# Evolution of unloading damage and distribution of fractures in gas channel under repeated mining

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**Abstract:** In order to solve the problem of over-limit gas in the corner of the mining stope, the influence of repeated mining on the unloading of the roof and the deepening of the mining fissure is analyzed based on the unloading rock mechanics. The damage factor and the infiltration are established by combining the damage mechanics. The relationship between the rate and the discrete element software is used to calculate the damage evolution law of the unloading gas channel before and after repeated mining. The influence range of the mining fracture field is obtained according to the relationship between effective stress and permeability. The results show that the unloading degree of the roof in the goaf increases nonlinearly with repeated mining. The greater the unloading amount and the damage factor of the roof in the goaf after repeated mining, the more the number of mining fissures develops, and the permeability of the goaf. The height of the mutation point and the development of the gas channel is greater.

## 1. Introduction

In recent years, with the improvement of mechanized mining level, mining intensity and depth, repeated mining has become a common phenomenon in coal mine production, and the related research on equipment, mining field pressure, roof control and other theories and practices[1].The more you come, the more remarkable results have been achieved. At present, the pressure of the unloading gas of the remnant coal in the over-mining area of the mining stop is large to the coal seam, and more multi-lane ventilation systems such as “two in one return” and “three in two and two return” are adopted. To some extent, the gas volume fraction in the working face and the goaf is reduced; however, due to the increase in the output of the repetitive mining stope, the working face and the upper corner are still prone to gas overruns, which seriously affects safety production. The return air flows into the atmosphere, causing waste of gas resources. Therefore, it is of great significance to study and solve the problem of gas overrun in repeated mining stope and realize the extraction and utilization of high concentration gas, which is to improve the mine safety environment, improve resource utilization and protect the environment. At the same time, due to the increase of the cumulative mining thickness, the mining space is superimposed, and the height of the fallen belt and the fault zone changes accordingly. The key layer of the stable "masonry beam" structure that can be formed in normal mining height will also enter the slump zone and form a new stable structure in the upper high-level, and the surrounding rock stress field and the fault zone will expand and develop[2].At present, the research on the roof of repeated mining stope mostly focuses on the structural characteristics of the roof and the influence on the law of mine pressure appearance, which is less than the unloading damage evolution characteristics of the gas channel in the mining stope[3]. Therefore, the author starts from the unloading damage angle of the fractured rock mass in the goaf, analyzes the stress unloading evolution of the roof in the goaf under repeated mining conditions and the fracture evolution characteristics of the gas channel, and uses the discrete

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element numerical software to simulate the repeated mining. The evolution law of stress relief, displacement and fracture of the roof in the goaf is studied. The unloading damage range of the fractured rock mass in the goaf under repeated mining conditions is studied, and the difference between the cracks under the normal mining and repeated mining is analyzed. Optimize and determine the mining area of the mining stope and its extraction technology, and then carry out the efficient mining and utilization of the repeated mining goaf, and provide decision-making basis for the accurate control of gas.

## 2. Effect of repeated mining on stress unloading of roof and evolution of gas channel in goaf

### 2.1 Effect of repeated mining on stress relief of roof in goaf

Compared with the first mining, the overall free space of the repetitive mining stope is increased, the overburden is subjected to secondary pressure relief, and the basic top of the primary pressure relief is re-spinning to form a higher support in the coal body in front of the stope. pressure. However, due to the influence of repeated mining, the unloading starting point of the roof rock mass in the goaf after high support pressure increased, which caused the roof crack damage expansion ability to increase, which led to the unloading damage effect of the roof crack in the goaf. Below the low roof crack field is the production space, the unloading degree and the rock mass breaking degree are the largest; while the middle and upper roof fissure field unloading and the rock mass breaking degree are small, so the unloading level of the goaf roof is to some extent. It determines the extent of rock mass breakage and fracture evolution. In order to analyze the influence of roof unloading on the mining fissures in the goaf, the initial unloading value of the rock mass in the goaf is set as $\sigma$. After unloading it was set as $\sigma_1$,the unloading stress $\xi$ is defined as[4]:

$$\xi = \frac{\sigma - \sigma_1}{\sigma} \times 100\% = \frac{\Delta\sigma}{\sigma} \times 100\% \tag{1}$$

It can be seen from the above that a high supporting pressure zone is formed in front of the basic top working surface of the repeated mining, which is larger than the supporting pressure when the first mining is started, and the corresponding starting point of the pressure relief pressure is correspondingly increased, and the unloading is known according to the formula (1).The stress and unloading capacity increase at the same time, which leads to the evolution of the crack in the roof of the goaf and the increase of the permeability. Therefore, it provides a basis for the study of gas drainage in the roof fracture zone of the mining stope.

### 2.2 The effect of repeated mining on the evolution of damage to its channel

There are many micro-defects or fissures inside the rock mass fissure. Under the action of mining stress, the internal fissures of the rock mass will crack, expand and connect to form macroscopic fractures and fractures. The repeated mining roof subjected to high supporting stress causes the damage of surrounding rock to be aggravated on the mesoscopic and microscopic scale due to unloading, and finally leads to the expansion and penetration of cracks in the fracture field.

According to the definition of damage mechanics and the principle of effective stress and strain equivalence, the damage factor $D$ [5] can be expressed as:

$$D = 1 - \frac{E}{E_0} \tag{2}$$

Where $E$ is the effective deformation modulus of the rock mass after unloading damage; $E_0$ is the deformation modulus of the rock mass unloading starting point.

According to the true triaxial unloading experiment, the relationship between the unloading amount and the deformation modulus is:

$$E = E_0(1 - a\xi^b) \tag{3}$$

Among them, $a,b$ is the parameters, they can be obtained according to the experimental fit. Joint type (2) (3) available

$$D = a\xi^{b} \tag{4}$$

After repeated mining, the unloading starting point of the mining stop roof will increase, resulting in an increase in the unloading amount $\xi$ and an increase $D$. The movement will cause the roof rock mass and mining crack damage to become more and more severe.

## 3. Evolution law of gas channel in the goaf of the goaf under repeated mining conditions

A 3DEC numerical model was established based on the geological and mining conditions of the 4308 working face of Chengzhuang Mine, and the rock self-heavy load is $\sigma_z = 6MPa$ and side boundary binding force were applied at the top $\sigma_x = \sigma_y = 4MPa$. The boundary conditions and several models are shown in Fig.1. The constitutive relation is based on the Mohr-Coulomb criterion and is limited by the computer memory. This simulation draws on the coal-rock formation with a width of 1 in the two-dimensional model, ignoring the influence of the trending direction rock fall. The length, width and height of the model are $600m \times 200m \times 1m$ respectively. When mining, the first mining of No. 3 coal, and then the mining of No.5 coal, mining the front coal seam roof at intervals of 6 to the top of the model to monitor the stress and displacement changes of the roof fractured rock mass under repeated mining.

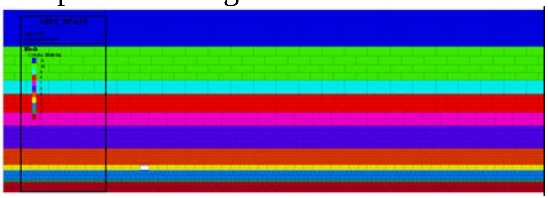


Fig. 1 3DEC calculation model

### 3.1 Engineering Geology

The 4308 working face adopts inclined longwall coal mining method to fully mine No. 3 coal at a time. The coal thickness is 3.25 and the buried depth is 370m. The No. 5 coal is located at 20 places below No. 3 coal, the coal thickness is 5.6, and all the fallen method manages the roof; coal seam The dip angle, the lithology of the top and bottom of the coal seam are shown in Table 1, and the overburden obeys the Hook-Brown strength criterion.

Table 1 Lithologic characteristics of coal seam roof and floor

| No. | Coal rock formation | Layer thickness [m] | Density [kg/m$^3$] | Volume Modulus [GPa] | Shear modulus [GPa] | Internal friction angle[°] | Cohesion [MPa] | Tensile strength [MPa] |
|---|---|---|---|---|---|---|---|---|
| 1 | Fine sandstone | 11 | 2538 | 2.8 | 1.1 | 72.6 | 1.69 | 2.33 |
| 2 | 5# coal seam | 3 | 1400 | 2.9 | 1.1 | 5 | 3 | 3.62 |
| 3 | Siltstone | 10 | 2648 | 3.2 | 1.2 | 80.74 | 7.8 | 3.62 |
| 4 | 3# coal seam | 6 | 1450 | 2.9 | 1.1 | 5 | 3 | 3.62 |
| 5 | Sandy mudstone | 18 | 2300 | 2.3 | 0.9 | 49.04 | 3.62 | 7.22 |
| 6 | Mudstone | 25 | 2751 | 13.1 | 4.8 | 24.5 | 19.11 | 2.33 |
| 7 | Fine sandstone | 15 | 2654 | 21.1 | 8.0 | 33.2 | 13.96 | 5.67 |
| 8 | Mudstone | 20 | 2706 | 12.34 | 5.0 | 36.3 | 9.48 | 4.47 |
| 9 | Fine sandstone | 15 | 2743 | 8.46 | 3.1 | 28.7 | 15.84 | 6.11 |
| 10 | Mudstone | 37 | 2627 | 5.77 | 2.4 | 17.5 | 23.32 | 3.35 |
| 11 | Mudstone | 40 | 2587 | 6.98 | 2.7 | 31.4 | 16.42 | 1.04 |

### 3.2 Roof stress unloading evolution law

In order to analyze the unloading deepening law of the top plate stress in the goaf under repeated mining, according to the numerical simulation results, the unloading starting point experienced by the gob area along the 30m behind the stope and the unloading before the stress recovery are minimized. The stress data of the value, combined with the formula (1),calculates the unloading stress and unloading amount of the roof of the goaf at different distances from the roof of the coal seam, and draws its evolution law as shown in Fig. 2. From Fig.2 that with the repeated mining, the unloading capacity of the fractured rock mass in the goaf is increasing, and the unloading stress is different before and after repeated mining. In the range of 80m from the roof of the coal seam, the first mining repetitive mining stress difference first increases and then tends to be equal. When the distance from the coal roof is about 40m,the unloading stress difference reaches about 32MPa,when the first mining is started. The maximum unloading value of the stress unit mining height is about 27 MPa/m, and the maximum unloading value of the unit mining height during repeated mining is 13 MPa/m. Therefore, the first mining stop is more obvious than the repeated mining unloading, and the unloading of the roof cracking field is adopted. The load stress increases nonlinearly with the increase of repeated mining.

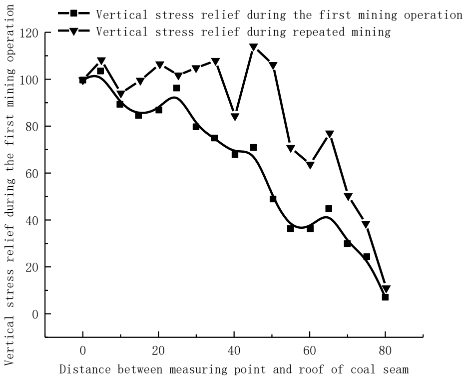



Fig. 2 Evolution law of vertical unloading stress before and after repeated mining

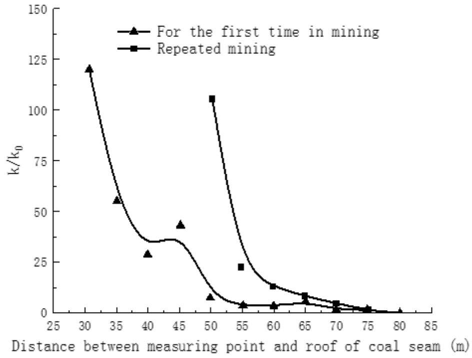
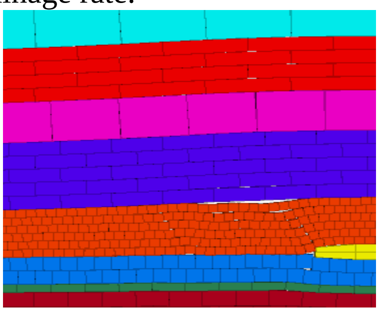


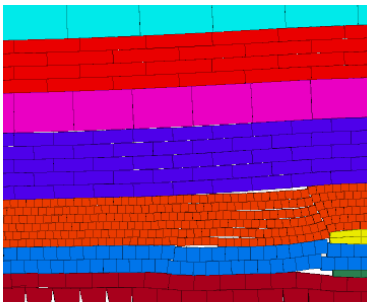

Fig.3 Permeability variation curves of unloading damaged roff with different mining height

### 3.3 Evolution law of roof gas channel

The development of roof cracks and gas channel deepening under repeated mining conditions are counted .It can be seen from Figure 4 that as the repeated mining progresses, the roof cracks and gas channels in the goaf continue to expand upwards; the development range of the gas channel after repeated mining is also expanded, so it is determined that the gas drainage plan will be more Conducive to gas lifting and migration, it can greatly expand the range of gas extraction drilling and increase gas drainage rate.



(a)First-time mining



(b) Repeated mining

Fig.4 Gas flow channel development law in goaf with different mining height

## 4. Gas channel unloading damage range under repeated mining conditions

After the coal seam is mined, the fractured rock mass in the goaf of the goaf begins to unload. Before the working face tends and the direction does not reach full mining, the unloading will continue to propagate to the middle and upper strata, and form a gas channel of the crust of the goaf. Development zone; the roof fissure also develops to the boundary when full mining is achieved.

The extent of crack propagation in the roof rock mass determines the permeability. After the fracture occurs, the permeability will be abruptly formed to form a gas channel. According to the infiltration law obtained by Xu Yusheng et al.

$$\frac{k}{k_0} = \exp\left\{\frac{-3c_0}{\alpha}\left[1-\exp\left(\frac{\alpha\sigma}{1-D_0}-\frac{\alpha\sigma_1}{1-D}\right)\right]\right\} \quad (5)$$

Where, $k_0$, $k$ respectively, the permeability of the fractured rock mass after initial and unloading; $c_0$ is the initial fracture compression system; $\alpha$ is the rate of change of the crack unloading expansion coefficient.

The unloading of the roof in the goaf is mainly the release of vertical stress and horizontal stress; the vertical stress is mainly in the penetration and expansion of the fracture and the formation of the gas channel. Therefore, the vertical stress should be used as the main aspect to analyze the unloading and infiltration of the roof fractured rock mass. The relationship of rates. After the pressure relief, the parameters of the fractured rock mass of the Chengzhuang ore roof, taken, $D_0 = 0$, $\alpha = 0.07MPa^{-1}$, $c_0 = 0.09MPa^{-1}$, $a = 0.28$, $b = 3$ substituting (5), combined with the numerical simulation results, can be fitted to the permeability curve of the rock mass before and after repeated mining. It can be seen from the analysis of Fig. 3 that after repeated mining, the permeability of the fractured rock mass in the goaf is increased after unloading damage; as the distance from the roof of the coal seam decreases, the permeability increases, and the distance changes when the distance decreases to a certain value. The sudden change of permeability after repeated mining moves to the deep part of the goaf. Due to the inter-layer lithology, the local layer permeability of the roof will decrease, but it does not affect the overall abrupt change of permeability. Therefore, the top plate unloading damage abrupt point can be used as the basis for determining the height of the gas channel in the repeated mining stope.

## 5. Conclusion

(1)Using the discrete element software to simulate the unloading of the roof and the evolution of the gas channel in the goaf after repeated mining: the unloading stress and unloading amount of the roof in the goaf are nonlinearly increased after repeated mining; after repeated mining, the number of fracture developments is greatly increased. The larger the development area of the gas channel in the roof of the goaf, the more developed the horizontal gas channel.

(2)Applying the relationship between effective stress and damage factor, unloading capacity and permeability, the unloading damage range of gas channel after repeated mining is obtained: after repeated mining, the roof crack and the gas channel unloading damage in the goaf. The permeability increases, when the distance between the roof and the coal seam is lower than a certain value, the permeability suddenly increases.

## Acknowledgements

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