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Research Article

Field Pull-Out Test and Analysis of Fiberglass Anchors in Sanshandao Gold Mine

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The Sanshandao gold mine is developed near the sea and has high-chloride ion content in the groundwater, resulting in serious corrosion of metal anchors and difficulty in maintaining metal anchors. To solve the corrosion problem of anchor rods in Sanshandao, the use of fiberglass anchor rods, instead of metal anchor rods, is proposed. To verify the feasibility of fiberglass anchor application, a fiberglass anchor (diameter: 27 mm) pulling test was conducted at the Sanshandao gold mine. The test results show that (1) the pull-out resistance of fiberglass anchor rods is better than those of metal pipe slit anchor rods and threaded anchor rods currently used in the Sanshandao gold mine; (2) the failure of fiberglass anchor rods is mainly because of the destruction of anchor washer discs and nuts, whose rods play only 69.90–77.7% of their performance and remain intact; (3) the fiberglass anchor rod was damaged to different degrees several times before the pulling failure, and the damage was accompanied by sound; (4) the fiberglass anchor continued to bear pressure after each damage until complete failure occurred; and (5) the anchor washer disc relative to the nut to allow the pressure effect can avoid nut pressure collapse and improve the pulling performance of the anchor rod to a certain extent simultaneously. Through the test, it was proved that the 27 mm fiberglass anchor can meet the support demand of the Sanshandao gold mine. It also provides an important reference for the promotion and application of fiberglass anchor rods in similar mines.

1. Introduction

The Sanshandao gold mine is located in Laizhou city, Shandong province, China. The mine site is adjacent to the sea, and its entrance is approximately 1.5 km from the coastline, as shown in Figure 1. Since the Sanshandao gold mine is close to the coastline, the mine's groundwater has a high-chloride ion content, which can easily lead to metal corrosion. Among them, metal anchors are seriously affected by corrosion, resulting in significant risk to the safety of underground rock support and increasing anchor maintenance costs.

To address the problem of corrosion of metal anchors, many scholars have conducted extensive research on anticorrosion and new materials. Wen et al. [1] comprehensively

Figure 1: Location of Sanshandao gold mine.

studied the instability mechanism and movement law of coal and rock mass. Li et al. [2] analyzed the failure mode of the tunnel support structure. Lin et al. [3] investigated the corrosion resistance of metal surface coatings on anchor rods. Zhu et al. [4] proposed an attractive waterborne epoxy that can provide good corrosion protection. Li et al. [5] studied the relationship between corrosion time and failure to grasp the failure node and then took maintenance measures in time. Cho et al. [6] investigated the corrosion protection effect of unbonded closure systems on anchor rods and anchor cables. Liao et al. [7] investigated a grouting corrosion protection method to compensate for the weakness of anchorage. Zou et al. [8] described the corrosion resistance of fiberglass anchor rods. Benmokrane et al. [9] reported that aramid and carbon-fiber-reinforced plastics have good corrosion resistance but they are expensive.

Research on the corrosiveness of anchors is reflected in three main areas: (1) the use of anticorrosive coatings for metal anchors, (2) use of unbonded protection or full-length bonded protection, and (3) replacement of anchors made of metal with corrosion-resistant materials. With the development of new material technology, the performance and cost of materials are increasingly converging with the needs of engineering applications, and thus, the development of new materials is a trend for the future. A fiberglass anchor is corrosion resistant and weighs approximately one-quarter of the weight of metal anchors, with a higher tensile strength than metal anchors [10]. Fiberglass anchors are more economical than carbon and aramid fiber anchors [11]. Therefore, in this study, we propose a support solution using fiberglass anchors, instead of metal anchors, to address the corrosion problem of metal anchors in Sanshandao.

Numerous studies on fiberglass have been conducted, and Kou et al. [12] studied the pull-out tests of fiberglass anchors as antifloating tools in weathered soils. Wang et al. [13] studied that an important method to improve the performance of concrete is to use alkali-resistant glass fiber (ARGF) as reinforcement. Ceroni et al. [14] and Ji [15] investigated the pull-out properties of glass-fiber reinforcement in combination with grouting materials. Shi et al. [16] studied that the addition of alkali-resistant glass fiber improved the compressive strength and tensile strength of grouting slurry. Wang et al. [17] investigated the pull-out performance of fiberglass anchor rods bonded to an anchor material interface using indoor tests. Sim et al. [18] studied the application of fiberglass anchors as permanent anchors in slope support through indoor tests, and the test results indicated that fiberglass anchors could replace metal anchors. Bai et al. [19] investigated the pull-out performance of fiberglass anchor rods using indoor tests. Huang et al. [20] investigated the structural damage mechanism of fiberglass anchor rods using field tests. Li et al. [21] investigated the load-bearing properties of fiberglass rods.

Numerous scholars have extensively studied fiberglass anchors, with the research results mainly focused on the interfacial bonding between fiberglass anchors and anchor solids and the tensile strength of fiberglass rods. There are many studies on laboratory tests, the field test was small. In the fiberglass pull-out test, there are more studies on the rod but the anchor role is a system that lacks field tests on the pull-out performance of the anchor rod, anchor washer disc, and nut supporting anchor system.

Therefore, the effectiveness of fiberglass anchors in supporting the Sanshandao gold mine and obtaining a scientific basis for future applications and promotions was determined. A field pull-out test was conducted at the Sanshandao gold mine. The results of the pull-out tests support the feasibility of the fiberglass material for application in the Sanshandao gold mine. It is also a reference value in similar mines where corrosion is severe.

2. Test Preparation

2.1. Test Material. The fiberglass anchor pull-out test material was supplied by Shandong SFT Industrial Co. Ltd. and comprised a fiberglass rod body, anchor washer disc, nut, and resin anchor fixation. A 27 mm diameter fiberglass rod was used for this test. The anchor washer disc, nut, and resin anchor fixations were matched to the rod specifications. The material parameters are shown in Table 1 and Figure 2.

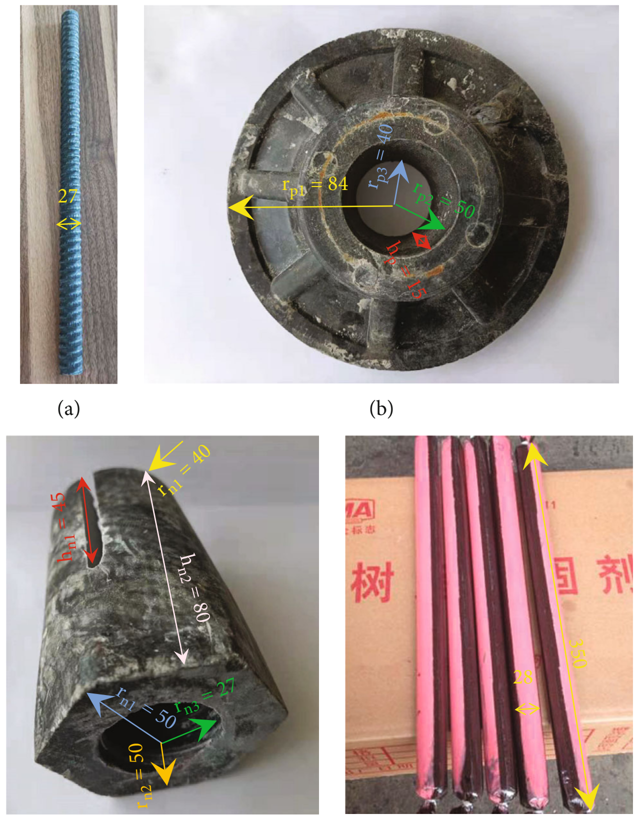
2.2. Test Equipment

2.2.1. Anchor Construction and Installation Equipment. The hole-making equipment for this test was a TY-28 rock drill, as shown in Figure 3(a). The anchor installation equipment was a ZQS-50/1.9S air-coal drilling rig, as shown in Figure 3 (b). The mixer model matches the wind-coal drilling rig and anchor diameter, as shown in Figure 3(c).

2.2.2. Anchor Pull-Out Test Equipment. The anchor rod pull-out test was conducted using a KYG-20T-70 mm–34 mm manual hydraulic hollow jack, as shown in Figure 3(d). It can provide 0–20 T (0–200 kN) with a maximum cylinder stroke of 70 mm. The pressure gauge range of this equipment is 0–60 MPa, that is, when the pressure gauge is 60 MPa, the force value it provides is 20 T.

Table 1: Test materials and technical specifications (provided by the manufacturer).

Component	Anchor rod	Anchor washer	Nut	Resin anchor fixation
Technical requirement	Tensile strength ≥ 300 MPa	Bearing capacity ≥ 105 kN	Bearing capacity ≥ 105 kN	Gelation time 40–90 s



(a) (b) (c) (d)

Figure 2: Test material (unit: mm). (a) Anchor rod. (b) Anchor washer. (c) Nut. (d) Resin anchoring agent.

3. Test Procedure

3.1. Test Location Selection. Considering construction safety, convenience, and typical features, the technical staff of Sanshandao operations recommended the test location to be chosen in the −330 m excavation tunnel of the Sanshandao gold mine, as shown in Figure 4. The surrounding rock at this location is mainly granite, the thickness of the rock layer is about 12.8~28.9 m, and the thickness of the aquifer is generally 11~43 m. The rock stores water in the form of fissures. The buried depth of the water level is 4.58~14.40 m, the water chemistry type is mainly Cl-Ca, and the salinity is 1.30~2.27 g/L. The tunnel surrounding rock is class III, with more obvious joints and fissures, relatively good rock integrity, and good control of light exploded in the surface surrounding rock, making it suitable for conducting basic tests.

3.2. Construction and Installation of Test Anchors

3.2.1. Anchor Layout and Drilling Construction. Three anchors were tested. Relatively flat surrounding rock conditions were selected by combining the site working face conditions, drilling, and anchor installation equipment. The feasibility of the application of fiberglass anchor rods in deep metal mines at sea was investigated by drawing the pull-out force-displacement curves of the three anchor rods through pull-out tests. The results of the three sets of anchor rod tests can be verified against each other, and the three anchor rods are named as no. 1, no. 2, and no. 3 anchor rods, respectively, as shown in Figure 5. The anchor spacing was 800 mm, and the anchor length was 2200 mm. The anchor diameter was 27 mm, and the drilling diameter was 34 mm. The distance between the tunnel face and the test site is 30 m. The test anchor holes were identified and drilled using a TY-28 rock drill.

3.2.2. Anchor Rod Installation. Two resin cartridges were placed in each hole, and the anchor rod was used to push the resin into the bottom of the hole. Adhesive cartridges are 28 mm in diameter and 350 mm in length. The stirrer was then tightened to the anchor rod body, and the air-coal drilling equipment was used to drive the rotation of the stirrer, which, in turn, drove the rotation of the anchor rod body, as shown in Figure 6. Simultaneous thrust was applied to the air-coal drill during the rotation of the rod,

(a) (b) (c) (d)

Figure 3: Test equipment. (a) Rock drilling. (b) Air-coal drill. (c) Mixing head. (d) Pulling equipment.

Figure 4: Site photo of the test location.

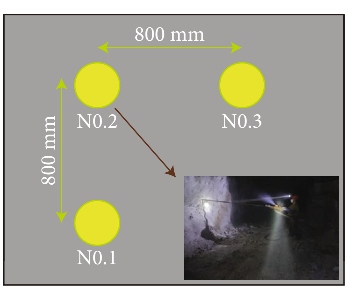


Figure 5: Location of test anchors and field tests.

causing the anchor rod to pierce the resin anchorant and agitate it at high speed. Stirring until the rod rotates with difficulty, the actual rotation time is approximately 60–70 s.

3.3. Anchor Pull-Out Test. When the construction of anchor rod no. 3 was completed, the anchor rod pull-out test was performed after waiting for half an hour. The actual test sequence was no. 2–no. 1–no. 3 anchor rods. During the test

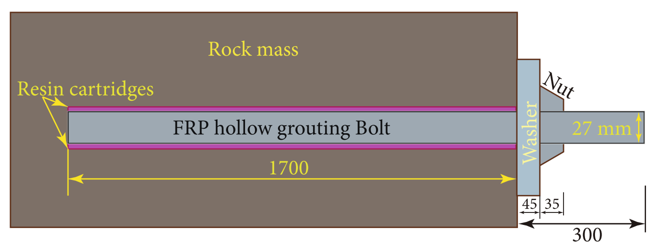


Figure 6: Schematic of anchor installation.

on anchor 2, the nut came into contact with the jack cylinder, resulting in premature damage to the nut. The test programme was temporarily adjusted on site, and two anchor washers were installed in contact, thus avoiding damage to the nut in contact with the cylinder. The specific test steps were as follows.

In step 1, the hollow jack is passed through the anchor rod body and the jack is in direct contact with the surrounding rock wall.

In step 2, the anchor washer and nut were sequentially fitted to the anchor rod.

In step 3, the jack is manually pressurised until the pressure drops suddenly. The pulling displacement of the anchor rod is measured by a vernier caliper, and the test time is timed by a stopwatch. Meanwhile, anchor damage is observed.

Anchor rods (that can continue to be pressurised) can be pressurised several times, recording the maximum pressure value for each pressure drop. The pressure value was used to calculate the load on the anchor rod, and the anchor

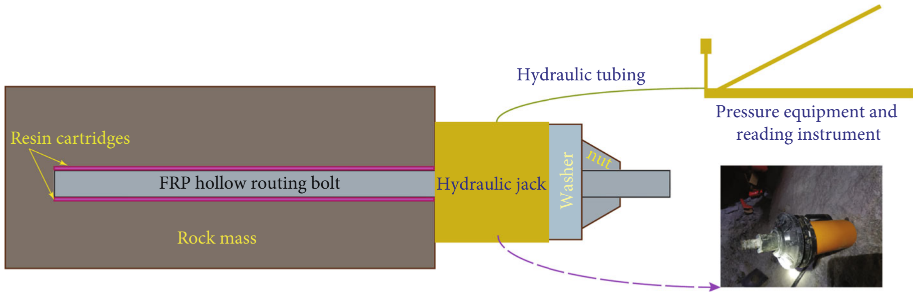


Figure 7: Installation view of the drawing equipment.

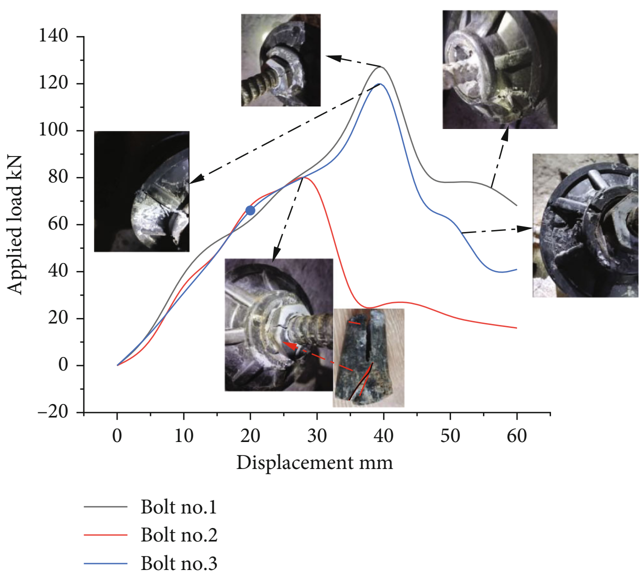


Figure 8: Anchor displacement-pulling force curve.

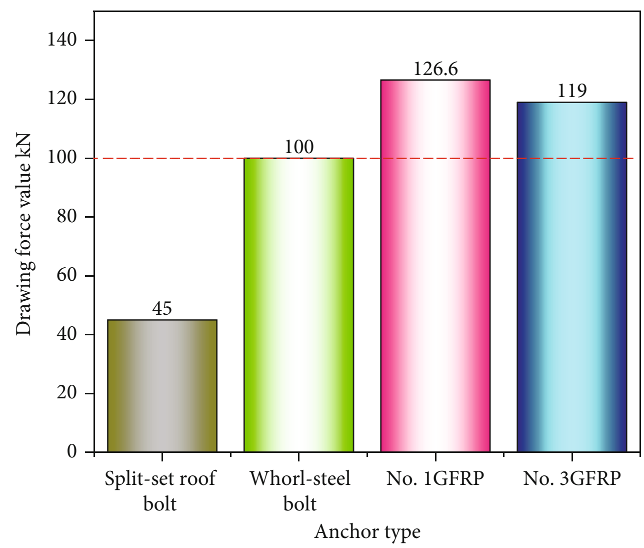


Figure 9: Comparison of pull-out values for different types of anchor bar.

rod and pulling equipment were installed, as shown in Figure 7.

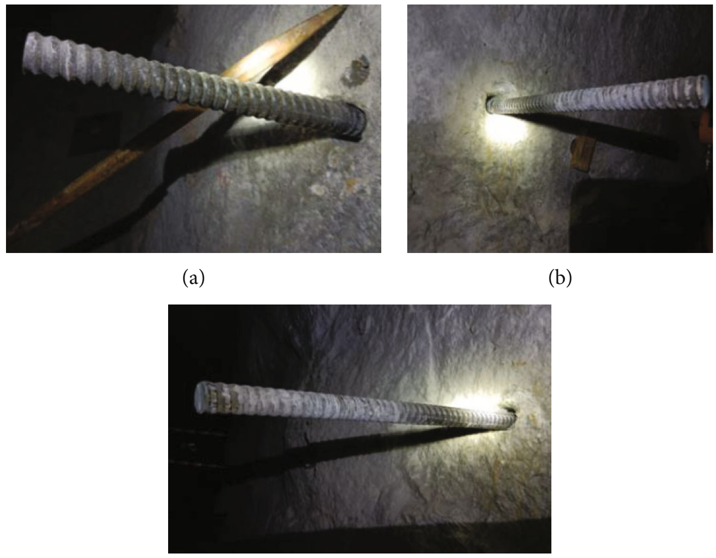
4. Results and Discussion

The pull-out test on the anchor rods allows the values of the tensile force and displacement of the anchor head when the anchor rod is damaged. The experimental results were analyzed in relation to the anchor rod damage phenomenon. To facilitate the analysis, it was performed in the order of the actual tensioning of the anchor rods.

4.1. Analysis of Tensile Test Results of the Fiberglass Bolt. As shown in Figure 8, during tensioning, the displacement-drawing force curve for anchor no. 1 was approximately linear until the peak pulling force was reached. When the pull-out displacement was 30 mm and the pull-out force was 86 kN, a reverse bending point occurred, at which the slope of the displacement-draw-out force curve increased, reaching a peak stress of 126.6 kN at a displacement of 40 mm. After the peak pull-out force occurs, there is a sudden change in the pull-out force, but at this time, the anchor still has a certain load-bearing capacity. When the pull-out displacement was 50 mm, the anchor still had a pull-out resistance of 78 kN, and when the tray and bolt were completely damaged, the anchor lost its pull-out resistance.

During the test, a low-frequency friction sound was emitted at the pallet position as the hydraulic jack was pressurised. When the peak of the pulling force is reached, the pallet produces an explosive sound similar to the breaking of plastic. In the process of continuous loading, with the increase in pull-out displacement, the bolt and pallet are constantly embedded and compacted. When the peak pull-out force is reached, the bolt is subjected to a large circumferential pressure. The gap between the predetermined notches shrinks sharply, resulting in the breaking of the bolt ends and the explosion sound generated during the test. At this point, the pallet exhibited smaller cracks. As the load continued, the displacement changes were large. When the pull-out displacement was 50 mm, the change in the pull-out displacement slowed. At this point, the pallet and bolt cracks gradually expand until the pallet is destroyed and the anchor loses its pull-out force.

As shown in Figure 8, the peak stress of anchor rod no. 2 is similar to that of anchor rod nos. 1 and 3 during the loading process and it changes in an approximate line. The peak stress was reached when anchor no. 2 reached a pull-out displacement of 30 mm and a pull-out force of 75 kN; subsequently, the pull-out stress drops sharply and turns when



(a) (b) (c)

Figure 10: Condition of the rod after completion of the test. (a) Anchor rod no. 1. (b) Anchor rod no. 2. (c) Anchor rod no. 3.

the pull-out displacement is 40 mm and the pull-out force is 26 kN, after which the pull-out resistance of the anchor gradually decreases, but the anchor still has a certain pull-out resistance at this time.

Comparing the field tests of anchor nos. 1 and 2, anchor no. 1 was tested with two pallets while anchor no. 2 was tested with only one pallet. As there was only one pallet, the inner cylinder of the jack directly contacted the nut during tensioning, resulting in rigid damage to the nut and through cracks along the preopening joints and cracks on both sides of the preopening joints, resulting in a lower peak pulling force in the pulling test for anchor no. 2.

Combining the field test anchor rods no. 1 and 2, the pull-out test of anchor rod no. 3 was conducted. As shown in Figure 8, the trend of the pull-out displacement-draw out stress curve before and after the peak pull-out force during the pull-out test for anchor rod no. 3 was similar to that for anchor rod no. 1 and the location of the sound that occurred during the test was also similar. The pull-out displacement at the peak curve position of anchor no. 3 was 39.5 mm, and the pull-out force was 119 kN. The anchor nuts and pallets of anchor nos. 3 and 1 broke in a similar manner and at similar locations.

Three fiberglass anchor pull-out tests have shown that when the borehole is not perpendicular to the surrounding rock, the anchor washer will be unevenly stressed, damaging the anchor washer. The destruction of the anchor washer disc facilitated the movement of the nut, which, to some extent, acted as pressure relief such that no chipping of the nut occurred. Meanwhile, this let-down effect, on the contrary, increased the pull-out resistance of anchors, relative to anchor rod no. 1, by approximately 5% in this experiment.

4.2. Analysis of the Feasibility of Applying Fiberglass Anchors in the Deep Metal Roadway Near the Sea. Based on the abovementioned fiberglass anchor pull-out test results, a graph of the pull-out force versus displacement can be drawn, as shown in Figure 9. As can be observed from the graphs, the pulling of anchor nos. 1 and 3 was normal, except for the pulling of anchor no. 2, which failed. The first breakage displacements occurred at 40 mm and 39.5 mm, with pulling forces of 126.6 kN and 119 kN, respectively. The second breakage displacements occurred at 55 mm and 50 mm with pulling forces of 77 and 62 kN, respectively. Anchor no. 1 failed after two tensioning procedures owing to nut failure. After the 3^{rd} tensioning, anchor no. 3 failed owing to the failure of the anchor washer disc when the hydraulic jack displacement was 55 mm and the maximum pulling force was 119 kN. The test results showed that the pulling effect of the fiberglass anchors was relatively constant.

Currently, pipe seam anchor rods and rebar anchor rods are used at the Sanshandao gold mine. Therefore, the fiberglass anchor rods were compared with both pipe seam anchor rods and rebar anchor rods and the results are shown in Figure 9. The pull-out requirement for the pipe slit anchor rod at the Sanshandao gold mine is 45 kN; the pull-out requirement for the threaded reinforcement anchor rod is 100 kN (this requirement is provided by the Sanshandao gold mine). The maximum pull-out values of the fiberglass anchor rods in the test were 126.6 kN and 119.0 kN for anchor rods no. 1 and 3, respectively. Consequently, the fiberglass anchor pulling effect meets the requirements of the Sanshandao gold mine support.

At the end of the pull-out test, the hydraulic jack was removed and found to be intact with only minor damage to the rod body, the rod body, and pallet and the nut bite position compared to other locations was white because, during the pull-out test, the nut pallet and rod bite provided tensile strength, as shown in Figure 10. According to the rod indoor pull-out test, the tensile strength of the rod is 300 MPa. It can be seen from the ratio of the peak value of the pull-out force failure in the field test to the peak value of the indoor tensile test of the anchor rod; the peak tensile strength of the anchor rod in the field pull-out test is only 69.90–77.7% of its performance. Consequently, there is still room to improve the matching anchor washer disc and nut for a 27 mm diameter fiberglass rod.

5. Discussion

This experiment is a field pull-out test based on an indoor test of 27 mm fiberglass anchors. The major difference between the field test and the indoor test is that the field test environment is complex and variable, involving various factors, such as temperature, humidity, lithology, and fissures [22–26].

Comparing the indoor tests with the field test data, the analysis of the anchor rod pull-out resistance shows that the fiberglass anchor rod is suitable for replacing metal anchor rods in deep metal mines in the sea [25]. Analysis of the field pull-out test results showed that the anchor rod damage was from the nut and pallet positions rather than the anchor rod body [27]. The next step in this research is to improve the performance of the nut and anchor washer disc in terms of structure and material, as well as to study the performance of fiberglass anchors under multifield coupling conditions through field tests for several aspects, such as high temperature, high ground pressure, and seawater erosion in deeper metal mines.

6. Conclusions

The test was conducted on an anchor rod comprising a 27 mm diameter fiberglass rod and its supporting components. The analysis of the pull-out test results shows that there are mutually mapped responses in terms of damage process, damage form, and damage response of the fiberglass anchor rod, with the following conclusions.

(1) The fiberglass anchor rod was damaged several times to varying degrees before pulling failure, mainly by cracking of the nut and anchor washer disc. Each time the fiberglass anchor was damaged, there was a sudden drop in pressure and audible noise. The fiberglass anchor rod can continue to be pressurised after each damage until it fails. According to the three sets of test results, the maximum pulling force when the nut is broken is 126.6 kN and the pulling displacement is 40 mm, and when the washer is broken, the pulling force is 78 kN and the pulling displacement is 50 mm

(2) The tensile performance of the fiberglass rod with a diameter of 27 mm was good, the rod remained intact during the test, and the performance of the rod was approximately 69.90–77.7%. The fiberglass anchor washer disc and nut are the weak links in the anchor support system and are prone to damage in the pull-out test

(3) The pressure of the anchor washer disc relative to the nut prevents the nut from collapsing under pressure and, to a certain extent, improves the pulling performance of the anchor rod

(4) The maximum drawing force of the 27 mm diameter fiberglass anchor is 126.6 kN and the drawing displacement is 40 mm, which meets the requirements of the Sanshandao gold mine with a minimum drawing force of 100 kN and a minimum drawing displacement of 50 mm

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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