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Application of Roadway Spray Material to Fire Prevention in Goaf Excavation

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Abstract

In order to reduce the risk of spontaneous combustion in goaf during goaf excavation process, polymer modified cement mortar spraying material was used to spray and seal the roadway surface. The experimental application was carried out in the upper channel 2304 of a mine in Henan Province. The test results showed that polymer modified cement mortar spraying material could effectively support the roadway and greatly reduce the deformation rate of the roadway. The best spraying thickness is 5 mm. Through the monitoring of tunnel air leakage, it is concluded that the polymer modified cement mortar spraying material can reduce the tunnel air leakage and play a better sealing effect.

Keywords

Goaf Excavation, Thin Layer Spraying, Construction Technology, Shotcrete Plugging, Air Leakage Plugging

1. Introduction

In order to improve the recovery rate of coal resources in the mining area and eliminate or reduce the coal pillar of underground roadway protection [1], a mine in Henan Province adopted the way of goaf excavation to achieve mining roadway excavation [2] [3]. Coal body is a kind of porous medium, and its internal pore structure is very complex. Under the influence of mining, cracks will occur in the coal body, and the cracks will connect with the pores inside the coal body, forming complex air leakage channels, resulting in spontaneous combustion of coal pillars or goaf, which brings adverse effects on roadway excavation [4]. Therefore, it is necessary to take shotcrete treatment for the 2304 upper transport tank of the mine.

For the time being, shotcrete or mortar is generally used to close the roadway

surface in domestic coal mines [5], but with the development of science and technology and the improvement of coal mine production capacity, the defects of such technology are becoming more and more obvious [6]: First, the construction speed is slow, the thickness of shotcrete is generally greater than 100 mm, coupled with the slow spraying speed of the spraying machine, in the process of tunneling, the construction speed and tunneling speed do not match, affecting the construction progress; Second, the construction site environment is poor. When shotcrete is used, the dust concentration on the construction site is high, which seriously threatens the recognized health [7]. Third, the transportation pressure is large, and a large number of sand and cement transportation on the transportation system causes a great burden; Fourth, cracks and peeling of shotcrete layer are easy to occur under the influence of mining. In the roadway with good stability, the concrete coating can maintain good stability and play a sealing effect on the roadway surface. However, in the goaf excavation alley with large roadway deformation, the concrete coating is prone to cracks and peeling, so it is necessary to re-spray the roadway and increase the maintenance cost of the roadway. Therefore, it is of practical significance to study spraying materials with better performance for roadway closure [8].

2. Supporting Mechanism and Advantages of Polymer Modified Cement Mortar Spraying Materials

2.1. Supporting Mechanism of Polymer Modified Cement Mortar Spraying Material

Polymer modified cement mortar spraying material is a new support concept [9], mainly composed of polymer and cement mortar [10], applied to the surface of roadway surrounding rock, plays a role in closing the roadway surrounding rock [11] [12]. The supporting mechanism of polymer modified cement mortar spraying material on roadway surrounding rock can be divided into three aspects [13]:

1) Bearing shell action. It is assumed that the spray layer of thin layer flexible spraying material is an independent supporting structure, which carries external load through its own compressive and bending strength. Its section is subject to normal stress, shear force and bending moment, and plays the role of bearing shell on surrounding rock.

2) Cementation. It includes two aspects: one is the bonding effect between polymer modified cement mortar spraying material and surrounding rock, which is reflected in the adhesion strength of polymer modified cement mortar spraying layer on the roadway surface; the other is the cementation effect of polymer modified cement mortar spraying material penetrating into the cracks of surrounding rock to improve the cohesion of joints. In short, the polymer modified cement mortar spraying material connects the roadway surface through cementation, forming a local composite bearing arch structure.

3) Wedge action. The collapse of roadway surrounding rock requires two

conditions: one is that the false main force is greater than the inter-block resistance; the other is that there is enough shear space during the slide of rock blocks. When the spray layer material penetrates into the crack space, it is like a wedge filling the crack space, and rock blocks will maintain stability during the fall due to insufficient shear space. Spray filling joints like grouting increases the compressive strength of rock mass as a whole [14] [15].

2.2. Advantages of Polymer Modified Cement Mortar Spraying Materials

Compared with the traditional shotcrete spraying layer, the polymer modified cement mortar spraying material has the following advantages:

1) Strong adhesion and good tightness. Due to the high viscosity of the polymer after mixing with water, the slurry can be firmly bonded on the roadway surface, and the water-loss film formation of the polymer and the hydration of the cement make the consolidated body after the solidification of the coating have better tightness.

2) The construction speed is fast. The construction process of polymer modified cement mortar spraying material is simple, the spraying thickness is thin, and the material consumption is small, so the construction speed of polymer modified cement mortar spraying material is much higher than that of shotcrete, which can save the time consumed in the spraying process and reduce the loss of human and material resources.

3) Energy saving and environmental protection, high safety factor. The polymer modified cement mortar spraying material has no dust generation in the construction process, which is friendly to the health of underground workers, and the polymer modified cement mortar spraying material has a low rebound rate during use, which reduces the waste of materials.

4) Low cost. The unit price of polymer modified cement mortar spraying materials is higher than that of concrete materials, but the amount is much smaller than that of concrete materials, and the transportation cost is much lower than that of concrete materials, after accounting for the cost, the cost of polymer modified cement mortar spraying materials is much lower than that of shotcrete.

3. Selection and Properties of Polymer Modified Cement Mortar Spraying Materials

3.1. Selection of Polymer Modified Cement Mortar Spraying Materials

Polymer modified cement mortar spraying material is a kind of spraying material based on cement mortar, adding polymer functional additives to improve the performance of cement mortar. It has the characteristics of low cost, high bond strength, high support strength and strong toughness. The water-cement ratio of polymer modified cement mortar spraying material used in this paper ranges from 0.45 to 0.5. The content of dispersible emulsion powder is 5%, and the

content of coagulant, retarder, thickener and water reducer is selected according to the literature research situation.

3.2. Properties of Polymer Modified Cement Mortar Spraying Materials

The initial setting time and final setting time of inorganic spraying materials are 10 min and 80 min respectively, which can prevent the slurry from flowing on the roadway wall and quickly close the roadway. The inorganic spray material was made into a standard test block, and the measured compressive strength of the slurry after curing was 8 MPa for one day and 26 MPa for 28 days. With the support of anchor mesh, it can play a certain role of bearing shell. The adhesive strength of inorganic spray material is more than 0.5 MPa in one day and more than 1.3 MPa in 28 days, which has strong bonding ability with coal and is not easy to cause "peeling" phenomenon. The flexibility is less than 0.3 mm.

4. Field Test

4.1. Overview of the Test Site

In order to improve the recovery rate and reduce the width of the protective coal pillar, a mine in Henan province adopts the goaf tunneling technology to drive the 2304 upper channel. The upper channel of 2304 is driven along the goaf of the lower channel of 2302. The width of the coal column between the upper channel of 2304 and the lower channel of 2302 is 5 m, and the distance is relatively close. The air flow in the roadway driving process may flow to the goaf through the protective coal column, which may cause the risk of spontaneous combustion of the coal seam in the goaf. To solve this problem, the whole section of 2304 upper channel mining area was sprayed. The position diagram of the upper groove of 2304 is shown in Figure 1.

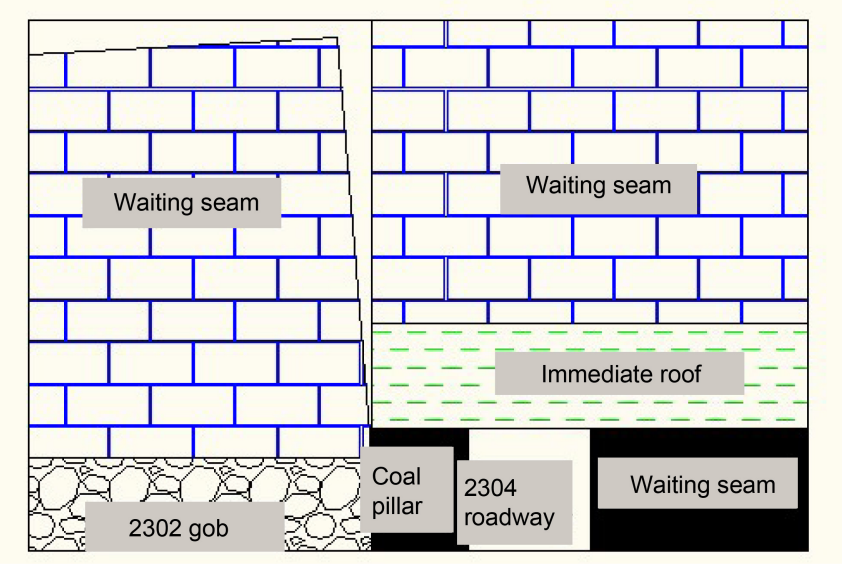

Figure 1. Schematic diagram of the position of 2304 upper winding groove.

4.2. Test Process

4.2.1. Preparations

Before construction, strictly implement the "knock on the roof" system of the roadway, carry out safety inspection on the construction site, check the cracking of the roof of the roadway, the living dirt, and the slurry skin, and deal with it, and confirm the safety before work.

Prepare the materials, equipment and tools required for construction, place the spraying equipment vertically in a safe place without traffic impact, and fix it to prevent toppling.

Firmly connect all pneumatic tools to the site air source, and thoroughly check the connection of the spraying device and pipeline.

The cables, pipelines, feng shui pipelines and other equipment at the spraying site should be properly protected and covered, and the sprayed surface should be washed with high pressure wind and water.

Before spraying, the receiver should set the spraying edge.

Before spraying, the construction personnel should connect the air and water pipes and carry out air supply and water supply tests to check whether there is air leakage and water leakage. Check the wear of the spray conveying pipeline to see if there is any air leakage and material running. Check the wear of the connecting parts and whether the water holes are blocked. Check whether there is any debris in the cylinder, and whether the discharge elbow is blocked; Piston cylinder, pressure gauge and other transmission components are normal; Check whether the operator handle is sensitive and reliable, whether each valve has air leakage, whether each sealing part is sealed, whether each bearing has oil, and whether the lighting and dust prevention facilities are complete and reliable.

The mixture must be stirred evenly, the ratio is correct, and the mixture should be used with the mix.

Before spraying, the personnel must wear a mask and dress neatly.

4.2.2. Construction Steps

The flowchart of construction steps is shown in the figure.

Safety inspection → Equipment preparation → water test pump → Starting → spraying operation → cleaning equipment → finishing site.

4.2.3. Construction Process

The spraying machine operation is to open the air first, adjust the wind pressure from small to large, and finally feed. When stopping, stop the material first, and then stop the wind after the storage material in the cylinder is sprayed.

Sprinkler operation: Adjust the water-cement ratio in time, and the appropriate water-cement ratio is between 0.4 and 0.45:1, and try to keep the sprinkler and the spray surface between 0.8 and 1.0 m; The spray sequence moves from bottom to top in a spiral trajectory, the diameter of the trajectory is 200 - 300 mm, and the wind pressure is not less than 0.5 MPa when spraying concrete.

The surface after spraying should be smooth, wet, and shiny, with no slip flow

phenomenon. When the surface after spraying is found to be dry, loose, falling, sliding or cracked, it should be removed in time and resprayed.

After spraying, clean the spraying equipment with water in time to ensure that there is no spraying paint in the equipment, and finally turn off the wind, water pipe and power switch.

5. Effect Analysis and Discussion

In order to investigate the spraying effect, the deformation of the roadway was compared between the sprayed position and the non-sprayed position by monitoring the deformation of the roadway. At the same time, the air volume of the roadway was monitored by setting measuring points in the roadway to reflect the air leakage of the roadway.

5.1. Roadway Surface Displacement Monitoring

The movement of the surrounding rock of the roadway can be determined by the monitoring data of the roadway surface displacement, and whether the surrounding rock enters the stable state can be analyzed. The surface displacement monitoring of the roadway includes the subsidence of the roof and the heave of the bottom plate. The measurement method is as follows: "cross layout method" is adopted. On the same monitoring section, the two sides and the top and bottom plate are painted as marks, and the two sides are suspended with measuring ropes. The distance from each measuring point to the reference point is measured separately, and the difference between the two test data adjacent to the two measuring points is the relative approximation of the two points, and the relative total approximation of the two points can be obtained by summing the difference between the two adjacent tests. Three measuring points are arranged in the roadway, respectively in the non-sprayed area and the sprayed area.

The tunnel deformation observed at the measuring point in the non-sprayed area of the upper channeling 2304 is shown in the figure.

As can be seen from **Figure 2** and **Figure 3**, since the beginning of observation, the changes of the top and bottom plate are relatively drastic. After 90 days of observation, the top and bottom plate are in a stable stage, at which time the displacement of the top plate is 25 mm, the bulking amount of the bottom plate is 61 mm, and the displacement of the top and bottom plate is 86 mm, and the deformation of the top and bottom plate is slight. The proximity of the two sides remained in a stable state after 90 d, reaching 390 mm, and the roadway deformation was relatively severe.

Figure 4 and **Figure 5** show the deformation of the roadway at the measuring point where the spraying thickness is 5 mm in the spraying area of the upper channeling of 2304.

It can be seen from **Figure 4** and **Figure 5** that since the observation of the measuring point of the upper groove of 2304, which is within the range of 5 mm spraying thickness, the deformation of the two sides and the bottom plate is

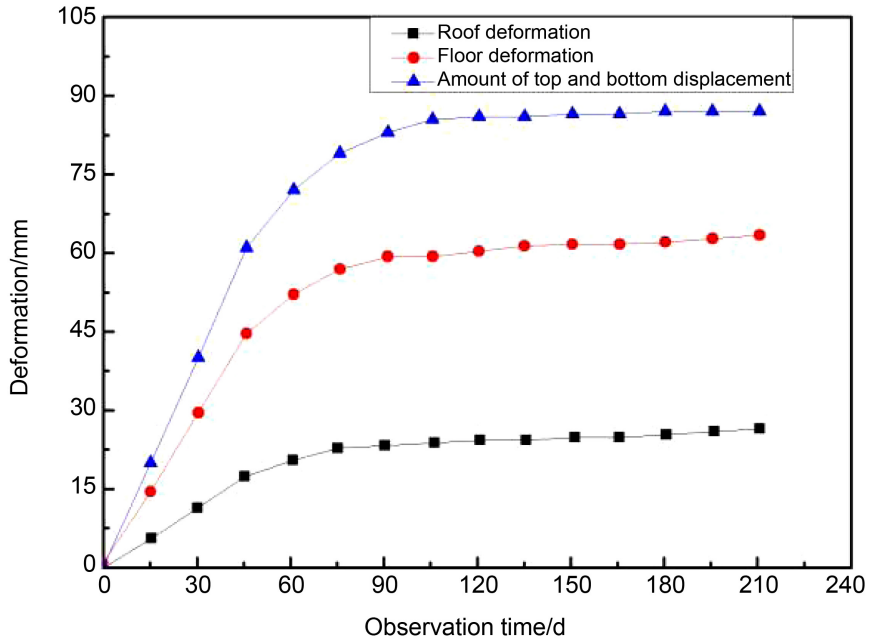

Figure 2. Deformation of the top and bottom plate of the measuring point in the non-spraying range.

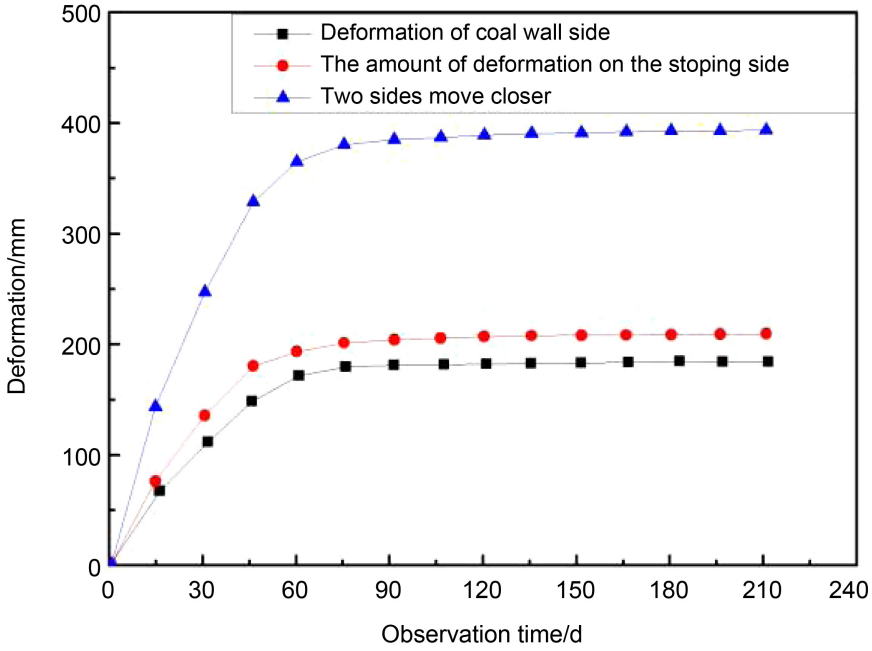

Figure 3. Deformation of the two sides of the measuring point in the non-spraying range.

relatively severe, while the deformation of the top plate has little change. About 75 d from the observation, the deformation of the roadway gradually stabilized, the deformation of the roof, the bottom plate, the coal pillar side and the mining side were 7 mm, 37 mm, 19 mm and 12 mm respectively, and the displacement of the top and bottom plate and the displacement of the two sides were 44 mm

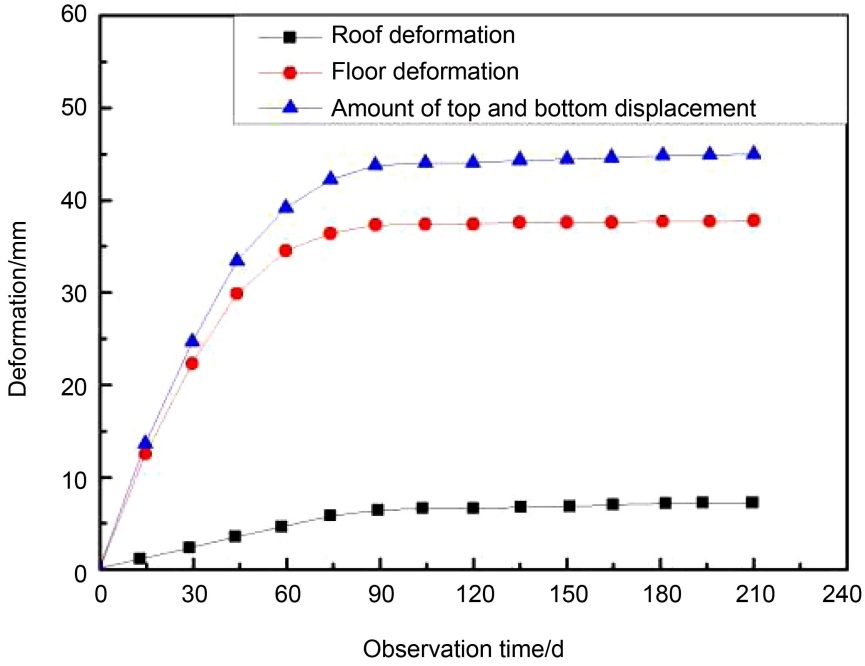

Figure 4. Deformation of the top and bottom plate of the measuring point within 5 mm spraying thickness.

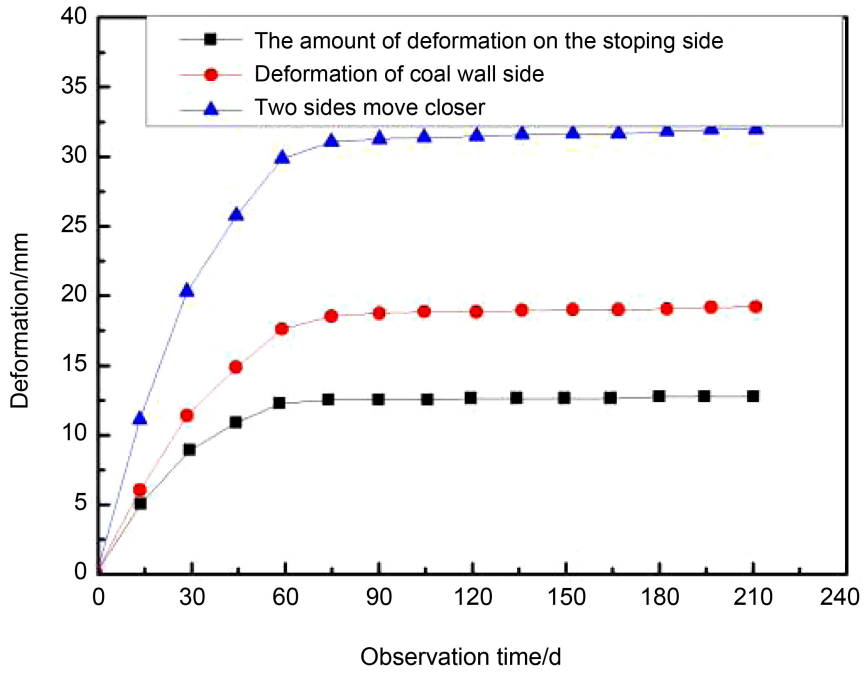

Figure 5. Deformation of the two sides of the measuring point within 5 mm spraying thickness.

and 31 mm respectively. Among them, the deformation of the bottom plate is the largest, which indicates that the bottom heave phenomenon of the section where the measurement point is located is more serious. Compared with the non-sprayed roadway deformation, the deformation of the roadway is weakened,

in which the deformation of the roof and the two sides decreases a lot, but the deformation of the floor changes little. The construction of spraying materials can only spray the roof and two sides, so it can reflect that spraying materials have an effective supporting effect on the roadway and curb the deformation of the roadway.

The deformation of the roadway at the measuring point where the coating thickness is 8 mm in the upper channeling spray area of 2304 is shown in Figure 6 and Figure 7.

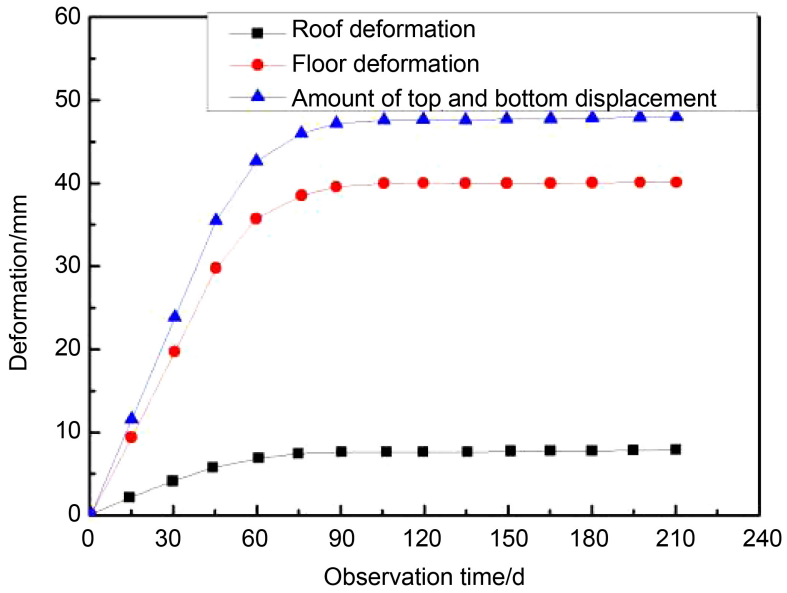

Figure 6. Deformation of the top and bottom plate of the measuring point within 5 mm spraying thickness.

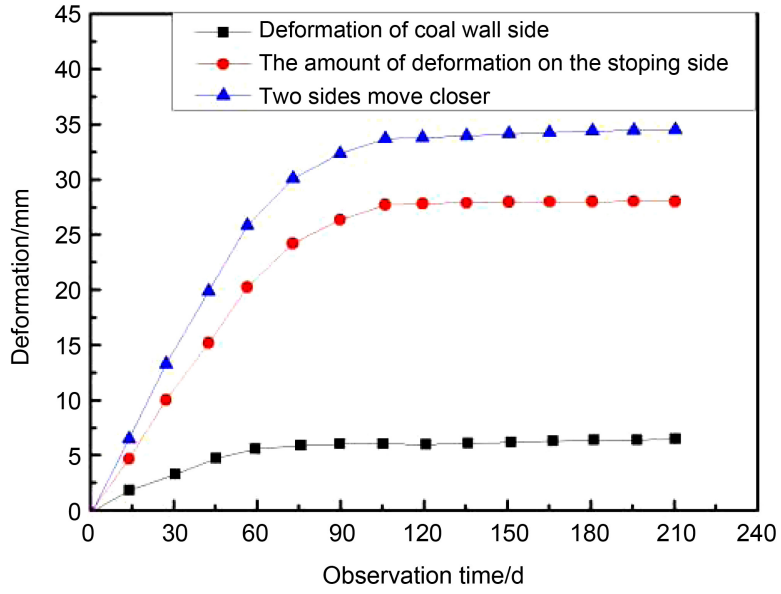

Figure 7. Deformation of the two sides of the measuring point within 8 mm spraying thickness.

It can be seen from Figure 6 and Figure 7 that since the observation of the measuring point of the upper channeling groove of 2304, which is within the range of spraying thickness of 8 mm, the deformation of the mining side and the bottom plate is relatively severe, while the deformation of the roof and the deformation of the coal wall have little change. About 75 d from the observation, the deformation of the roadway gradually stabilized, the deformation of the roof, the bottom plate, the coal pillar side and the mining side were 8 mm, 40 mm, 6 mm and 28 mm respectively, and the displacement of the top and bottom plate and the displacement of the two sides were 48 mm and 34 mm respectively. Among them, the deformation of the bottom plate is the largest, which indicates that the bottom heave phenomenon of the section where the measurement point is located is more serious. Compared with the deformation of the roadway with a coating thickness of 5 mm, the deformation of the roadway is weakened except for the mining side, but the change is little. The reason for the large variation of the stoping side may be the influence of mining. Therefore, it can be reflected that there is little difference between the supporting effect of spraying thickness of 5 mm and 8 mm on the roadway. Therefore, in order to reduce the amount of material loss, it is recommended that the spray thickness be controlled at 5 mm.

5.2. Air Leakage Monitoring

Air volume monitoring points are arranged in the open roadway, and the air leakage of the roadway is calculated by monitoring the air volume of the inlet and outlet of the roadway, and the air leakage situation of the roadway is mastered, and the sealing effect of spraying materials is investigated.

The measurement location was arranged in the air inlet and air outlet of the upper channel of 2304, and was measured every 10 days.

By analyzing the data in the Table 1, it can be seen that before the shotcrete, the air leakage volume of the tunnel reached 80 m^3/min. With the gradual expansion of the shotcrete range, the air leakage volume of the tunnel gradually decreased and finally stabilized at 23 m^3/min, with the air leakage rate only 4.5%.

Table 1. Statistical table of air volume monitoring.

Monitoring time/(d)	Air intake volume of roadway/(m^3/min)	Return air volume of roadway/(m^3/min)	Air leakage in roadway/(m^3/min)
0	505	425	80
10	500	438	62
20	505	460	45
30	495	459	36
40	496	465	31
50	502	474	28
60	502	477	25
70	500	477	23
80	503	480	23
90	503	479	24

6. Conclusions

1) Compared with the traditional shotcrete spraying layer, the polymer modified cement mortar spraying material has fast construction speed, simple process, small transportation pressure, strong bonding ability and better performance, and is more suitable for the surface spraying of roadway.

2) After spraying, the spray layer has a significant supporting effect on the roadway, the roadway deformation is effectively controlled, and the optimal thickness of spraying is 5 mm.

3) After spraying the layer, the air leakage in the roadway is reduced from the original 80 m^3/min to 23 m^3/min, and the air leakage rate in the roadway is only 4.5%, which is effectively controlled.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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