

## Article

# Research and Practice on Filling Technology of Fully Mechanized Coal Mining Face through Trend Abandoned Roadway

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**Abstract:** Taking the fully mechanized mining face (FMMF) through the abandoned roadway (AR) in a coal mine in Shanxi Province, China as the engineering background, the field investigation, theoretical analysis, numerical simulation and field test were comprehensively used to study the instability mechanism of the trend AR. The deformation and failure evolution of the trend AR roof were deduced into four stages: initial deformation, bending and separation deformation, fracture failure, and collapse destruction. The high span ratio proved to be the key factor affecting the stability of the trend AR, and the control principle of timely support and reduction of roof span should be followed for controlling the roof of trend AR. Comparing the traditional method through the trend AR with the perspectives of technological and economic benefits, the technology of filling and controlling the trend AR with the high water material over in the FMMF was proposed, and the effect of the filling body on the roof of the trend AR was revealed. The key parameters of the filling body were identified: the strength of the filling body is 1.0 MPa, and the water-cement ratio corresponding to the high-water material is 8:1. Based on this information, the process of the trend AR filling was designed systematically. Industrial tests show that during the FMMF through the trend AR, the roof was effectively supported by the filling body and the normal coal mining was not significantly affected, so the safe mining of coal resources was guaranteed.

**Keywords:** abandoned roadway; instability mechanism; high water material; backfill

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## 1. Introduction

Energy is the foundation and power of human civilization and progress [1]. As one of the energy mineral resources, coal accounts for 25% of the world's primary energy consumption. In 2020, the total global coal production will be about 7.438 billion tons, and China's coal production will be 3.84 billion tons, accounting for more than 50% of the global coal production [2,3]. However, with rapid economic growth and increasing coal consumption in China, some coal enterprises excessively pursue short-term economic benefits, resulting in disordered mining of coal resources, resulting in huge waste of coal resources. The subsequent mining of coal resources was seriously restricted by the large number of AR left over, which also indirectly increases the difficulty and safety risks of mining engineering [4–6].

AR is the connecting roadways for recovering corner coal or coal pillar when coal resources are exhausted, or the roadways left in the middle of working face due to the change of mining design scheme. According to the position relationship between AR and advancing direction of working face, it can be divided into three types: incline, inclined, and trend. Coal working face through AR, especially the AR which is easy to collapse, is a

technical problem often encountered in coal mine production. Therefore, many scholars have carried out a lot of research on the surrounding rock stability and control of AR, and achieved rich research results. Yang [7] examined the roof failure characteristics, forces acting on supports, and action characteristics of abutment stress observed in front of a longwall face when an AR was installed in front of a cave working face. A solution for roof presplit in the AR was proposed by Liu [8], and the research results indicated that the roof vertical stress and vertical displacement could be reduced effectively by roof presplit. Ma [9] studied the occurrence mechanism of advanced coal pillar instability failure and support crushing accidents during a long-wall face passing AR period, and put forward the occurrence mechanism and prevention measures. Bai [10] analyzed the surrounding rock movement law of AR in front of coal mining face, constructed the stability model of AR roof, and determined the stability of AR basic roof. Liu [11] established the mechanical model of the basic roof breaking in the AR of the second mining face, and revealed the mechanical mechanism of the basic roof leading fracture. Xie [12] established the basic roof fracture structure model of fully mechanized top coal caving face through AR, analyzed the surrounding rock stress and failure characteristics of fully mechanized top coal caving face passing through AR, and determined the time and space nodes and relevant parameters of the implementation of comprehensive control technology. Yin [13] studied the instability mechanism of coal pillar between working face and AR by catastrophe theory, and analyzed the basic roof stress state and breaking position of coal pillar after instability based on thin plate theory. Xu [14] established the basic roof mechanical model of AR, revealed the stability mechanism of AR roof, and determined the minimum support resistance to maintain the stability of AR roof. In addition, many on-site engineering and technical personnel have also carried out beneficial practices and explorations on AR in coal mining faces [15–18].

However, at present, many experts and scholars focus on the working face through incline and inclined AR, and less on the working face through the trend AR. Compared with the incline and inclined AR, the working face through the trend AR has longer passing distance and time, more unstable factors and higher safety risk. The traditional methods of incline and inclined AR mainly include dense pillars or wooden stacks, anchor mesh cable beam reinforcement and rearrangement of the working face with the AR as the cut-out. The above method has great limitations when the working face through the trend AR, it is questionable whether the surrounding rock stability of AR can be guaranteed in the long-term advancing process. Therefore, based on the engineering and technical problems of a FMMF in Shanxi Province, the surrounding rock instability mechanism of the AR by theoretical calculation method was studied, and the technology of filling the AR with high water material by comprehensive technical and economic factors was proposed, and the action mechanism of the filling body on the roof of the AR by means of numerical simulation was revealed. On this basis, the key parameters of the filling body and the filling process scheme were determined, and the industrial test exploration was carried out successfully.

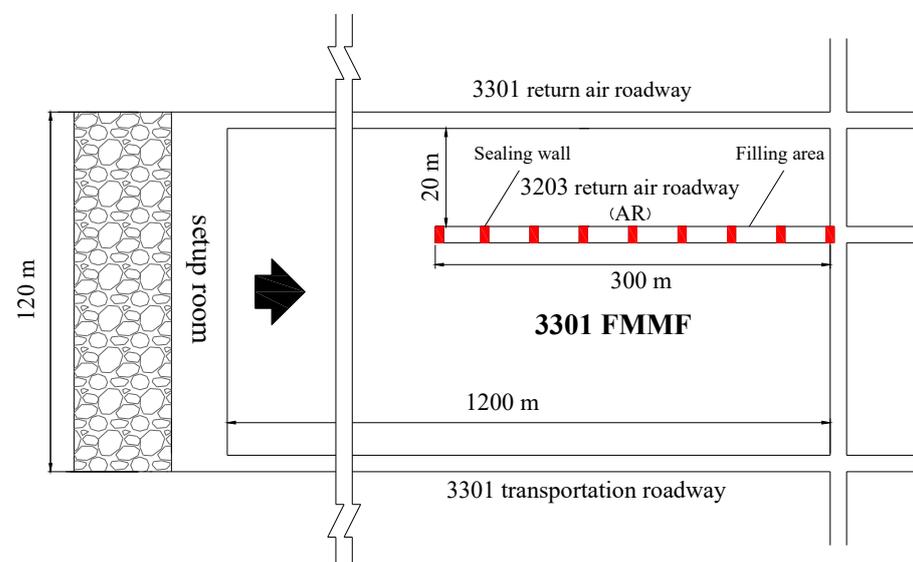
## 2. Engineering Background

A coal mine is located in Shanxi Province, China, which belongs to the resource integration mine. The well field is 5.73 km long from east to west, 3.19 km wide from north to south, 12.75 km<sup>2</sup> in area, with production capacity of 0.9 Mt/a and service life of 19 a. At present, the main coal seam is 3# coal seam. 3# coal seam belongs to the main coking coal, with developed joint fissures, with an average buried depth of more than 1000 m, thickness of about 2.40 m and inclination angle of 3–9°. The roof is managed by the full height fully mechanized mining technology in one time and the whole caving method is adopted. The average buried depth of 3301 FMMR in the first mining area is 1050 m, the strike length is 1200 m, and the inclined length is 120 m. The occurrence conditions of coal seams in the mining area are relatively stable. The lithology of roof and floor with 3301 FMMR is shown in Table 1.

**Table 1.** The lithology of roof and floor with 3301 FMMF.

Sketch	Lithology	Thickness (m)	Basic Description
	false roof shale	0.45	Broken, with charcoal grain.
	immediate roof sand shale	1.65	The hardness coefficient is 4.0 and there are many layers.
	basic roof sandstone	5.68	It is grayish white and contains more quartz.
	immediate floor sand shale	3.70	The hardness coefficient is 3.0, gray black.
	basic floor sandstone	11.46	It has a high degree of carbonization and contains plant fossils.

When 3301 FMMR is advancing, it needs to pass through an AR parallel to the strike of working face and with the same level, namely 3203 return air roadway. The length of 3203 return air roadway is 300 m, the cross-section size is 4.5 m × 2.5 m, and the horizontal distance from 3301 FMMR is 20 m. The whole cross-section is supported by bolt, mesh and cable. As the service life is more than five years, the surrounding rock, especially the roof, of the AR is seriously deformed and damaged. It is estimated that it will take at least two months for 3301 FMMR through the AR. The excavation engineering plan is shown in Figure 1.

**Figure 1.** The excavation engineering plan.

### 3. Study on Roof Instability Mechanism of AR

In the process of FMMF passing through the AR, the stability of the roof is a key factor that affects the safe mining of coal. Therefore, it is necessary to theoretically analyze the mechanism of roof deformation and instability of the trend AR. Simplifying the trend AR into a two-dimensional plane model, it can be known from the elasticity plane strain theory that the shear stress concentration of the surrounding rock formed by the excavation of the roadway is the main reason for its deformation and failure, and the damage degree of the surrounding rock can be used to characterize the plastic area.

### 3.1. Stress Distribution Law of Surrounding Rock with AR

3203 return air roadway is the working face channel with a rectangular cross section. In order to qualitatively explain the stress distribution law of surrounding rock of the trend AR, the rectangle of roadway section is approximately equivalent to an ellipse which is tangent to the roadway. The stability of the surrounding rock of roadway is evaluated by analyzing the distribution characteristics of stress and plastic zone around the flat ellipse roadway. The mechanical model is shown in Figure 2.

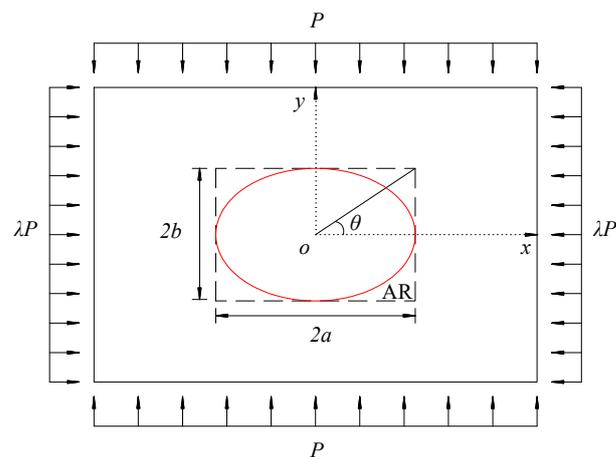


Figure 2. Mechanical model.

According to the classical elastic mechanics theory, the tangential stress distribution around the deep-buried elliptical roadway:

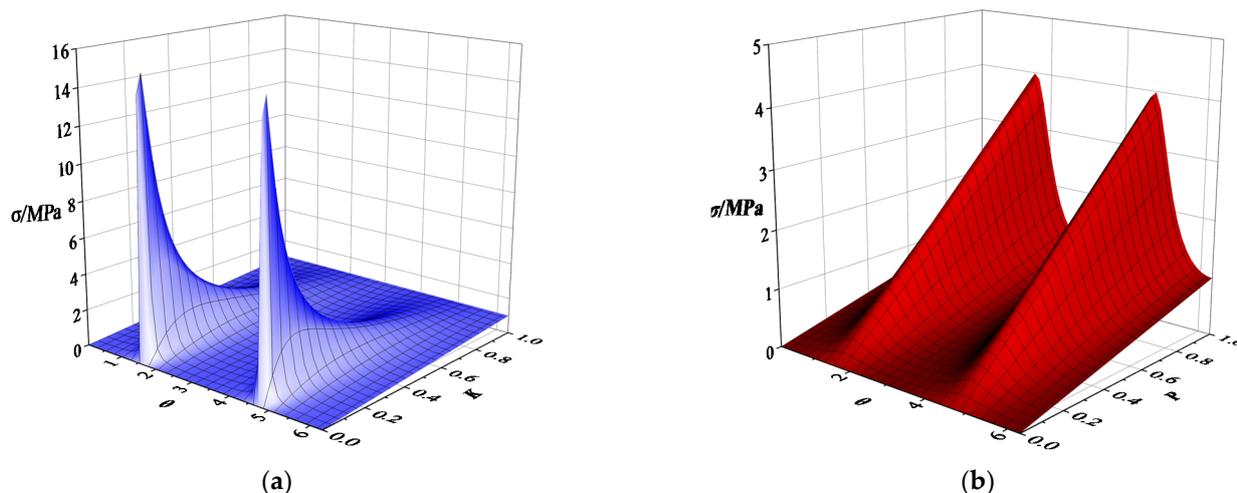
$$\sigma_{\theta} = \frac{P}{a-b} \left[ \frac{4ab(a-\lambda b)}{(a^2+b^2)+(a^2-b^2)\cos 2\theta} + (a+b)(\lambda-1) \right] = \frac{P}{\cos^2 \theta + K^2 \sin^2 \theta} [2K \sin^2 \theta + K^2 \sin^2 \theta - \cos^2 \theta + \lambda(\cos^2 \theta + 2K \cos^2 \theta - K^2 \sin^2 \theta)] \quad (1)$$

where,  $a$ —half of the span of the AR;  $b$ —half of the height of the AR;  $P$ —vertical stress;  $\theta$ —rotation angle;  $K = b/a$ —height span ratio;  $\lambda$ —lateral pressure coefficient.

In order to explain the problem qualitatively, combining with the engineering analogy method, taking the lateral pressure coefficient  $\lambda = 1$ , there are:

$$\sigma_{\theta} = \frac{4abP}{(a^2 + b^2) + (a^2 - b^2) \cos 2\theta} = \frac{2KP}{\cos^2 \theta + K^2 \sin^2 \theta} \quad (2)$$

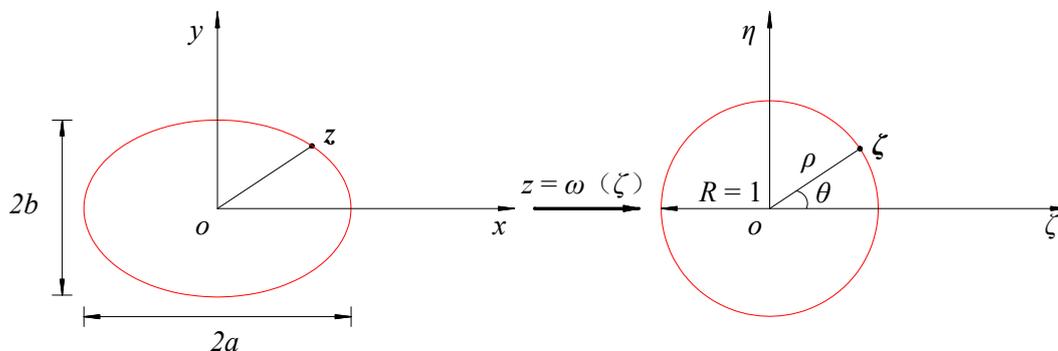
From Formula (2) and Figure 3, it can be seen that the shear stress of the surrounding rock of the AR is affected by two parameters  $K$  and  $P$ : with the increase of the load  $P$ , the stress of the surrounding rock increases; with the increase of the height span ratio  $K$ , the stress of the roof and floor decreases, and the stress of the two sides increases; when  $K = 1$ , the stress of the surrounding rock is equal, and the height span ratio  $K$  has the greatest influence on the stress of the surrounding rock. For the control of surrounding rock, the ratio of height to span is the key factor affecting the stability of surrounding rock under the condition that the stress field of surrounding rock can not be changed.



**Figure 3.** Stress distribution law of surrounding rock with AR. (a) The relationship between  $\sigma$  and  $K$ ; (b) The relationship between  $\sigma$  and  $P$ .

### 3.2. Deformation and Failure Characteristics of Surrounding Rock with AR

The failure degree of the surrounding rock of the trend AR can be expressed by the range of the plastic zone. The complex variable function method is used to convert the elliptical boundary into a circular boundary by conformal transformation, and then the obtained analytical solution is inversely transformed to obtain the distribution range of the plastic zone of the elliptical roadway [19,20]. The conformal transformation principle is shown in Figure 4.



**Figure 4.** Conformal transformation.

The relationship between  $z$  plane and  $\zeta$  plane coordinate:

$$\left. \begin{aligned} x &= R \left( \rho + \frac{m}{\rho} \right) \sin \theta \\ y &= R \left( \rho - \frac{m}{\rho} \right) \cos \theta \end{aligned} \right\} \quad (3)$$

Among them,  $R = (a + b)/2$ ,  $m = (a - b)/(a + b)$ .

The radius of the plastic zone per unit circular roadway on the  $\zeta$  plane is obtained by using the rubinite solution of the elastic-plastic analysis of the circular orifice:

$$\rho_L = R_0 \left\{ \frac{[P(1 + \lambda) + 2C \cot \varphi](1 - \sin \varphi)}{2C \cot \varphi} \right\}^{\frac{1 - \sin \varphi}{2 \sin \varphi}} \left\{ 1 + \frac{P(1 - \lambda)(1 - \sin \varphi) \cos 2\theta}{[P(1 + \lambda) + 2C \cot \varphi] \sin \varphi} \right\} \quad (4)$$

where,  $R_0$  is the radius of the mapping plane,  $\rho_L$  is the polar diameter,  $\theta$  is the polar angle,  $\varphi$  is the cohesive force, and  $C$  is the internal friction angle.

The radius of plastic zone of elliptical roadway on  $z$  plane is obtained from Equations (3) and (4):

$$r_p = R_{\rho_L} \left( 1 + \frac{m^2}{\rho_L^4} + \frac{2m}{\rho_L^2} \cos 2\theta \right)^{\frac{1}{2}} \quad (5)$$

From Formula (5) and Figure 5, it can be seen that the plastic zone range of the AR is affected by the eccentricity  $m$  and the plastic zone radius  $\rho_L$  of the circular roadway on the  $\zeta$  plane,  $m$  depends on the height span ratio  $K$  of the roadway section, and  $\rho_L$  depends on the properties of the surrounding rock.

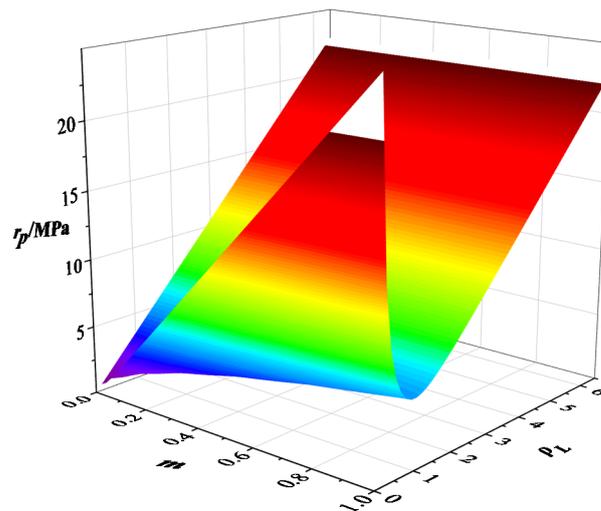


Figure 5. Distribution characteristics of plastic zone in surrounding rock of AR.

With the decrease of the height span ratio  $K$ , the eccentricity  $m$  increases, the range of plastic zone increases, and the damage degree of surrounding rock increases. Therefore, the ratio of height to span is the key factor to affect the surrounding rock properties of the AR.

To sum up, for the control of surrounding rock with the AR, especially the roof rock, the principle of reducing the roof span should be followed in both the improvement of surrounding rock stress environment and the control of surrounding rock deformation.

### 3.3. Roof of AR Deformation and Failure Deduction

Tunneling of AR breaks the balance of original rock stress field. Under the action of mining stress, the AR is destroyed rapidly. According to the theoretical calculation results, combined with engineering analogy [21], the deformation and failure process of AR roof is deduced: initial deformation, bending separation deformation, fracture failure and collapse destruction, as shown in Figure 6.

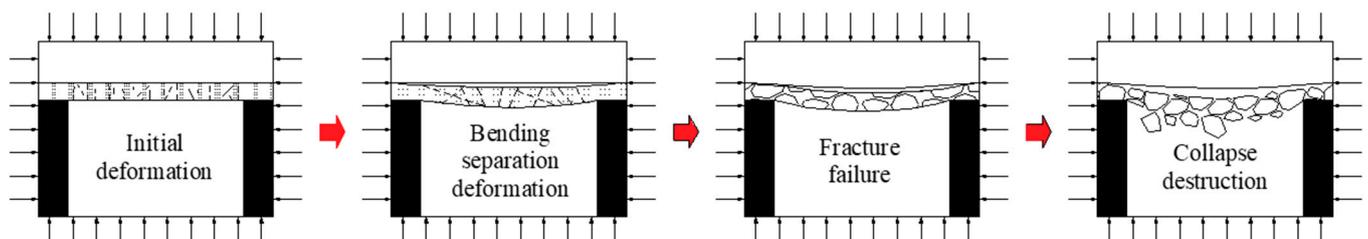


Figure 6. Deformation and failure process of roof with AR.

- (1) Initial deformation. The span of the immediate roof rock is enlarged and the deformation occurs due to the influence of the overburden pressure after the tunneling of AR.

The results show that the deformation of rock strata is basically perpendicular to the normal direction of the bedding plane, and the fissures of surrounding rock gradually develop into joint fissure group with the tunneling of AR;

- (2) Bending separation deformation. With the advance of the working face, the overlying rock of the upper part of the AR appears deflection, and the vertical asynchronous movement between the immediate roof and the basic roof forms longitudinal separation, resulting in bed separation;
- (3) Fracture failure. With the increase of disturbance degree, the amount of separation layer increases gradually, the cohesion between layers is lost, the deflection of immediate roof layer increases rapidly, and the fracture failure begins;
- (4) Collapse destruction. Under the action of mining stress, the immediate roof is rapidly transformed from fracture to collapse with the work facing the AR. If it is not supported in time, it will directly threaten the safety of equipment and personnel.

To sum up, the AR roof failure is a gradual mechanical process. It is difficult to effectively control the initial deformation of the roadway with the instant of excavation; if the AR has not been separated, it is necessary to control the roof in time to avoid the separation; if the AR has been bent and separated, it is necessary to strengthen the support of the roof to prevent it from entering the stage of fracture and collapse. Therefore, for the roof control of the trend AR, the principle of timely support should be followed from the perspective of retarding the deformation and failure process.

#### 4. Determination of FMMR through the Trend AR

##### 4.1. Technical Perspective

The traditional way of FMMF through incline and inclined AR is prone to accidents such as rapid roof subsidence and support crushing, which seriously affect the progress of the working face, and may also cause a waste of resources, with great limitations and risks. In order to overcome the above disadvantages, we propose to use high water material to fill the trend AR and control the roof. High water material is a kind of special cement, which sets rapidly under the condition of high water cement ratio. It is divided into material A and material B. When material A and B are mixed with water alone, they are not easy to set within 24 h. If they are mixed with water, they will quickly set and harden. It has the advantages of high stone rate, short and adjustable solidification time, good plasticity, micro expansion, no water separation, large water content of consolidation body, and long distance transportation. The stress-strain curve of high water material solidified at 1.5:1 water cement ratio for seven days is shown in Figure 7.

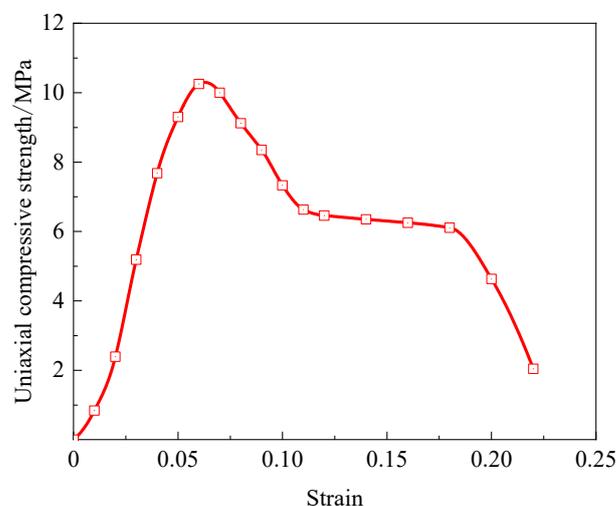


Figure 7. Stress strain curves of high water content materials.

According to Figure 7, with the increase of strain load, the bearing capacity of high water materials increases gradually, with the peak value exceeding 10 MPa; with the increase of strain, the bearing capacity decreases gradually, but the reduction rate is far lower than that of ordinary concrete; under the condition of water cement ratio, when the strain is 10%, the bearing capacity exceeds 69% of the peak strength, and the load-bearing performance is close to 60% of the peak strength when the strain is 17%. Therefore, the high water material has obvious plastic characteristics, which allows large plastic deformation and slow strength attenuation. When the roof of the AR begins to sink and compress the filling body, the backfill will produce the support reaction to prevent the roof from sinking. While supporting in time, the equivalent span of the AR is reduced, and the deformation of the roof of the AR can be effectively controlled. When the FMMF is recovered to the AR, the filling body will be cut as the coal mining, and the mining equipment will not be damaged.

#### 4.2. Economic Perspective

- (1) The support is strengthened by dense pillars or wooden stacks. 3301 FMMF through the AR, each coal cutting cycle requires the removal of dense pillars or wooden stacks, the process needs to stop for 20 min, a total of 120 min a day, which is equivalent to cutting a knife less coal per shift. It takes two months for the FMMF through the AR, and the economic loss is not less than 1.2 million RMB;
- (2) The FMMF moves around the AR. 3301 FMMF moved for at least 15 days, during which a large amount of coal resources were less exploited, and the economic loss was not less than 2 million RMB;
- (3) High water material filling. The filling space of the AR is 1800 m<sup>3</sup>. According to the water cement ratio of 8:1, 160 tons of high water materials are needed, and the cost of filling materials is 368,000 RMB, the purchase of special filling equipment is about 200,000 yuan, and the total cost is no more than 600,000 RMB.

Therefore, compared with other treatment methods, AR filled with the high water material is technically feasible, efficient, with low cost, and has good technical and economic benefits. It is an ideal way for FMMF to pass through the AR.

## 5. Determination of Key Parameters for Backfill

### 5.1. The Establishment of the Model

With the advance of the FMMF, the roof of the AR subsides and the backfill supports the roof of AR, but the roof control effect and cost of the backfill with different strength are not the same. Therefore, the FLAC3D numerical simulation software is used to study the stress and deformation characteristics of surrounding rock of the AR during the advancing of the FMMF to determine the effect of roof control, and to determine the key parameters of the filling body: the strength of the filling body and the water cement ratio of high water material.

Based on the actual production geological conditions, a numerical simulation model is established, as shown in Figure 8. Model size is with length  $\times$  width  $\times$  height = 200 m  $\times$  100 m  $\times$  50 m, horizontal displacement constraint is set at left and right boundary, fixed constraint is set at lower boundary, and equivalent stress is applied at upper boundary. Mohr Coulomb criterion is adopted, and lateral pressure coefficient is 1.0. According to laboratory test results and geological exploration report, comprehensive determination of physical and mechanical parameters of coal and rock mass is shown in Table 2.

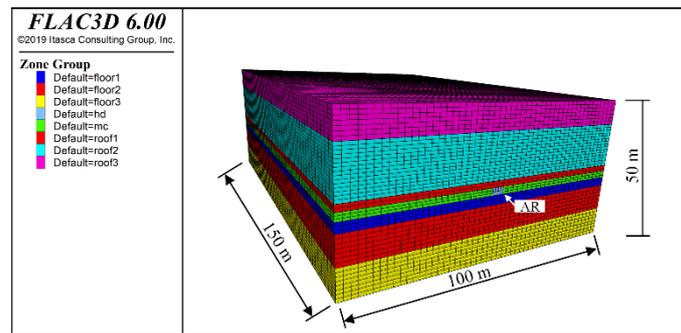


Figure 8. Numerical calculation model.

Table 2. Physical and mechanical parameters of coal and rock mass.

Stratum Name	Thickness (m)	Density (kg·m <sup>-3</sup> )	Bulk Modulus (GPa)	Shear Modulus (GPa)	Cohesion (MPa)	Internal Friction Angle (°)	Tensile Strength (MPa)
Overlying strata	50	2450	1.02	0.46	1.9	36	1.4
Sandstone	1.0	2250	3.02	1.58	1.3	28	1.1
Sand shale	2.0	2680	4.65	2.76	1.8	33	2.0
Shale	6.0	2450	3.45	1.85	1.6	29	1.2
Coal seam	2.0	1450	1.20	0.37	0.8	23	0.6
Sand shale	4.0	2680	4.65	2.76	1.8	33	2.0
Sandstone	11	2250	3.02	1.58	1.3	28	1.1

The strength of filling body of high water material can be adjusted by changing the volume of water distribution or the ratio of admixture. The experimental results are shown in Figure 9. The cost of high water material is relatively high. On the basis of meeting the roof control effect, the water cement ratio should be increased as much as possible. Considering the technical and economic factors, four simulation schemes are proposed, as shown in Table 3.

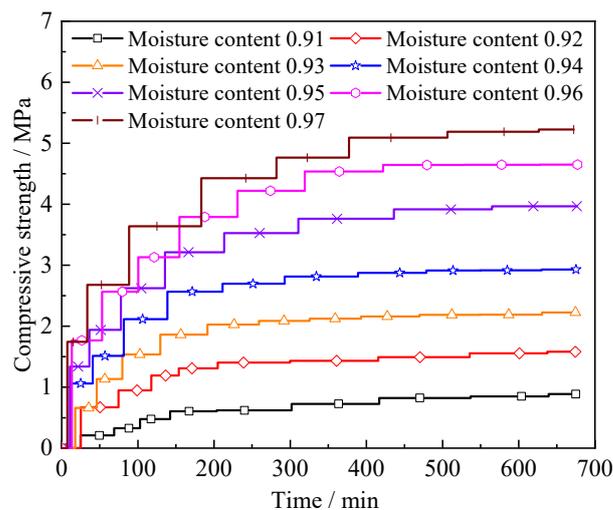


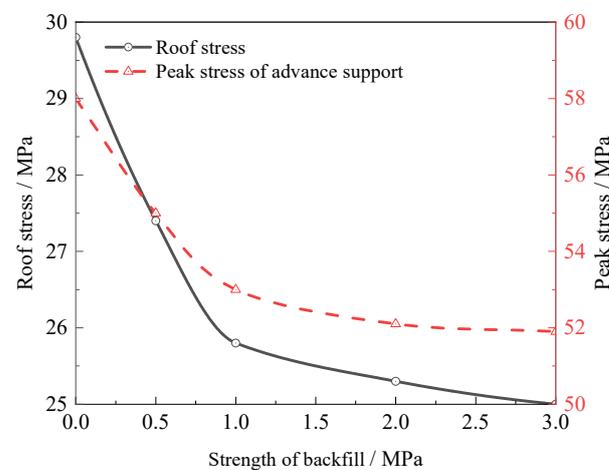
Figure 9. Curve of filling body strength with time.

**Table 3.** Numerical simulation scheme.

Program	Water Cement Ratio	Moisture Content	Compressive Strength (MPa)
1	11:1	0.97	0.5
2	8:1	0.96	1.0
3	6:1	0.95	2.0
4	5:1	0.94	3.0

### 5.2. Stress Distribution Characteristics of Surrounding Rock with AR

In order to more intuitively understand the influence of different filling body strength on the improvement of surrounding rock stress, the influence law of different filling body strength on roof support stress and working face advance support stress is plotted as a curve, as shown in Figure 10.

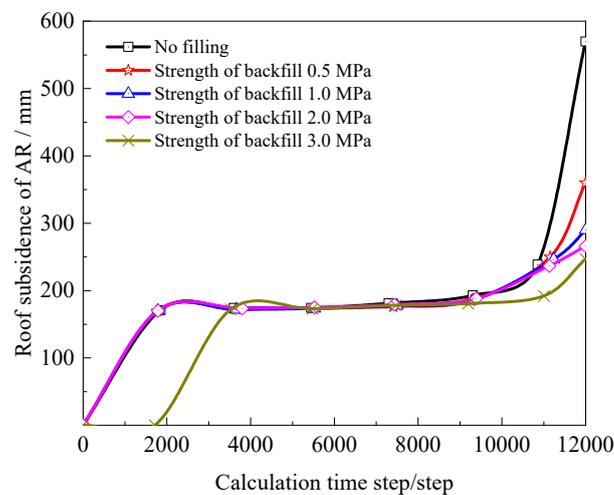
**Figure 10.** Influence of filling body on surrounding rock stress with AR.

From Figure 10, it can be seen that with the increase of filling body strength, the roof stress and the peak stress of advance support with working face will decrease. Compared with the non-filled AR, the stress reduction degree and the stress improvement effect with AR are obvious. Compared with the strength of filling body 1.0 MPa and 0.5 MPa, the stress of filling body is reduced by 1.6 MPa and 2.0 MPa, respectively. Compared with the strength of filling body 2.0 MPa and 1.0 MPa, the stress of filling body is reduced by 0.5 MPa and 0.9 MPa, respectively. Compared with the strength of filling body 3.0 MPa and 2.0 MPa, the stress of filling body is reduced by 0.3 MPa and 0.2 MPa, respectively. Therefore, the strength of filling body is 1.0 MPa and 0.5 MPa, which has obvious effect on the stress improvement of surrounding rock in the AR, while the effect of filling body on the stress improvement of surrounding rock in the AR is not significant when the strength of the filling body is 1.0 MPa, 2.0 MPa, and 3.0 MPa, and the control effect of the filling body on the roof of the AR is better.

### 5.3. Deformation Characteristics of Surrounding Rock with AR

The roof deformation law of the AR under different filling body strength is shown in Figure 11. At the end of the program calculation, the roof subsidence of the filled AR is significantly reduced compared with that of the non-filled AR, and the effect of the filling body on the roof control of the AR is significant. Compared with the strength of 1.0 MPa and 0.5 MPa, the deformation decreases by 70 mm; compared with the strength of 2.0 MPa and 1.0 MPa, the deformation decreases by 25 mm; compared with the strength of 3.0 MPa and 2.0 MPa, the deformation decreases by 19 mm. Therefore, when the strength of filling body is 1.0 MPa and 0.5 MPa, the control effect of filling body on the AR roof is improved significantly. When the strength of filling body is 1.0 MPa, 2.0 MPa and 3.0 MPa,

the improvement degree of the control effect on the AR roof is similar, but the control effect of filling body on the AR roof is better.



**Figure 11.** Law of roof deformation in AR.

To sum up, when no filling is carried out, the stress concentration of the roof of the AR is high and the subsidence is large. When the working face is advanced to the AR, it not only increases the difficulty of mining, but also is prone to roof fall in front of the support. Therefore, the AR must be filled. When the strength is 1.0 MPa, 2.0 MPa and 3.0 MPa, the filling body has better control effect on the whole roof of the AR, and the roof subsidence value is controlled within 300 mm. Therefore, considering the technical and economic factors, the filling body with strength of 1.0 MPa is selected, and the corresponding water cement ratio of high water material is 8:1.

## 6. Industrial Test

### 6.1. Filling Scheme

In order to ensure that the roof does not fall in advancing of 3301 FMMF, the filling effect of AR is very important. The AR is divided into eight sections and filled in turn. The filling scheme is shown in Figure 12. First of all, the filling bags with the size of 2.5 m × 4.8 m × 3.0 m are set up from the head of the AR to construct the closed wall. Secondly, after the sealing wall is fully consolidated and compacted, the temporary single hydraulic prop is set up first, and then the filling hole is drilled in the outer sealing wall for filling. Finally, the AR in the remaining section is filled in turn. Considering the safety of personnel, local fans should be set in the whole filling process.

Filling operation includes conveying materials, preparing slurry, filling AR, cleaning pipeline and mobile equipment, etc. It includes two working areas: the main pumping station and the moving filling point. The filling equipment mainly includes four mixing barrels, two filling pumps and two slurry suction pipes, etc. The double liquid filling pump model with 2ZBYSB 13.2-4.2/1-10-22; the mixing barrel can be equipped with 1.5 m<sup>3</sup> slurry at a time, and the single slurry pipe and mixing pipe are high-pressure rubber pipes with a diameter of 31.5 mm.

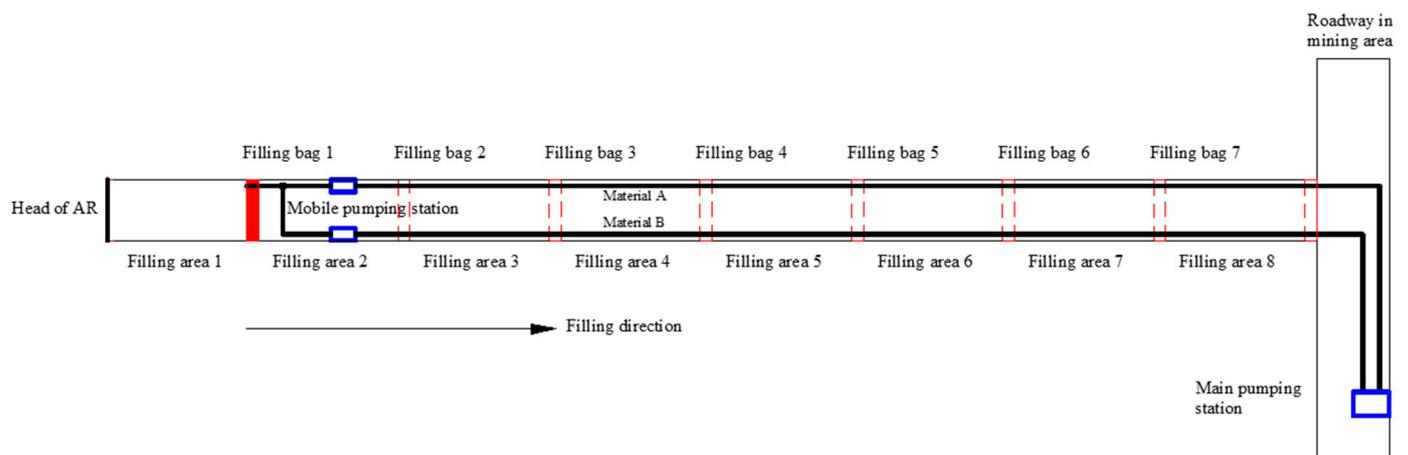


Figure 12. Schematic diagram of filling scheme.

### 6.2. Filling Effect

Two measuring stations for working resistance of hydraulic supports are set up 35 m away from the upper and lower ends of the FMMF, and the data of three hydraulic supports are selected at intervals. The monitoring process is divided into three stages: (1) From 40 m away from the AR to 30 m after entering the AR; (2) From 100 m to 160 m after entering the AR; (3) From 200 m after entering the AR to pushing out the AR. Taking the average working resistance of hydraulic support as the evaluation index, the monitoring curve is shown in Figure 13.

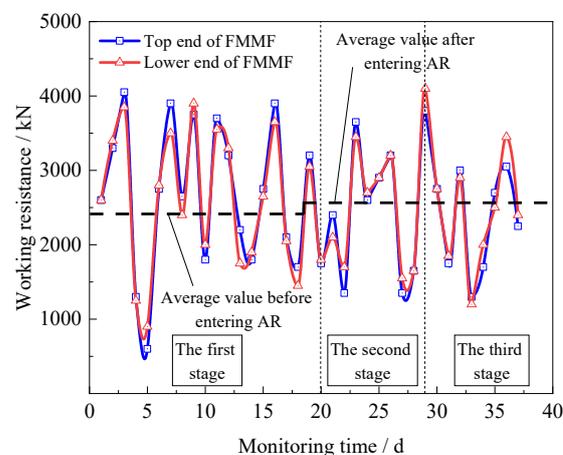


Figure 13. Working resistance monitoring of hydraulic support.

Before and after the working face enters the AR, under the action of mining support stress, the space between the filling body and the roof is compressed. Then, after a little compression, the filling body and the roof have coordinated deformation, and the deformation further increases. Because the increment of the average working resistance of the hydraulic support is less than 150 kN, the roof subsidence of the whole process is relatively small, which almost does not affect the normal advance of FMMF, indicating that the effect of high water material filling roof control is well.

### 7. Conclusions

- (1) Through theoretical calculation, the instability mechanism of surrounding rock with AR is studied, and it is determined that the ratio of height to span is the key factor affecting the stability of surrounding rock with AR. The four stages of deformation and failure evolution of with AR roof are deduced: initial deformation, bending and

separation deformation, fracture failure, and collapse destruction. It is proposed that the control principle of timely support and reducing roof span should be followed for controlling surrounding rock strata of AR.

- (2) By comparing the traditional way of FMMF through the AR and considering the technical and economic factors, it is proposed the use of high water materials to fill the AR roof control technology. The mechanism of the filling body and the surrounding rock of the AR is researched, and the key parameters of the filling body are determined. The strength of the filling body is 1.0 MPa, and the water cement ratio of the corresponding high water material is 8:1.
- (3) The industrial test shows that the average working resistance increment of hydraulic support does not exceed 150 kN before and after the FMMF through the AR, and the roof subsidence of the AR is small, which ensures the safe promotion of the FMMF, and the effect of filling and controlling the roof is good.

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