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Experimental Study on the Effect of Resin Anchoring Agent Mixing with Steel Grit

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ABSTRACT: To improve the anchorage effect, steel grit or steel shot of different size and different amount were mixed into resin agent commonly used in China coal mine. 19 groups tests were conducted using right-whorled rebar bolt anchored into steel sleeve. Three bolt specimens were prepared and tested for each group, and as a comparison, the first group of bolt specimens was tested using resin anchoring agent without grit and steel. In the 2-10 groups, steel grits were added with different amount of 30, 40 or 50 and different particle sizes of 1.5, 2.0 and 2.5 mm. Each particle size corresponds to three quantities, a total of 9 groups of tests were conducted. Steel shots were added in 11-19 group tests with different amount and different particle size. The average peak pulling force of the first group is 121.3 (±3.1) kN, 5 of 9 groups of specimens with steel grit are more than 121.3 kN, and 8 of 9 groups of specimens have better average peak pulling force than 121.3 kN. It can be concluded that, under the condition of testing, the anchorage effect can be improved after steel shots are mixed into resin anchoring agent.

KEYWODS: *Anchor; Grout; Steel; Pullout*

1 INTRODUCTION

Since 1912 bolting support was first used in underground roadway of Germany Xie Des mine, rock bolt has been used in roadway support more than 100 years [1]. Bolting support was used in rock roadway of China coal mines from 1950s, and it was applied in coal roadway support from 1980s [2-3]. Rock bolting technology can improve rock strength of surrounding rock and self-stability of the underground roadway, reduce the volume of supporting structure and deadweight, which results in improved construction safety. This technology has become one of the most economical and effective ground support method to improve surrounding rock stability and solve supporting problems [4-5].

Nowadays, rock bolt has gradually become main supporting means in modern coal mines. The total length of roadway excavation in coal mines in China has exceeded 12000 km per year [6]. Along with the mining depth increasing, the surrounding rock conditions are deteriorating continuously [7-8]. Therefore, the bolt support effect needs being further improved. Via analysis of rock bolting failure, it shows that shear failure of the grouting agent is one of common structural failure mode. Previous studies suggest that, the bond strength can be enhanced via increasing of shear strength of the grouting materials. Improving grout performance can improve shear strength of anchored rod thus improve bolt support effect.

2 STATE OF THE ART

Currently, anchor grout used in coal mines rock bolting is often resin bonded materials prepared by using unsaturated polyester resin with catalyst agent, marble powder auxiliary materials according to certain proportion. Full length anchor bolts can provide large shear resistance for anchorage load transfer. This shear resistance occurs once grouting material is filled into the void between bolt and surrounding rock. Therefore, through improvement of shear strength of the grouting material, the performance of the anchorage can be enhanced directly [9-10]. Cao et al. introduced a method to improve bolt support strength. Metal particles are mixed into grout material to improve shear performance of the resin grout. Experimental results show that the peak load of pullout test increases when metal particles are mixed with resin anchor agent [11-12]. However, there is no quantitative study to identify the proper shape, size and number of the aggregate. This paper studies the influence of aggregate shapes, sizes and numbers on anchorage effect for commonly used dextral bolt via laboratory pullout test.

To further investigate the influence of metal particle addition on pull force of anchor rod, 19 groups (each group of 3 specimens) pullout tests were conducted. Average peak load of each pullout test was measured during experiment. Among them, there were no steel pellets in group 1, which was used as contrast test group. The remaining 18 groups tests were added with different diameters and quantities of steel grit or steel shot. Through this experimental research, the influence of resin grouting agent plus steel pellet on the pullout force of anchored rod is studied.

3 MATERIALS AND METHOD

3.1 *Bolt, Resin, and Steel shot*

The right-screwing rebar bolt was used in the test as shown in Figure 1. It is the most commonly used rebar bolt in coal mine in China, the geometrical and mechanical parameters are shown in Table 1. Anchorage grouting agent used in the tests is bulk slow resin, the catalyst is 4% in volume and curing time is 10-15 min. The average compressive strength of anchorage agent was of 53.99 (±4.2) MPa.

Table 1. Profiles configuration and mechanical parameters of right-screwing rebar bolt

Name	Value	Name	Value
Diameter φ (mm)	20	Lateral angle of transverse rib α (°)	72
Transverse rib high h (mm)	1.83	Rib spacing L (mm)	12
Yield strength (MPa)	403.1	Transverse rib rise angle β (°)	78
Tensile strength (MPa)	567.5	Transverse rib top width / bottom width b (mm)	4.34/5.65

Steel grit and steel shot are made of high quality steel. The appearance of steel grit and steel shots is shown in Figure 2. The first row is three kinds of steel grit used in the test, whose diameter is 1.5 mm 2.0 mm and 2.5 mm, respectively. The diameter of steel shots shown in the second row was 1.4 mm 2.0 mm and 2.5 mm, respectively

Figure 1 Right-screwing rebar bolt

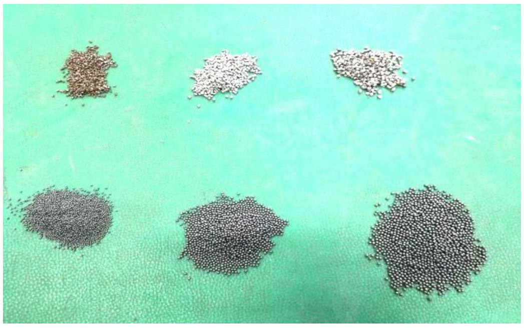

Figure 2 Different steel grit and steel shot.

3.2 *Preparation of specimen*

This experiment uses high quality steel pipe with outer diameter of 45 mm and inner diameter 30 mm, 1.0 mm screw was made to increase the friction between the resin and steel cylinder wall. The thickness of sleeve wall is 7.0 mm with length of 100 mm, as shown in Figure 3.

Figure 3 Steel sleeve used in the experiment

The pulling equipment used in the test is 40Cr steel car sleeve drawing tooling, and its test fixture is shown in Figure 4. The yield strength of the tooling is 785 MPA, and the tensile strength is 980 MPa

Figure 4 The structure of pull-out test tool.

3.3 *Preparation of anchor bolt specimen*

These 19 groups of right-handed screw rod bolts with length of 280 mm were prepared. Each 3 bolts were used as a set of specimens for tests. Anchoring specimens of anchor rod are anchored to 7.0 mm steel sleeve and numbering. Steel particle was not added into 3 specimens in group 1. The diameter of steel grit added into resin in group 2, group 3 and group 4 was 1.5 mm. The numbers were 30, 40 and 50 respectively. The diameter of steel grit added into resin in group 5, group 6 and group 7 was 2.0 mm and the numbers were 30, 40 and 50, respectively. The diameter of steel grit added into resin in group 8 , group 9 and group 10 was 2.5 mm and 30, 40 and 50, respectively. The diameters of steel shots added in 11, 12 and 13 group resin were 1.4 mm with 30, 40 and 50, respectively. The diameters of steel shots added into 14, 15 and 16 groups resin anchors were 2.0 mm, with 30, 40 and 50, respectively. The diameters of steel shots added in 17, 18 and 19 resin anchors were 2.5 mm, with 30, 40 and 50, respectively. Then the anchor specimens are placed at 22 ℃ oven for 2 hour. Strain gauges are placed symmetrically positioned in middle sleeve to ensure that the steel sleeve is in elastic stage. Grouted bolt samples are shown in Figure 5.

Figure 5 Grouted bolt samples.

3.4 *Pullout test*

The experiment adopts microcomputer controlled electro hydraulic servo universal testing machine. 19 groups of anchoring specimens prepared were placed in fixture installed on tester clamps and connected with DH 5929 dynamic strain meter at loading rate of 2mm/min, as shown in Figure 6.

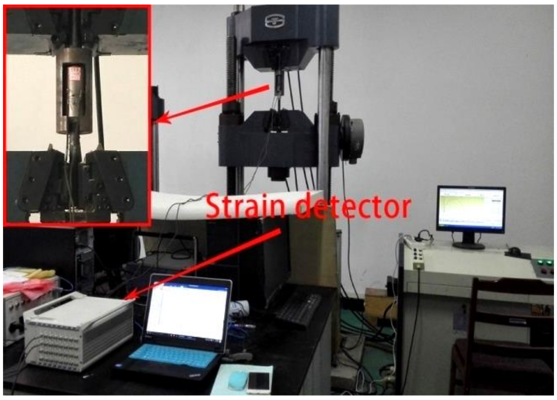

Figure 6 Pull-out test system.

The main parameter measured in the tests is peak pulling force of each specimen, and average values are then being calculated. The pulling force can be measured by the sensor itself. The test results of the average peak pull force value and variation amount of each specimen of steel grit specimen are shown in table 2. The test results of the average peak pull force value and variation amount of each specimen of steel shot specimen are shown in table 3.

Table 2 The average peak pulling force of bolt after add steel grit

Experimental group	Average peak pull force (KN)	Percentage increase (%)
Group 1 (contrast group)	121.3 (±3.1)	0
Group 2	123.8	2.1
Group 3	116.5	-5.4
Group 4	126.8	4.6
Group 5	124.0	3.0
Group 6	123.4	2.2
Group 7	117.0	-3.6
Group 8	123.4	1.8
Group 9	120.8	-0.4
Group 10	114.3	-5.8

Table 3 The average value of peak pulling force of bolt after add steel shot

Experimental group	Average peak pull force (kN)	Percentage increase (%)
Group 1 (contrast group)	121.3 (±3.1)	0
Group 11	135.1	11.4
Group 12	132.2	9.0
Group 13	116.8	-4.0
Group 14	124.8	3.0
Group 15	123.5	2.0
Group 16	129.9	7.1
Group 17	133.8	10.3
Group 18	128.0	5.5
Group 19	132.0	8.9

4 RESULTS AND DISCUSSION

4.1 *Failure mode analysis of the resin*

There are two typical types of failure modes of anchorage bodies. The first type is that resin-rock interface slips. Another failure type is at the resin-bolt interface, i.e. bolt rib passing through the resin grout. In this case, the fracture surface of anchorage body extends downward along transverse rib to resin-bolt contact interface (Figure 8). After pullout tests, the failure state of the bolt specimen is shown in Figure 7. In the tests, there is no slippage between resin-sleeve interface. The fracture surface of the anchorage body extends downward along the transverse rib to the resin-sleeve contact interface, which indicating that its failure mode is the later cases.

Aiming at this kind of failure condition, the increase of peak value of pull force after adding steel grit or steel shot into the resin grouting agent can be explained as follows: after adding steel grit or steel shot into the resin, the shear resistance between bolt ribs and the resin increases. Steel particle in the resin play a small pin bolt on the shear failure surface of at the ribs and resin interface [13-14], as shown in Fig.8. Green squares in the diagram is steel particle, which can prevent relative displacement between the bolt rib and the resin, thereby enhance pulling force of anchor rod.

However, for some specimen, the peak pullout force decreases when adding steel particles into the resin anchor agent. It can be explained as follows: in volume space of sleeve, remove anchor bolt part, the residual volume space should be uniform distribution space between resin and sand or steel pellets, because the space volume of rib groove of the bar is small, the probability for the steel particle installed in the failure surface, i.e. the effective zone, is relatively low.

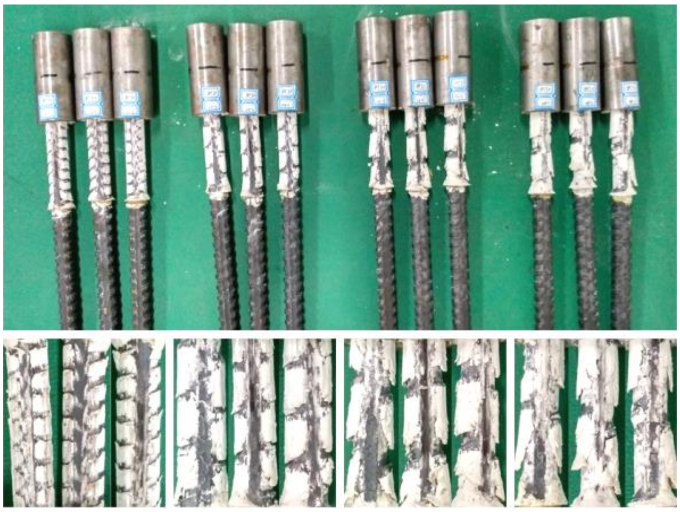

Figure 7 Resin failure state after pull-out test.

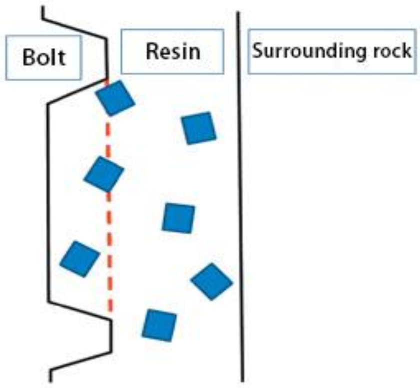

Figure 8 Conceptual schematic of mixing metal particles into a resin.

That is, most steel particle is placed in the space between the bolt rib tips and the sleeve wall, which has nearly effect on the shear strength of the failure surface. In the test, dextral rebar bolt, which is the most commonly used rib support bolt in coal mine roadway in China, was used as reinforcing element. However, the rib width of the bolt is large, resulting considerable reduction of the groove volume between adjacent two transverse ribs, as shown in Figure 1. The measured groove volume is about 6 cm^3, accounting for only 15 % of the total volume (40 cm^3) of the resin ring. Consequently, the added aggregate can hardly enter into effective area, which reduces the doweling effect of the aggregate greatly.

4.2 *Analysis of pulling Force of Anchor Rod*

The relationship between average peak pulling force and particle size and quantity of steel grits added in 10 groups is shown in Figure 9.

The relationship between average peak value of drawing force and particle size and quantity of steel shots added in 10 groups is shown in Figure 10.

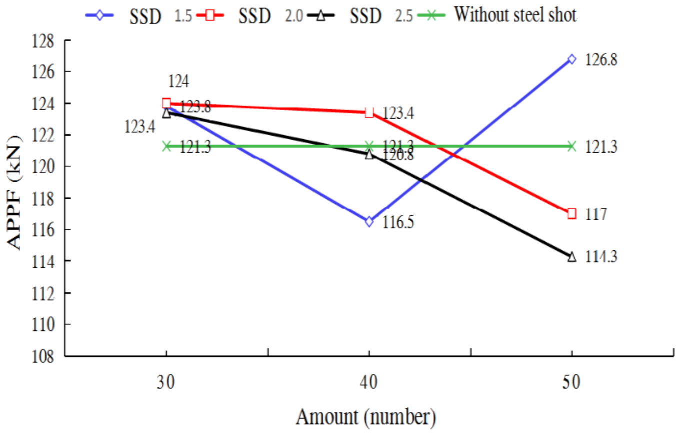

Figure 9 The relationship between the quantity and average size of steel grit and average peak pulling force (APPF).

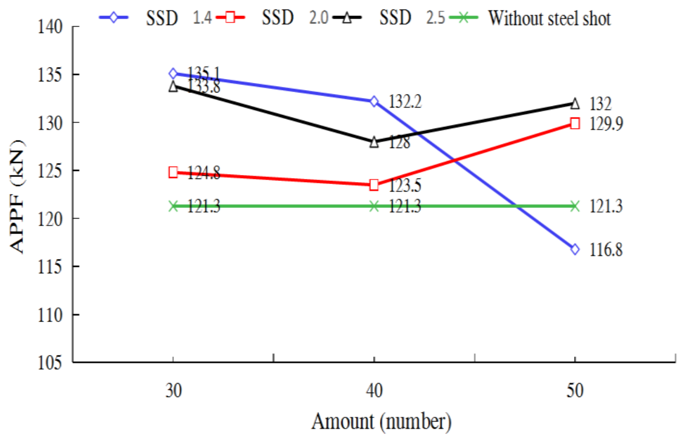

Figure 10 The relationship between the quantity and average size of steel shots and average peak pulling force (APPF).

5 CONCLUSIONS

To improve the anchorage effect, steel grit or steel shot of different size and different amount were mixed into commonly used resin agent in China coal mine. 19 groups tests were conducted using right-whorled rebar bolt anchored into steel sleeve of 7 mm wall thickness. The main conclusions are as follows.

(1) Through pullout testing of steel particles added into resin grout, it is found that adding steel particles has certain influence on the peak pulling force. In addition, with the change of particle size and quantity of steel particles, the influence on peak pulling force also changed. Under this condition, the additional steel particles have a similar lifting effect on pulling force.

(2) Under this test condition, the average peak pullout force of several specimens decreased in the test, it may be caused by small space volume between two bolt ribs.

(3) It can be preliminarily concluded that the relationship between the size and the quantity of the steel particles is closely related to the pullout force of the anchor rod. This method provides an initial study for optimum steel particle parameters which can improve anchorage pulling force.

6 ACKNOWLEDGEMENT

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