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Analysis on simulation experiment of outburst in uncovering coal seam in cross-cut

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Abstract

Based on the criteria of the Hoek-Brown rupture, the stress state of the coal's outburst is analyzed. The establishment of coal mining mechanical model and the critical pressure of the gas outburst are obtained on the basis of catastrophe theory, and then cross-cut outburst process of uncovering coal is classified as outburst breeding, outburst initiation, outburst development and outburst termination. Choosing Luling coal mine's #8 coal seam as a sample, this article relies on the large-scale three-dimensional coal and gas outburst experiment platform of the Key Laboratory of Mine Disaster Prevention and Control of Shandong University of Science and Technology to conduct cross-cut uncovering coal outburst simulation experiment. Through analysis of the surrounding rock stress and gas pressure experimental data, surrounding rock mechanical properties and the change situations when outburst happens in the process of uncovering coal are obtained. The experiments show that: when outburst occurs, the greater changes of crustal stress and gas pressure happen near the outburst mouth; and the stress and gas pressure in front of outburst mouth change significantly more than that at the rear of the mouth.

Keywords: uncovering coal in cross-cut; outburst simulation; experiment analysis; criteria; model

Nomenclature

p	gas pressure in coal seams (MPa)
σ'_1	the maximum principal stress when broken, depending on the nature and integrity of the rock (MPa)
σ'_3	minimum principal stress (MPa)
σ_t	tensile strength (MPa)
σ_{ic}	uniaxial compressive strength of intact rock (MPa)
m, s	constants
b	is the coefficient for the potential function, $b=(1024\pi D^2/a^6q_0-1/25\pi q_0)^3_{}\sqrt[3]{25/(3\pi q_0)}$
D	bending stiffness of the board, $D=\frac{Et^3}{12(1-\mu^2)}$
E	board modulus of elasticity (MPa)
μ	Poisson's ratio
a	radius of the board (m)
t	board thickness (m)

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1. Introduction

Various stress state, the gas pressure distribution state and instant coal changes throughout the process of coal and gas outburst [1–2] are extremely complex. Before uncovering coal of cross-cut, the coal's crustal stress in the equilibrium, gas pressure presents a uniform state. With cross-cut coal uncovering process, crustal stress is constantly changing, and accompanied by the stress concentration zone, the gas pressure distribution law changing also with the advance of the excavation. To study gas pressure [3] changes in the cross-cut coal's outburst process only by a one-dimensional space, two-dimensional space and even a limited three-dimensional simulation [4–7] is not enough, not able to reflect various factors' role in the outburst. To this end, in this article, based on the synthesized role's hypothesis, the stress state of the coal body is analyzed. By means of large-scale three-dimensional coal and gas outburst bench [8] of the Key Laboratory of Mine Disaster Prevention and Control of Shandong University of Science and Technology, cross-cut coal outburst process simulation is conducted, and crustal stress and gas pressure changes before and after outburst are obtained by data analysis, which has a very important theoretical and practical significance to the guidance of the mine production.

2. Theoretical analysis of cross-cut coal outburst process

2.1. Criteria of coal outburst

In order to understand the stress state of the outburst coal, the Hoek-Brown rupture criteria [9–10] is conducted to analyze.

In the pressure rupture area:

$$\sigma'_1 \geq \sigma'_3 + \sqrt{m\sigma_{ic} + s\sigma_{ic}{}^2} \tag{1}$$

In the stretching rupture area:

$$\sigma'_3 \geq \sigma_t \tag{2}$$

$$\sigma'_i = \sigma_i - p \tag{3}$$

The above relationship can be indicated in Fig.1. It can be seen that the rock strength and stress state are related, the higher the confining pressure, the greater the intensity. If a point of stress state is located on the right side of the intensity curve, rock broken is proved not to happen. Only at place where the maximum principal stress is equal to or greater than the strength, it is possible to produce destruction and lead to the occurrence of coal and gas outburst accident.

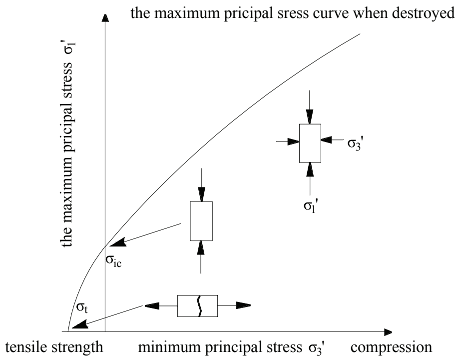

Fig. 1. Relation curve of maximum and minimum principal stress of rock destruction.

2.2. Coal mining mechanical model and analysis based on catastrophe theory

To simplify the analysis, simplifying the tunnel as circular and boring head as the round upright spallation body, the mechanical model is then set up (Fig.2).

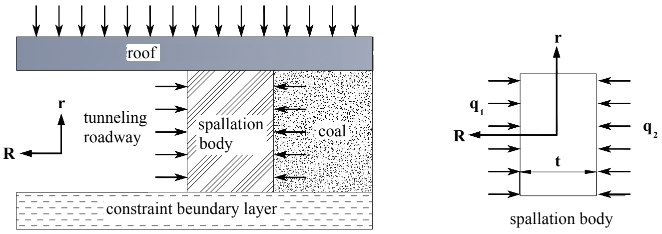

Fig. 2. Model of circular layer crack body.

The assumptions of the model are as follows: (1) the angle between coal seam and the spallation body is 90°; (2) The seam is continuous uniform elastic-plastic medium, isotropic; (3) Coal body weight is ignored; (4) Considering at the moment of being exposed, gas pressure inside boring head is evenly distributed. Among them, the radius of the board a equals to the tunnel radius; R is the radius of the circumcircle of the roadway space; q_1 represents the roadway air pressure on the left side of the board, which is regarded as a uniform pressure with gas pressure q_2 on the right side, and their resultant $q_0=q_2-q_1$, with direction the same as gas pressure's direction. The spallation body is regarded as the board with thickness of t.

Fold catastrophe theory is applied to analyze. The system potential function is obtained as follows:

$$\Pi = 1/3y^3 + by \tag{4}$$

Equation (4) is the standard form of the mutation model. Coal and gas outburst in the process fits the fold catastrophe model, so balance equation of this system is obtained as follows:

$$\mathrm{d}\Pi / \mathrm{d}y = y^2 + b = 0 \tag{5}$$

Catastrophe theory shows that when b>0, the system appears to be an empty state; when b<0, two values can be taken for the state variable; when b=0, the system is in critical state between stability and instability. Let b=0, then the following is obtained after transformation.

$$q_0 = \frac{40Et^3}{3a^3(1-\mu)} \tag{6}$$

Equation (6) is the critical pressure of gas outburst. When the pressure exceeds this value, gas outburst happens; otherwise, the system is stable.

3. Cross-cut coal outburst process analysis

3.1. Cross-cut coal outburst stage division

Through analysis of the coal body stress state, cross-cut coal outburst is divided into four stages: outburst breeding, outburst initiation, outburst development and outburst termination, as shown in Fig.3. Outburst breeding and development is a continuous dynamic process of change of coal, during which the stress state and strength change or destruct over time. And both the start and termination of the outburst are mutation points in the process.

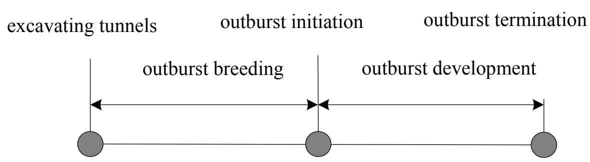

Fig. 3. Outburst stage partition of rock cross-cut coal uncovering.

3.2. Outburst stage description of rock cross-cut coal uncovering

Outburst stage of rock cross-cut coal uncovering is shown as Fig.4.

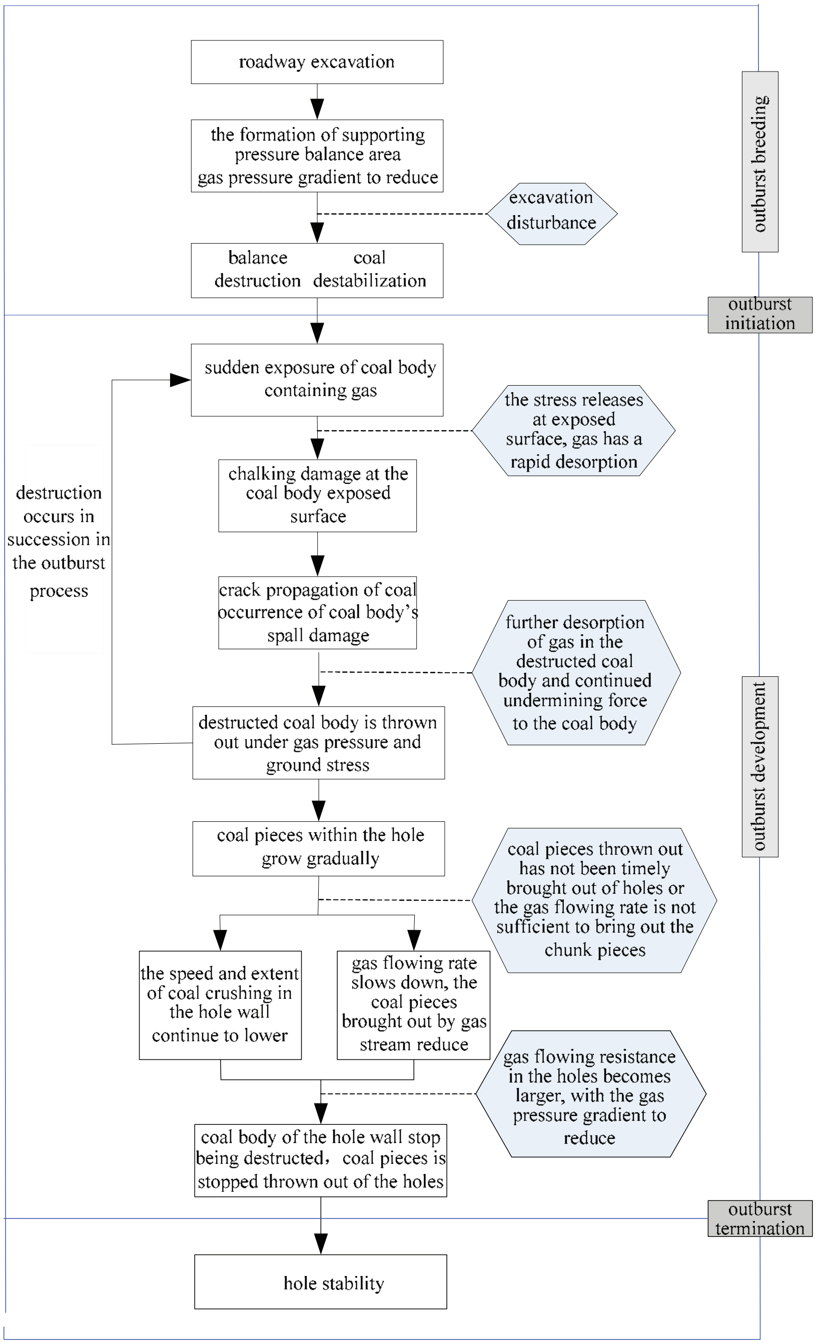

Fig. 4. General process of coal and gas outburst while rock cross-cut coal uncovering.

4. Experimental analysis of outburst

4.1. Experiment platform of outburst model

For simulation of the outburst process of cross-cut uncovering coal, supported by large 3D coal and the gas outburst bench (schematic diagram as shown in Fig.5) of the Key Laboratory of Mine Disaster Prevention and Control, Shandong University of Science and Technology as the basis, the Luling coal mine's #8 seam is selected as the coal samples to conduct cross-cut uncovering coal gas outburst simulation.

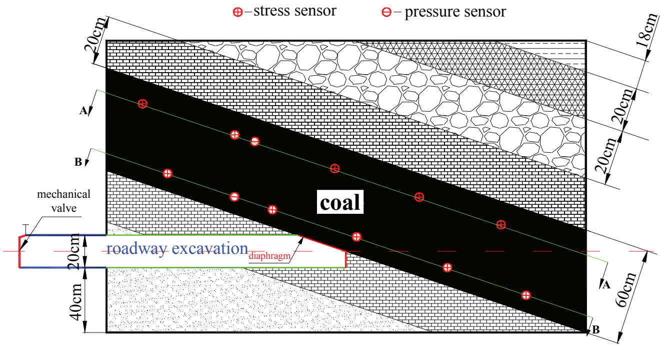

Fig. 5. Main view profile of three-dimensional simulation test-bed.

4.2. Outburst phenomenon

By observing the pressure of the nitrogen balance pipe (tunnel internal pressure) and gas pressure changes of the measuring point in data acquisition system, hydraulic cylinders maintain a pre-load pressure. When seam gas pressure stabilized (charging gas for 84 h), the quick-opening device is quickly opened. Then coal and gas outburst happens, with data collecting accompany to capture the outburst phenomenon of the outburst process, as shown in Fig.6. During the simulation, the entire outburst process lasts about 7 s or so, with average thickness of the accumulation about 3 cm and outburst pulverized coal sorting (but unobvious). For the length between prominent roadway port and the outburst points is 1.5 m, the outburst is impacted by the tunnel wall friction, with the spray distance up to 5.24 m and spewing coal weight about 7.2 kg.

Fig. 6. Open process of coal and gas outburst port during uncovering coal seam in cross-cut.

4.3. Analysis of experimental data

4.3.1. Crustal stress data analysis

Based on the layout of crustal stress measurement points on experimental platform, stress changes before and after the outburst process are collected by DH3815N static data collection system. The measured point data is then summarized and analyzed. Situation of crustal stress changes before, the moment and after outburst is simulated by MATLB software, as shown in Fig.7 and Fig.8.

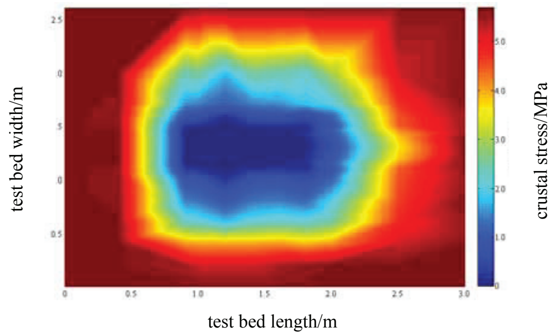

Fig.7. Distribution of crustal stress at B–B profile when outburst occurrence.

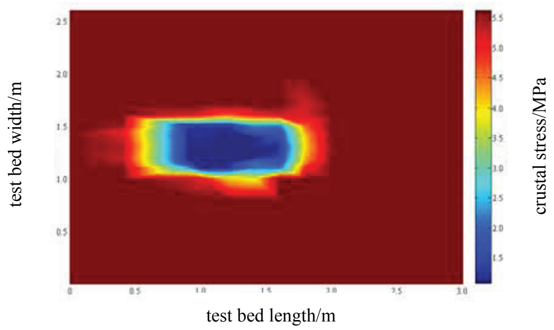

Fig. 8. Distribution of crustal stress at B–B profile when outburst steady.

Through the analysis of experimental data, the main factor influencing the crustal stress is proved to be the load applied during the experiment. With the conduct of the loading process, the stress increased significantly to reach the intended load, and the maximum stress remains at 5.95 MPa steadily. When outburst happens instantaneously, the crustal stress shows mutations, with the biggest drop of 0.85 MPa. During the outburst coal deformation in front of the outburst mouth is significantly larger than the deformation of the rear mouth. While the impact on the roadway axis position by outburst is greater than that affected on both sides of the roadway axis.

4.3.2. Gas pressure data analysis

According to the layout of gas pressure measuring point of the test-bed, gas pressure changes are collected before and after the outburst process through the DH5923 dynamic data acquisition system. The gas pressure measuring point curve is shown in Fig.9 and Fig.10.

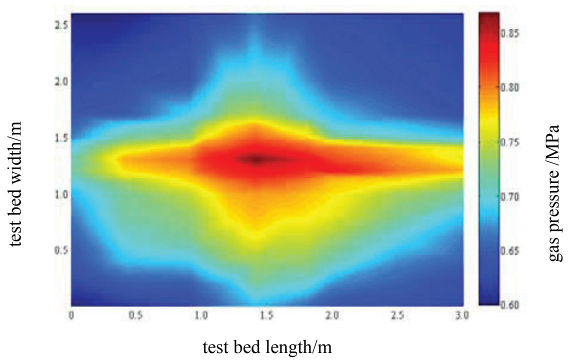

Fig. 9. Distribution of gas pressure at B–B profile before outburst occurrence.

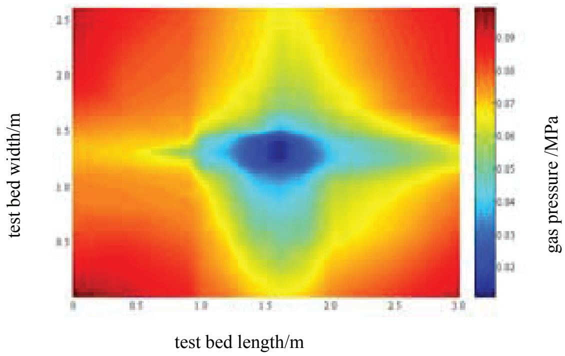

Fig. 10. Distribution of gas pressure at B–B profile after outburst occurrence.

As can be seen from Fig.9 and Fig.10, the main factor influencing on gas pressure is the high-pressure gas charging into the coal seam. Before the inflation gas pressure is balanced to 0 MPa. At the beginning of the inflation, the methane gas pressure collected by data acquisition box significantly changes and fluctuates as gas charging into it, reaching the saturation stage of inflatable gas pressure stabilized at 0.37 MPa. Through the analysis of experimental data, at the moment of the outburst changing amplitude of gas pressure in front of the outburst mouth is significantly larger than the amplitude of the rear mouth. While changing amplitude on the roadway axis position is greater than that on both sides of the roadway axis. This also verifies the above conclusion that during the outburst coal deformation in front of the outburst mouth is significantly larger than the deformation of the rear mouth. While the impact on the roadway axis position by outburst is greater than that affected on both sides of the roadway axis.

5. Conclusions

(1) Through coal analysis based on the rupture guidelines and catastrophe theory, the stress change and critical conditions of destruction in the coal mining process are analyzed;

(2) Outburst process analysis of cross-cut uncovering coal is conducted by study of state of stress and crustal stress field. cross-cut coal outburst is divided into four stages: outburst breeding, outburst initiation, outburst development and outburst termination. According to the process, the development of stress, gas pressure changes of the four stages is described in detail;

(3) In the experiment, using data collected by the data acquisition box, surrounding rock mechanical properties and outburst phenomenon are obtained in cross-cut uncovering coal process by stress, gas pressure in the analysis of experimental data on the surrounding rock. Experimental results show that when outburst happens, the crustal stress and gas pressure near outburst mouth changes greater than others; the stress and gas pressure in front of outburst mouth change significantly more than that at the rear of the mouth.

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