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Comparing potentials for gas outburst in a Chinese anthracite and an Australian bituminous coal mine

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ABSTRACT

Gas outbursts in underground mining occur under conditions of high gas desorption rate and gas content, combined with high stress regime, low coal strength and high Young's modulus. This combination of gas and stress factors occurs more often in deep mining. Hence, as the depth of mining increases, the potential for outburst increases. This study proposes a conceptual model to evaluate outburst potential in terms of an outburst indicator. The model was used to evaluate the potential for gas outburst in two mines, by comparing numerical simulations of gas flow behavior under typical stress regimes in an Australian gassy mine extracting a medium-volatile bituminous coal, and a Chinese gassy coal mine in Qinshui Basin (Shanxi province) extracting anthracite coal. We coupled the stress simulation program (FLAC3D) with the gas simulation program (SIMED II) to compute the stress and gas pressure and gas content distribution following development of a roadway into the targeted coal seams. The data from gas content and stress distribution were then used to quantify the intensity of energy release in the event of an outburst.

1. Introduction

In China, underground coal mining is often associated with the risk of gas outburst. This risk grows as the depth of mining increases. Currently, most Chinese coal mines extract coal at depths of more than 500 m; these coals usually contain large volume of gas (up to 40 m^3/t in anthracite). The combination of high gas content and stress magnitude at these depths leads to frequent gas outbursts. China's National Energy Administration recorded 350 fatalities from 72 outburst events in Chinese mines in 2012. The reduction in the number of events and fatalities is mainly due to closure of small mines using unsafe mining methods and no gas drainage plan.

Fig. 1 shows the evolution of outburst events and fatalities in Chinese coal mines since 2005. The occurrence of outbursts in Australian mines of similar depth is, however, very rare; no fatalities from gas outburst events have been recorded over the past two decades. The aim of this study was to compare the geo-mechanical and gas reservoir factors that influence the occurrence of gas outbursts in typical Chinese and Australian coal mines prone to outburst.

Gas outburst occurs when all or some of the following conditions are present: high gas content, high rate of gas desorption, high stress level, low strength but high Young's modulus of coal, geological structure and fast advance rate of mining [1–5]. Other factors, such as coal permeability, mining depth and coal thickness, may also influence the occurrence of outburst [6–9]. Gas drainage and stress relief are the most effective primary approaches to reducing outbursts in collieries [10–13].

In this work, we developed a conceptual model for occurrence of outburst and used it to compare the gas outburst potentials of two typical Chinese and Australian outburst-prone coal mines. This model is expressed in terms of an index, which we call the outburst indicator. The indicator is based on the ratio of available energy from compressed gas and strained rocks to the required energy to crush and eject coal into the open voids. To compute stress redistribution due to excavation, the FLAC3D code was used. Similarly, SIMED II was used to compute the redistribution of gas content and pressure due to the excavation. We then used the model to compare the potential for outbursts from coal seams with a roadway constructed into the seam.

2. Development of a conceptual model of outburst

We assume that both the strain energy and gas expansion energy contribute to coal failure, pulverization and ejection of coal

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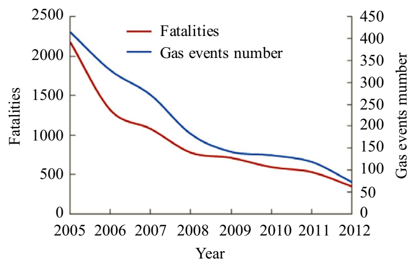

Fig. 1. Gas outbursts and fatalities in China since 2005.

during a gas outburst event. In this analysis, we assume that the expansion of desorbed gas is isothermal. In this model, an outburst occurs if the sum of gas and strain energy is higher than the energy required for coal pulverization and ejection into the roadway, i.e.,

$$W_e + W_s > E_c + E_k \tag{1}$$

where W_e and W_s are the gas expansion energy and strain energy; and E_c and E_k the energy required to crush coal and to eject coal. We define an outburst indicator, u, to evaluate the proneness of outburst in a location in the mine:

$$u = \frac{W_e + W_s}{E_c + E_k} \tag{2}$$

The gas expansion energy is estimated as follows:

$$W_e = \rho c V_c P_a = \rho clwhP_a \tag{3}$$

where P_a and V_c are the atmospheric pressure and volume of coal in place prior to the outburst; c the gas content of coal; ρ the coal density; and l, w and h are the length, width and height of the roadway, respectively.

Strain energy is estimated using the following equation:

$$W_s = \frac{1}{2} V_c \varepsilon \sigma = \frac{1}{2} V_c \sigma^2 \left(\frac{1-\upsilon}{E}\right) \tag{4}$$

where ε is the average strain in coal; σ the average effective stress; E the Young's modulus; and υ the Poisson's ratio [3].

Rittinger's law states that the work required to crush a solid is proportional to the new surface created. It is quantified in terms of specific crushing energy, or the amount of energy required for increasing the coal surface by a unit area [14]. Hence, the energy required to crush a coal volume of a surface area S is:

$$E_c = e\Delta S \tag{5}$$

where e is the specific crushing energy; and ΔS the surface increment after the coal is crushed. Cai and Xiong measured the specific crushing energy of several Chinese coals [14]. It varied from 10.7 to 28.8 J/m^2, and was positively correlated with the hardness coefficient of these coals (Protodyakonov's coefficient) (Table 1).

Table 1
Crushing energy of some Chinese coals [14].

Coals	Hardness coefficient	Specific crushing energy (J/m^2)
Soft coal from Taiji Colliery, Beipiao city	0.300	28.8
Coal from Sanbao Colliery, Beipiao city	0.240	22.4
No. 6 coal from Weitang Colliery, Tonghua city	0.225	20.2
No. 6 coal from Weitang Colliery, Tonghua city	0.179	15.5
No. 6 coal from Weitang Colliery, Tonghua city	0.206	16.2
Coal from Jiulishan Colliery, Jiaozuo city	0.119	10.7
Outburst-prone coal from Xiaosiping Colliery, Fushun city	0.250	25.6

Assuming that the crushed coals have spherical shapes, then the surface area and its increments can be expressed in terms of particle diameter:

$$S = \frac{6V}{d} \tag{6}$$

where V is the volume; and d the diameter of spherical particles. The surface increment due to crushing of a volume V_c of coal is:

$$\Delta S = 6\left(\frac{1}{d} - \frac{1}{D}\right) V_c \tag{7}$$

where D and d are the diameters of spherical coal particles before and after crushing, respectively.

In practice, the diameter D of coal before crushing is much larger than the particle diameter after it is crushed. Therefore, Eq. (7) can be simplified to

$$\Delta S = \frac{6}{d} V_c \tag{8}$$

The energy of crushing coal is:

$$E_e = \frac{6}{d} V_c e \tag{9}$$

The energy required to eject the crushed coal mass is

$$E_k = \frac{1}{2} m\upsilon^2 = \rho lhw\upsilon^2 \tag{10}$$

where m and υ are the mass and velocity of the ejected coal, respectively.

Lastly, the outburst indicator u can be evaluated as follows:

$$u = \frac{\frac{1}{2} c\rho lhwP_a + \frac{1}{2} lhw\sigma^2 \left(\frac{1-\upsilon}{E}\right)}{\frac{6}{d} elhw + \frac{1}{2}\rho lhw\upsilon^2} \tag{11}$$

$$u = \frac{\frac{1}{2} P_a c\rho + \frac{1}{2}\sigma^2 \left(\frac{1-\upsilon}{E}\right)}{\frac{6}{d} e + \frac{1}{2}\rho\upsilon^2} \tag{12}$$

If $u > 1$, an outburst may occur. A larger u indicates a stronger probability of an outburst.

In next sections, we will use this model and outburst indicator to compare an Australian and a Chinese outburst-prone coal mine. In applying this model, it is assumed that:

(1) The length of the outburst into the coal face zone (l) is equal to the distance between the coal face and the location of the intact coal in front of the face.
(2) The outburst is only due to the combined effect of coal stress and coal mechanical and gas reservoir properties.
(3) It is assumed that only 50% of volume of gas initially trapped in coal would be released during the outburst event.

It should be noted that the geological factors, such as faults and structures, are not taken into account in this model.

3. Materials and methods

3.1. Geological conditions of the studied mines

To use the approach developed in Section 2, publically available data from two typical gassy mines in Australia and China were used to estimate potentials for outburst in development headings.

The Australian mine, here called Mine A, extracts bituminous coal; and is located in the southern coal region of the Sydney Basin. Coal is extracted from Bulli Seam using longwall mining. During mining, mechanized shearers cut and remove the coal at the longwall face of the mine. Hydraulic-powered supports hold up the roof