The Physical Simulation Experiment on the Effect of Mining Height and Critical Layer on Overburden Rock Fracture

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Key words: fracture, mining height, first sub-key strata, caving zone, fissure zone

Abstract: By employing the physical simulation experiment and theoretical analysis, this paper aims to study the effect of mining height and the first sub critical layer on the evolution law of mining-induced fractures. The mining-induced fracture density, fissure characteristics, height of broken fractures, height of separated strata and their correlation with mining height and the first sub critical layer are analyzed quantitatively. As mining fissure is the key area to gas extraction, the authors fully consider the mining height and the location of the first sub critical layer, so as to determine their relatioinship. Through extracting pressure relief gas in test mine, we have verified the effect of mining height and the first sub key layer on broken fracture height, providing a theoretical basis for parameter arrangement of extracting pressure relief gas.

Introduction

With the increasing depth and intensity of mining, the number of gas-related accidents is also growing, which seriously restricts the safety and efficiency of mining. Meanwhile, mine gas occurrence in China has the feature of "three highs and three lows", which affects gas pre-pumping. In order to improve gas drainage effect, high pumping lane and high-level borehole have become effective means to control gas. In terms of relief-pressure gas drainage, gas gathers in caving zone and fracture in overlying strata after mining where high pumping lane and high-level borehole are layout to extract high concentration gas, thereby reducing gas emission in working face and achieving the purpose of gas control. Over the years, domestic and foreign scholars have made many tests and theoretical analysis [1-5] on underground mining fissure development, morphological characteristics [6-12] and coal rock fracture distribution, and have made great achievements that guide the safety and effencicy of coal mining. As complex evolution of underground mining crack and characteristic are affected by mining height and the first sub critical layer, we have studied the relationship among mining fracture morphology, mining height and the first sub critical layer, and then we have determined proper gas drainage methods and parameters. All these efforts provide a theoretical foundation and practical application value of exploring suitable gas drainage technology and controlling gas disaster in coal minning.

Similar physical model building

Experimental model

The main mininig coal seam of the test mine is Taiyuan group 15# coal seam. This layer is positioned at the lower part of Taiyuan formation, above K1 sandstone limestone, under K_2 limestone, 130 ~ 150m away from 3# the coal seam, 12 ~24m away from K_2 limestone, and about 20m away from the K1 sandstone. The coal is characterized by its large thickness and deposition stability. According to drilling data, the coal seam thickness is from 0 to 5.71m, with an average of 5.1m, and the angle is from 1 degree to 15 degrees, with an average of 8 degrees. By employing long-wall mechanized mining full height mining method, the mining height is 3.87 ~ 5.1m. Immediate roof is mudstone, dark gray to black, containing sand partly; old roof is sandstone, gray to grayish black and sorting are round in shape and with calcitic cementation; direct bottom is aluminum mudstone, grayish black. For physical and mechanical properties of coal and rock strata, see Table 1.

Table 1 Physical and mechanical properties of model

Serial number	Name	Volume-weight /kN·m^{-3}	Elasticity modulus /Mpa	Compressive strength /Mpa	Poisson ratio	Cohesion /Mpa	Dilatancy angle /（°）	Nternal friction angle/（°）
1	Mudstone	20.80	20019	20.5	0.195	0.93	8	31
2	Sandy mudstone	26.40	56767	48.8	0.278	1.38	8	34
3	Medium sandstone	26.60	50430	65.1	0.28	2.27	10	31
4	Carbon mudstone	15.00	35234	14.8	0.24	0.78	8	22
5	Packsand	26.20	43020	69	0.26	1.93	10	31
6	Ssiltstone	26.00	54739	58.5	0.253	1.3	12	35
7	Limestone	26.50	46636	91.2	0.23	3.1	12	41
8	Aluminum mudstone	13.00	40500	16	0.25	0.83	8	24
9	coal	14.60	14142	13.5	0.275	0.72	8	20

Experimental model design

The mining coal seam overburden distribution is the experimental model, and its mining height is 5 meters, and the first sub critical layer is 20 meters. We adjust the mining height to 1 m, 3m and 5m and the first sub critical layer to 10m, 20m and 30m as the experimental object. We study fracture development process of overlying rock in different mining heights and the first sub critical layer. In the similar physical simulation experiment, by obersving floor stress, abscission rate after caving, fracture density, caving range, caving type, broken feature in the process of mining, we study the deformation rule of overburden movement and fracture distribution, and the influence rule of mining height and the first sub key strata on development and the evolution of mining fracture.

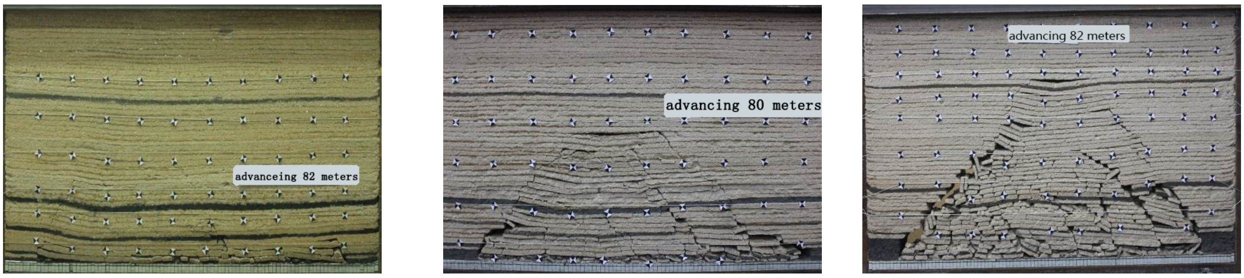
Experimental process

The distance between open-off cut and model boundary is 10cm. The similarity ratio is 1:100, and open-off cut is 8cm，so the original is 8m; Every advancing distance is 2m, and every 20min per advancing.

The mining fracture evolution characteristics under different mining heights

Mining fissure expansion characteristics under different mining heights

Fissure development under different mining heights is shown in Figure 1. We can conclude that delamination fracture with 1, 3 and 5m mining height develop noticeably, 12.5, 32.5 and 43.5m away from coal seam roof, and mainly in bending deformation.



(1)Mining hight is 1m (2) Mmining hight is 3m (3) Mining hight is 5m

Figure 1 Types of mining fracture development under different mining heights

Broken characteristics of rock mass are measured by broken expansion coefficient; differential and integral thought is used to deal with cracks produced during experiment. The broken bulking coefficient is obtained under different mining heights, as shown in Figure 3.

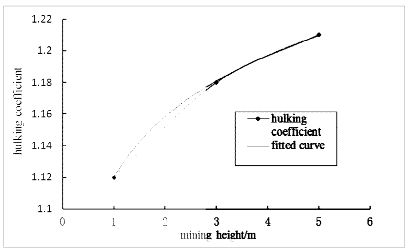


Figure2 Curve of bulking coefficient affected by mining height

Curve of bulking coefficient affected by mining height is fitted, and the relationship between bulking coefficient and mining height is:

$$K_p = 0.0557 \ln M + 1.1197 \quad (1)$$

In the formula, K_p is bulking coefficient; M is mining height, m.

As shown in Figure 2, with the increasing of mining height, bulking coefficient of the same mining overburden layers increases. It is positively correlated between bulking coefficient and the logarithm of mining height. The mining height will not affect the bulking coefficient when mining height reaches a certain value

Analysis of mining-induced fracture under the different mining heights

Broken fissure, bed separated fissures and strata movement of the mining overlying stratum are not fully synchronized, and development of mining overlying strtum is not in uniform motion. The relation between caving zone height, fissure zone height and mining height is shown in Figure 3. With the increasing of mining height, fissure zone height increases. It is positively correlated between fissure height and the logarithm of mining height. The growth speed will decrease when mining height reaches a certain value. With the increasing of mining height, caving zone height increases, and it is a linear positive correlation between caving zone height and mining height.

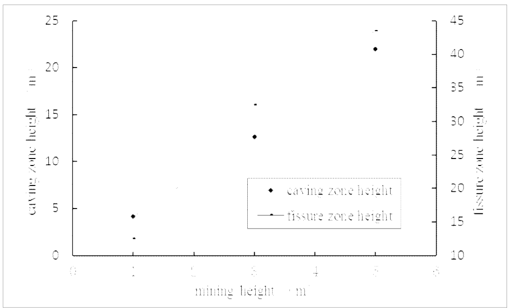


Figure 3 Relation between mining fissure height with mining heght

By analyzing the caving zone height and fissure zone height under different mining heights, we can obtain the following formula （2）～（3）. In the formula, G is caving zone height, m; F is fissure zone height, m; M is mining height, m.

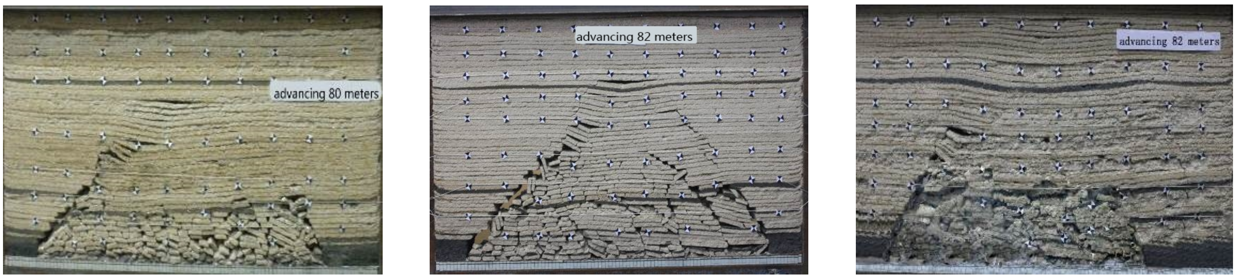
$$G = 4.475M - 0.525 \quad (2)$$

$$F = 19.093 \ln M + 12.265 \quad (3)$$

The effect of first sub key strata on evolution and distribution characteristics

The mining fissure broken characteristics under different first sub key strata

The first sub-key stratum in test coal mine is K_2 limestone. As the distribution is uneven, the position of the first sub-key strata in the experimental model is adjusted to 10m, 20m, 30m. When working face advances to a certain value, mining fissure development form is shown in Figure 4.



(1) K_2 limestone is 10m (2) K_2 limestone is 20m (3) K_2 limestone is 30m

Figure 4 Mining fracture evolution curves under different first sub key strata

By fitting the whole bulking coefficient K_p, the bulking coefficient in caving zone Kpg, the bulking coefficient in fracture zone Kpf and the first sub key layer horizon, we can obtain the relationship between bulking coefficient of different zone and the first sub key layer horizon, as shown in formula 5.

$$K_P = -0.027 \ln L + 1.193 \quad (4)$$

$$K_{Pg} = -0.027 \ln L + 1.232 \quad (5)$$

$$K_{Pf} = -0.027 \ln L + 1.153 \quad (6)$$

In the formula, K_p is the whole bulking coefficient; K_{pg} is the bulking coefficient in caving zone; K_{pf} is the bulking coefficient in fracture zone; L is the first sub key layer horizon, m.

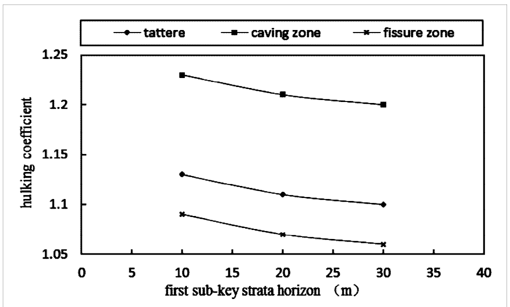


Figure 5 Relationship between bulking coefficient and first sub-key strata

We can see from Figure 5, with the working face advancing, mining dynamic overburden bulking coefficient between each measuring line and the roof of coal seam decrease with the increase of the first sub key strata. From Figure 5 and formula (4) , (5), (6), the whole bulking coefficient, the bulking coefficient in caving zone, and the bulking coefficient in fracture zone increase with the first sub strata decreasing, and the coefficient and log of the first sub key layer horizon has a negative correlation.

Mining-induced fracture height under different first sub key layer horizon

In order to study how the first key sub layer affect the evolution of mining fissure, how the mining overburden fracture height and falling height change with the first sub critical layer needs further research. Figure 8 shows the distribution of fractured zone and caving zone when the first sub key layer horizon is 10m, 20m and 30m.

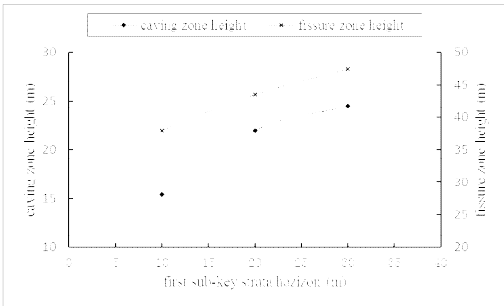


Figure 6 Caving zone and fissure zone in different first sub-key strata

By fitting the height of the caving zone G, the height of crack belt F and the first sub key layer horizon under different horizon of K2, we can obtain formula (7) - (8).

$$F = 8.4893 \ln L + 18.349 \qquad (7)$$

$$G = 8.4166 \ln L - 3.7733 \qquad (8)$$

In the formula, F is the height of crack belt, m; G is the height of the caving zone; L is the first sub key layer horizon, m.

Figure8 and Formula (7), (8) shows that with the increase of the first sub key strata, the height of caving zone and crack belt grows accordingly. The log of the first sub key layer horizon shows a positive correlation.

Effect of mining height and first sub key layer horizon on mining fracture

Regarding to the mining area concerning gas extraction, to carry out research on mining fissure development, especially on the height of the caving zone and the height of crack belt within the scope of mining fracture plays an important role in instructing the mining work of gas drainage in pressure releasing area.

To determine the height of caving zone and fractured zone under the geological conditions of the test mining area and to guid following production, field investigation and similar physical simulation experiment are combined to study the mining height and the first sub key layer horizon effect on mining fracture evolution.

Analysis of fractured zone height

During the period of working surface stoping, overlying strata emgeres periodic caving with the working face advancing, thus forming the caving zone and fractured zone. In the process, relationship between caving zone, fractured zone and mining height is shown as:

$$M + F = [F + (1 - c) \cdot M] \cdot K_p \qquad (9)$$

In the formula, M is mining height, m； F is height of crack belt, m； c is stoping rate; K_p is the whole bulking coefficient.

Meanwhile, according to 3.2, the relationship between the bulking coefficient of mining fissure and the first sub key strata can be obtained:

$$K_p = p\ \ln L + q_1 \quad (10)$$

In the formula, L is the first sub key layer horizon, m; p and q1 are coefficients, and their value are mainly determined by the overlying strata lithology, p is negative and q_1 is positive.

Substituting formula (10) into (9), we can obtain the relationship between height of crack belt, mining height and the first sub key strata:

$$F = M \cdot \left(\frac{c}{1 - \dfrac{1}{p\ \ln L + q_1}} - 1\right) \quad (11)$$

For mechanized mining face of the test mining area, the recovery rate is more than 90%, and the C value is 1; P is -0.027; Q is 1 1.183. Relationship of height of crack belt, mining height and the first sub key layer horizon in test mining area is

$$F = \frac{M}{0.153 - 0.027 \ln L} \quad (12)$$

Analysis of the caving zone height

In the process of mining face, caving zone formation precedes the fractured zone. Many scholars have made a lot of research on determining the height of caving zone and obtained the empirical relationship between the caving zone and the mining height. However, the first sub key strata has certain influence on the caving zone height, and relationship between the caving zone height, the height of fracture zone and the mining height after the formation of the mining fissure zone is shown as:

$$M = G \cdot (K_{pg} - 1) + (F - G) \cdot (K_{pf} - 1) + M \cdot (1 - c) \cdot K_p \quad (13)$$

In the formula, *G* is the height of the caving zone, m; ***M*** is mining height, m; ***F*** is the height of crack belt, m; K_{pg} is the bulking coefficient in caving zone; K_{pf} is the bulking coefficient in fracture zone; *c* is stoping rate; K_p is the whole bulking coefficient.

Meanwhile, according to the 3.2, relationship between bulking coefficient in caving zone, the bulking coefficient in fracture zone and the first sub key layer horizon can be obtained:

$$K_p = p\ \ln L + q_2 \quad (14)$$

$$K_p = p\ \ln L + q_3 \quad (15)$$

In the formula, L is the first sub key layer horizon, m; p, q2 and q3 are coefficients, and their value are mainly determined by the overlying strata lithology; p is negative, while q2 and q3 are positive.

Substituting formula (10), (11), (14), (15) into (13) can obtain the relationship between the height of fracture zone, the mining height and the first sub key layer horizon:

$$G = M \cdot \frac{(q_1 - q_3) \cdot [1 - (1 - c) \cdot (p \ln L + q_1)]}{(q_2 - q_3) \cdot (p \ln L + q_1 - 1)} \tag{16}$$

For mechanized mining face in test mining area, recovery rate is more than 90%; C value is 1; P is -0.027; q_1, q_2, and q_3 are 1.183, 1.212, 1.163 respectively. Then the relationship between height of crack belt, mining height and the first sub key layer horizon in test mining area is

$$G = \frac{0.408M}{0.183 - 0.027 \ln L} \tag{17}$$

Engineering application

Engineering background

Test face mainly mines the Taiyuan group 15# coal seam, and its thickness is 4.85～5.71m, averaging 5.1m. Dip angle is 1°～15°, with an average of 8°. By adopting the method of longwall mechanized mining full height mining, the mining height reaches 5.1m.

High level suction roadway pressure relief drainage gas technology

Test face is the first mining face, and the main source of gas is coal seam, gob and adjacent layer. Because 15# coal seam permeability is not high, and pre-pumping effect is not as expected, reservoir migration area of gas in mining fissure is the key to effective gas drainage. According to coal seam occurrence and overlying strata distribution, we can obtain that fracture zone height is 45.5m and caving zone height is 22.8m from formula (14) and (19). Thus the high drainage roadway of test face lies 27.8m away from coal seam roof, so as to ensure the high extraction efficiency in high drainage roadway.

Analysis of the effect of extraction

Through studying the results of high level suction roadway drainaging gas in the test working face (as shown in Figure 7), we obtain the following data: during normal working hours, the averag pure quantity of extraction reaches 52.9m^3/min, and drainage volume accounts for 69.5% of total methane emission. In May 2013 to July 2014, the working face advances 1542m, and coal output is 2 milliont. Working face, upper corner and return air lane maximum gas volume fraction are controlled within 1%, which has realized efficien and safe production in working face.

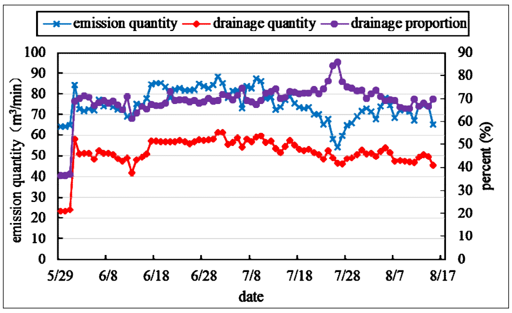


Figure 7 Drainage volume in high drainage roadway

Conclusion

(1) By physical simulation experiment, effect of mining height and the first sub critical layer on crack density, broken characteristics, broken fissures and delamination crack height in evolution process of mining fracture is analyzed quantitatively.

（2）Coal layer and rock layer are distributed unevenly in test mining area. Combining influence of mining height and the first sub key strata on mining fissure evolution, formula are obtained to calculate the height of caving zone and fracture zone, when comprehensively consider the effects of mining height and the first sub critical layer.

（3）Throught analysis of the actual fracture height and effect of drainage pressure relief gas, the formula can be applied to calculate the height of fractured in this mine, and to provide a theoretical basis for drainage parameters of pressure relief gas.

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