rock characteristic curve is shown as curve 1 in Fig. 2. In “one high” stage, neither structural deformation nor expansion deformation was effectively controlled, such as the situation of curve 2. Curve 3 is corresponding with the “two high” stage: much better control of the two kinds of deformation and more reliable stability of roadway.

On the basis of high strength bolt and high pre-stress technology, bolt strengthening technology and the concept of high system stiffness of surrounding rock support system were raised. In this stage works being and to be done include:

- To emphasize the performance of bolt accessories;
- To further upgrade the mechanical properties of bolting materials to get higher bolting strength;
- To further enlarge pretension force of bolts;
- To rationalize the supporting systems though get higher system stiffness.

Fig. 2. Relationship between support load and deformation

The new bolt technology, characterized by “three-high” (namely high strength, high pretension force and high system stiffness) obviously improves support effect and makes safety production more reliable. It should be noted that the pretension force, super torque nut and large plate together play a key role in roadway stability. Curve 4 describes the ideal state realized by timely adoption of “three high” bolting technology: virtual elimination of expansion deformation, and great decrease of structural deformation.

Useful suggestions for practical application are\cite{6}:

To make sure that the support system matches the needs in every single case, the following geological and geotechnical parameters should be measured and evaluated beforehand: roof bedding structure, distance of tectonic elements like faults and folds to the roadway, mobility of jointed blocks into the entry and etc.
To monitor the bolting states is of special importance to avoid over-designing the support system and have a high priority in terms of safety.
To control construction quality is essential for achieving the best performance.

3. An engineering case

At present, this technology has been successfully applied in gob-side retained entries and high stress soft rock roadways. Practice shows that large deformation of a retained roadway usually occurs after lag mining. The deformation is 3 to 8 times greater than that of the roadway in solid coal. The main reason lies in sharp increase of stress due to the overburden rotating during the formation of the large structure of the surrounding rocks [7, 8]. Being one of the most difficult roadways to support, a retained roadway--1115(1) working face in Guqiao mine is chosen to illustrate the application of this bolting technology.

To control digging deformation and realize the target of gob-side entry retaining, the concept of strengthening bolt bearing capacity, strengthening surrounding rock, and strengthening bearing structure of the surrounding rock is put forward.

The roadway is 5.0m wide and 3.0m high. Super high strength bolts (Φ24×2500mm, made of 20SiMn, grade III) were installed, and two cables (Φ17.8×6300mm) were structured through holes of the 2500mm-long steel beam at both ends as shown in Fig 3. This cable of high bearing capacity and high pretension force was used for roof or rib support. It should be noted that the diameter of the cable is 18 mm instead of the conventional size of 15 mm, which makes it possible to increase pretension force. Meanwhile roof-truss type of support is adopted in controlling ribs [9] as shown in Fig 4.

Thus the deformation of surrounding rock is well controlled with only 100 to 200 mm side to side convergence and 50 to 80 mm roof to floor convergence before retaining of the tailgate.

4. Conclusion

The internationalization of the coal mining industry has led to great interest in bolting. Though it develops in a zigzag way and even was banned in Germany for a time, it has been playing a significant role in rock reinforcement and ground support as a cost effective and competitive alternative to conventional methods. In China we have witnessed its stage 1 (high strength bolting), stage 2 (high strength and high pretension force bolting), and stage 3(combination of high strength, high pretension force and high system stiffness bolting). Now we are looking forward to the more amazing stage 4, 5...because we are always challenged by more complicated mining conditions and safer, more efficient, and more cost-saving requirements.

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