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Experimental Investigations on Continuous Flow Method for Predicting Coal Roadway Outburst

Yuming Zhao[1, 2]

[1]China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400039, China

[2]State Key Laboratory of Coal Mine Disaster Prevention and Control, Chongqing 400039, China

Abstract

Coal and gas outburst has always been one of the main disasters affecting coal mine safety production, and the main areas where coal and gas outburst accidents occur are mainly coal roadway excavation. Taking the 3501 intake and return airway of the 3rd coal seam in Xinyuan Coal Mine as the research object, the latest continuous flow coal roadway excavation outburst prediction technology is introduced. Starting from simulating the in-situ coal seam on the coal roadway simulation test platform, the sensitivity and critical value of the outburst hazard index of the simulated coal seam with known outburst hazard are determined through drilling tests. At the same time, the critical values were applied to the continuous flow method on-site verification work. After application, the critical values of the outburst prediction indicators for the No. 3 coal seam excavation working face of Xinyuan Coal Mine were determined: the critical value of weak outburst due to initial gas release expansion energy was 42.98mJ/g, the critical value of K_1 outburst due to drilling cuttings desorption index was 0.41mL/g • min$^{1/2}$, and the critical value of S_{max} outburst was 6.1147Kg/m.

Keywords

Continuous Flow Method; Coal Roadway Outburst Prediction; Coal and Gas Outburst; Gas Flow Rate.

1. Introduction

Coal and gas outburst is one of the serious natural disasters threatening the safety production of coal mines. Among many outburst accidents, the number of outburst accidents during coal roadway excavation is the largest, accounting for about 45% of the total number of coal mine outburst [1-3]. For prominent mines, it is necessary to study the sensitivity of various predictive indicators based on their own conditions to determine the sensitive indicators and their critical values. The Markeyev Coal Mine Safety Research Institute of the former Soviet Union used coal temperature prediction method to compare the temperature of drilling cuttings in the protected zone and unprotected zone of the protruding dangerous coal seam, and found that the temperature of drilling cuttings in the protruding dangerous zone was 1-3 °C lower than that in the protected zone [4-5]. Based on this, a non-contact thermometer for mining was developed, which records the intensity of infrared radiation. Germany uses the V_{30} characteristic value to predict the risk of gas outburst when drilling and blasting coal tunnels [6,7]. V_{30} refers to the ratio of gas emission in the first 30 minutes after blasting to the amount of collapsed coal, measured in m^3/t. Poland uses the radon concentration in coalbed methane for prediction, with a sharp decrease in radon concentration before outburst and a sharp increase after outburst [8-11]. Jiang Chenglin and other experts and scholars from China University of Mining and Technology have proposed the continuous flow method for predicting

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coal roadway outbursts, also known as the "line prediction" technology [12-14]. By studying and analyzing the dynamic law of gas emission distribution at various points during the drilling process and its relationship with the risk of coal roadway outbursts, the ZTL20/1000 continuous flow method coal roadway outburst prediction equipment has been successfully developed. This device continuously collects real-time data on the gas emission rate and corresponding drilling depth during the drilling process, and calculates predictive indicators to determine the risk of coal outburst in front of the excavation face and the position and distribution of structural coal in the coal body. It achieves a "line prediction" of coal roadway outburst risk and provides a new and more effective method for predicting coal and gas outbursts in coal roadway excavation faces.

2. Determination of Prediction Indicators for Coal Roadway Outburst

2.1. Basic Principles of the Experiment

According to the theory proposed by Pavlov of the former Soviet Union in the 1960s, there exists a pressure-relief zone ahead of the working face in coal seam roadways. When this zone is sufficiently long, excavation and blasting operations conducted within it will not trigger outbursts. Conversely, if the pressure-relief zone is short, the same tunneling and blasting process may suddenly expose soft coal containing high-pressure gas, leading to outbursts. However, current coal roadway outburst prediction methods rely on "point-based prediction," which fails to reflect the distribution of the pressure-relief zone ahead of the working face. The ZTL20/1000 continuous flow method coal roadway outburst prediction device can plot the distribution curve of initial gas emission flow as the drill bit advances. It enables real-time detection of the location of tectonic coal containing high-pressure gas and the distribution of the pressure-relief zone ahead of the working face, quantitatively assessing outburst risks in the coal mass. This system provides a safe excavation distance in advance for coal roadway tunneling, serving as a novel "line-based prediction" system for coal roadway outbursts. The measurement method is referred to as the continuous flow method.

According to Professor Jiang Chenglin's theory of spherical shell instability, the initial release of gas expansion energy W_p index is a comprehensive outburst prediction index that can comprehensively reflect the composite index of geostress, gas pressure, and physical and mechanical properties of coal. From Figure 1, it can be seen that as the initial release of gas expansion energy Wp increases, the outburst strength increases and the amount of outburst coal increases. According to 54 simulated statistical experiments on protrusion, protrusion will not occur when $W_p \leq 42.98$ mJ/g. When 42.98 mJ/g≤ $W_p \leq 103.8$ mJ/g, the protrusion is weak and the amount of protruding coal is small. When $W_p \geq 103.8$ mJ/g, the amount of protruding coal suddenly increases and the protrusion becomes strong. At the same time, through LDA discriminant analysis, it can be seen that 42.98mJ/g and 103.8mJ/g are the boundary between weak and strong outbursts. When the initial released gas expansion energy W_p reaches 42.98mJ/g, the predicted results are consistent with the actual outburst simulation results, with an accuracy of 0.967. When the initial release of gas expansion energy W_p reaches 103.8mJ/g, the predicted results are consistent with the actual outburst simulation results, with an accuracy of 0.9097. When the initial release of gas expansion energy $W_p \leq 42.98$mJ/g, the predicted results are consistent with the actual outburst simulation results, with an accuracy rate of 100%. This indicates that when the initial release of gas expansion energy predicts no outburst, coal and gas outbursts will definitely not occur. At present, the initial release of gas expansion energy technology has been widely applied in Yunnan, Guizhou, Sichuan, Shanxi, Henan, Xinjiang and other places. At the same time, the critical value of 42.98mJ/g for this indicator can be recommended as a "four in one" predictive indicator, which can accurately divide the outburst coal seam into outburst danger zone, weak outburst danger zone, and no outburst danger zone. This indicator can also be used to accurately predict the risk of coal outbursts in wellbores and stone gates.

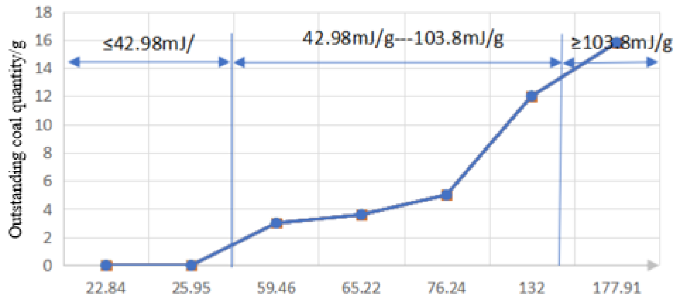

Figure 1. Relationship between intensity of gas burst and Wp

2.2. Determination of Initial Gas Release Expansion Energy W_P

The initial release gas expansion energy measurement device mainly consists of four parts, namely the coal sample tank, the inflation and deflation system, the data acquisition and automatic control system, and the constant temperature system. The physical object is shown in Figure 2.

Figure 2. Practicality picture of EEIRG

By collecting coal samples from the No. 3 coal seam of the 3501 intake and return airway excavation working face in Xinyuan Coal Mine, the initial gas release expansion energy W_p parameter was measured under different conditions. The results of the initial gas release expansion energy and gas pressure are shown in Table 1.

Table 1. Test result of EEIRG

Parameters	1	2	3	4
Gss pressure(Mpa)	0.23	0.43	0.59	0.65
W_p(mJ/g)	30.51	51.26	70.19	76.92
Highlight hazard assessment	No prominence	Weakly prominent	Weakly prominent	Weakly prominent

3. Determination of Sensitivity and Critical Value of Continuous Flow Method Prediction Indicators

3.1. Determination of Coal and Gas Outburst Hazard Indicators

Reasonable indicators are necessary to accurately determine the outburst hazard of the original coal seam. As described earlier, when the initial release of gas expansion energy $W_p \leq 42.98$mJ/g, the predicted results are consistent with the actual outburst simulation results, with an accuracy rate of 100%. According to the research results of Han Ying et al., it is known that there

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is a linear relationship between gas pressure and initial release gas expansion energy. According to Table 1, a curve of gas pressure initial release gas expansion energy W_p can be drawn, as shown in Figure 3.

From Figure 3, it can be seen that the correlation coefficient of the fitting formula for gas pressure P-initial release gas expansion energy W_p reaches 0.999. When the expansion energy reaches the weak outburst critical value of 42.98mJ/g, the corresponding coal seam gas pressure in the mine can be calculated as 0.35MPa. This means that during the excavation process of the 3501 intake and return airway in the No. 3 coal seam of Xinyuan Coal Mine, there may be a risk of coal and gas outburst when the gas pressure reaches 0.35MPa.

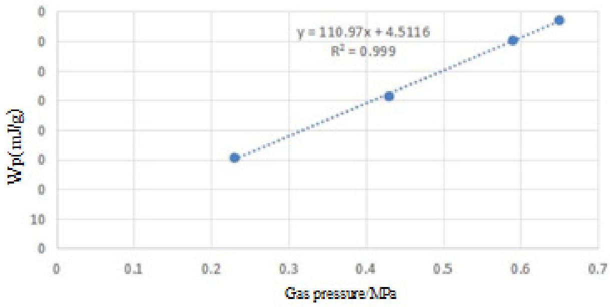

Figure 3. Relationship between P and W_p

3.2. Determination of Critical Values for Desorption Indicators of Drill Cuttings

Through on-site measurement and statistical analysis, the relationship between the specific gas desorption index K_1 and the initial release of gas expansion energy is shown in Figure 4. From Figure 4, it can be seen that there is a linear relationship between the desorption index K_1 and the initial released gas expansion energy W_p, that is, the larger the desorption index K_1, the larger the W_p. However, the maximum correlation coefficient between the two through the fitting formula is 0.6799, and the minimum value has reached 0.5353.

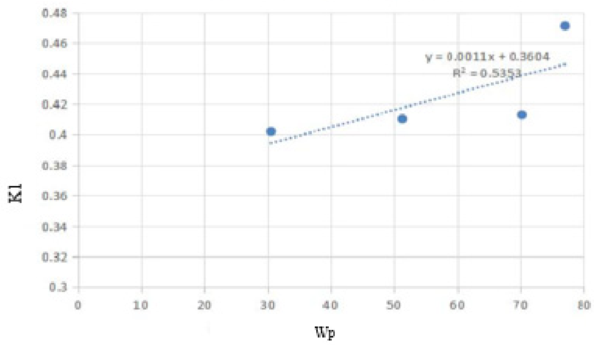

Figure 4. Relationship between K_1 value and W_p

3.3. Determination of the Critical Value of Smax for Drilling Cuttings Quantity

The relationship curve between the initial gas release expansion W_p and the amount of drilling cuttings S_{max} was obtained through on-site measurement and statistical analysis, as shown in Figure 5. It is preliminarily analyzed that there is a linear relationship between the two. Through linear fitting of the data, the fitting formula y=0.0317x+4.7823 can be obtained, with a maximum correlation coefficient of 0.681. Combined with the critical value of Wp outburst of 42.98mJ/g, the critical value of Smax outburst can be obtained as 6.1147Kg/m, slightly higher than the reference critical value of 6.0Kg/m in the "Detailed Rules for Prevention and Control of Coal and Gas Outburst". Therefore, the critical value of Smax protrusion is determined to be 6.0Kg/m.

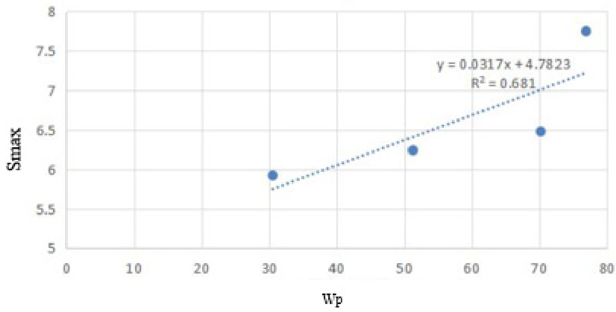

Figure 5. Relationship between S_{max} and W_p

4. Sensitivity Analysis of Outburst Prediction Indicators in Xinyuan Coal Mine

The initial release of gas expansion energy index is a comprehensive index that reflects the stress, gas pressure, and coal strength, and has been verified through a large number of laboratory and field experiments to accurately predict the risk of coal seam outburst. From the second section, it is clear that the correlation coefficients between various indicators and the initial gas release expansion energy W_p are linearly fitted. The correlation coefficient of the drilling chip quantity indicator S_{max} (Kg/m) is relatively high at R^2=0.681, while the drilling chip quantity desorption indicator K_1 is relatively small at R^2=0.5353. Therefore, the drilling chip quantity indicator can accurately predict the outburst during coal roadway excavation, and it is also the most sensitive. According to the on-site measurements of the 3501 intake airway and 3501 return airway in Xinyuan Coal Mine, there are currently about 54 tested groups, of which 48 are effective groups. Two groups experienced perforation during the data measurement process and were treated as invalid data, as shown in Figures 6 and 7.

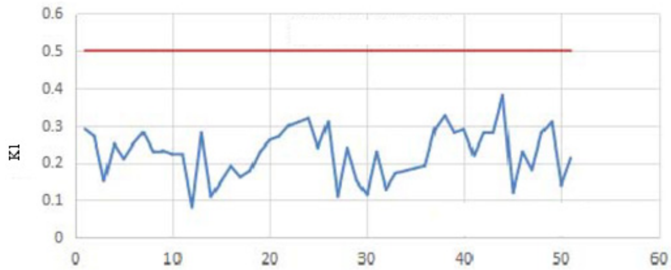

Figure 6. Trend Chart of Desorption Index Change

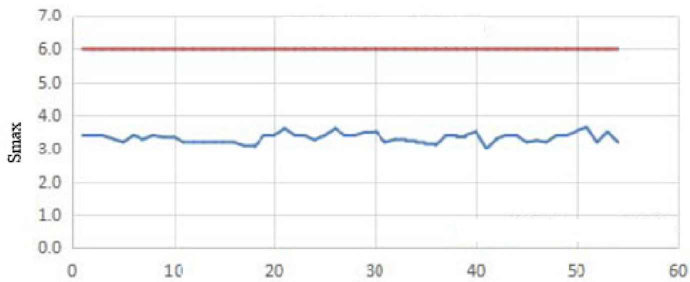

Figure 7. Trend Chart of Drilling Cut Volume Change

Figures 6 and 7 show the prediction of coal mine excavation face using continuous flow method and conventional prediction indicators simultaneously. In Figure 6, it can be analyzed that during the coal roadway excavation process, the predicted desorption index K1 value did not exceed the standard, and was all below the critical value of 0.5, which is basically between 20%

and 55% of the critical value. This is similar to the judgment results of the continuous flow method prediction index conducted synchronously. Figure 7 shows the Smax index of drilling cuttings, which shows little variation and is normally only 50% of the critical value of the drilling cuttings index. This is similar to the judgment results of the continuous flow method prediction index that is performed synchronously.

5. Conclusion

(1) The critical values of the outburst prediction indicators for the excavation face of the No. 3 coal seam in Xinyuan Coal Mine have been determined: when the initial release of gas expansion energy leads to weak outburst, the critical value is 42.98 mJ/g, and the desorption index K_1 of drilling cuttings is 0.41 mL/g • min$^{1/2}$, and the critical value of S_{max} is 6.1147 Kg/m.

(2) By analyzing the correlation coefficients between various indicators and the initial release of gas expansion energy, the sensitivity of each indicator was found to be $S_{max}>K_1$. The Smax value correlation coefficient of the drilling chip quantity index is the highest, indicating that this parameter is the most sensitive among the prominent prediction parameters.

(3) Through 54 on-site tests, it has been verified that the continuous flow method for predicting coal roadway outbursts can accurately predict the danger of outbursts in the working face. So far, the accuracy rate of predicting non outbursts has reached 100%.

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