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Evaluation of current coal burst control techniques and development of a coal burst management framework

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ABSTRACT

Coal burst has been increasingly attracting attention in Australian coal mines recently as they go deeper. Coal burst is well known for its catastrophic destruction, complex mechanisms and difficulty of control in the mining industry. This paper summarises the control measures used globally for this dynamic failure, and shows how to develop site specific control management plans. Firstly, relevant terminology used in dynamic rock failure events in the international underground mining industry is discussed. Preventative controls and mitigating controls are then presented and discussed. Current coal burst controls include general management strategy, mine design, preconditioning and destressing as risk mitigation, and ground support strategies. Optimum layout methods, mitigating strategies, including latest ground support techniques and destressing techniques, are reviewed in this paper. A framework of coal burst management is then proposed, including three critical stages: identification of coal burst profile, development of a management plan and management of coal burst.

1. Introduction

As a major type of rock or coal dynamic failure, coal burst is one of the most catastrophic events for underground excavations, especially for those at greater depth. Since the first coal burst in Britain in 1738 (Dou and He, 2001), burst events have been reported worldwide and severely threaten mine safety and productivity. The first official documented coal burst in Australia (Hebblewhite and Galvin, 2017), a rib burst, occurred at Austar mine in New South Wales in 2014. Table 1 summarises international coal burst occurrences.

This paper extends previous reviews on coal burst contributing factors, mechanisms, monitoring and controls (Bräuner, 1994; Zhang et al., 2017), with a focus on coal burst control strategies. Four major groups of coal burst controls are discussed in this paper: general management strategy, preconditioning and destressing as risk mitigation, mine design, and support technologies and strategies.

There is still a lack of understanding of appropriate and effective control techniques and their implementation under different mining and geological conditions. Therefore, this paper summarises and compares the control measures based on a worldwide database, identifies knowledge gaps and proposes a general systematic control strategy for coal bursts. Although the paper focuses on coal bursts in underground mines, it can also inform burst control strategies in other underground excavations such as tunnelling since the fundamentals of control of this type of dynamic rock or coal failure are similar.

2. Coal burst terminologies, occurred conditions and monitoring systems

Coal burst is a dynamic form of rock failure and usually happens with audible sound and large deformation of roadways. Strain energy stored in the surrounding rock mass is suddenly released at the same time (Jiang et al., 2014; Galvin, 2016; Mark, 2016). There are other terms used to describe seismic activities, such as pressure burst, strain burst, outburst, tremors, bump and bounce, as described below.

The term pressure burst is synonymous with coal burst, but coal burst, together with pillar burst, refers specifically to a pressure burst event that expels coal into excavation, as opposed to rock from roof or floor (Hebblewhite and Galvin, 2017). A strain burst is a form of coal burst, but with lower magnitude of energy release. Coal mine tremors, bump and bounce mainly refer to a sudden shake scenario with significant audible sound, but have no or minimal rock mass ejection (Jiang et al., 2014; Galvin, 2016). The term coal burst refers to seismic activities with ejection of materials but no or minimal gas pressure, which is the main energy source for outburst. The key outcome of a coal burst event is that it causes damage to the excavation and can result in personnel injuries or equipment destruction. The Mine Safety and Health Administration (MSHA) (Whyatt et al., 2002) defines coal burst

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Table 1
Summary of coal bursts in different countries (Zhang et al., 2017).

Country	Years	No. of burst events	Fatalities	References
USA	1905–2014	492	132	Iannacchione and Tadolini (2008a), Iannacchione and Tadolini (2016), Mark and Gauna (2016)
China	1949–2015	~2000	300 during 2006–2013	Dou and He (2001), Dou et al. (2014), Jiang et al. (2014)
Poland	1977–2015	109 (> 60% of mines experienced coal bursts)		Patyńska and Kabiesz (2014), Makówka (2016)
Czechoslovakia and Czech Republic	1930–2015	467	72	Ptacek (2017)
Germany	1973–1992	50	27	Bräuner (1994)

as (1) causes persons to be withdrawn, (2) impairs ventilation, (3) impedes passage, or (4) disrupts mining activity for more than one hour.

Coal burst occurs under various conditions. The previous literature review has discussed a range of contributing factors in great detail (Zhang et al., 2017). The major parameters are briefly summarised in this section, as the presence of these factors influences coal burst control strategies. The major contributing factors can be classified into two categories:

(1) Coal seam and surrounding strata conditions: one of the most important factors causing coal burst is the existence of massive roof and floor layers (Bräuner, 1994; Iannacchione and Zelanko, 1995; Karfakis and Wu, 1995; Mark and Gauna, 2016). Coal seam in this condition is referred to as a "bump sandwich" (Mark, 2016). The massive roof layers would highly likely lead to an irregular periodic weighting, which results in burst-potential seismic activities (Iannacchione et al., 2005). There are also other localised parameters contributing to coal burst at various levels, such as cover depth and variable thickness of the coal seam, which are assessed based on field studies and numerical simulations (Osterwald et al., 1993; Bukowska, 2006; Dou et al., 2009).
(2) Geological discontinuities: folded and faulted areas are always highly stressed and vulnerable to coal bursts (Holland, 1958; Gay, 1993; Iannacchione and Tadolini, 2008a; Alber et al., 2009). Other types of geological structures, such as dykes and sandstone channels (Salamon, 1983; Galvin, 2016), also have a pronounced impact on coal burst occurrences.

The occurrence of coal burst is highly complex due to varying geological, geotechnical and mining conditions. For instance, data from China (2004–2014) showed that 38% of coal bursts occurred in weak coal seams and some even occurred in coal mines with no significant burst history (Jiang et al., 2014). Mark (2016) stated that burst proneness has no strong relationship with the composition of coal. Hence, in most conditions, one type of factor does not fully contribute to a burst event; therefore, prediction and control of coal burst should use analysis of various potential contributing factors according to the site specific conditions. These parameters are used as indexes to quantify the coal burst proneness, such as the uniaxial compressive strength (UCS or R_C), elastic strain energy (W_{ET}), bursting energy (K_E), dynamic failure duration (D_T) and energy release rate (ERR) (Heasley, 1991; Linkov, 1996; Mitri et al., 1999; Mazaira and Konicek, 2015; Cai et al., 2016).

Coal burst monitoring aims to understand the signatures of seismic activities, stress changes and geological conditions at a specific location. Monitoring techniques can be classified into two main groups (Jiang et al., 2014). The first technique aims to monitor the process of deformation of the excavations and stress redistributions. Usually, stress and displacement monitoring instruments are used, such as extensometers, tell-tales, borehole stress observation systems and load monitoring system of hydraulic roof supports. The second group of monitoring methods are based on geophysics, such as the electromagnetic emission method (EME), acoustic emission (AE) method, microseismic method and seismic computed tomography (CT) detection, and focus on monitoring the fracturing process in rock masses. Coal burst monitoring is usually conducted at two levels: regional monitoring and localised monitoring. Reginal monitoring focuses on the risk classification of coal mine. It is usually achieved by combining with comprehensive index methods and multi-factor coupling methods (Dou et al., 2014; Zhang et al., 2017). Localised monitoring methods are then performed in specific and targeted areas to achieve more accurate, reliable and real time monitoring and risk classification.

Regional monitoring usually utilities microseismic monitoring and seismic wave tomography. Electromagnetic emission and acoustic emission monitoring are usually used for localised monitoring. These methods can lead to relatively large errors caused by the complicated underground conditions, such as underground water and a complex electromagnetic environment (Qu et al., 2011). In these conditions, test drilling/borehole drilling and roof displacement measurements are conducted for more accurate monitoring and forecasting.

Currently, the most widely used monitoring methods in China are electromagnetic emission methods, acoustic emission methods, microseismic methods, borehole stress observation and test drilling methods. These methods have been implemented in high coal burst prone mines (Jiang et al., 2014) and some have been verified as successful monitoring by case studies (Dou et al., 2003; Jiang et al., 2006). Due to the complexity of coal burst, precursor signals and multiple monitoring parameters have been extensively studied and recognised as the future research direction for forecasting methods (Jiang et al., 2014).

3. Coal burst control strategies

Coal burst control is an important element of overall coal burst management, as it directly relates to mine safety and productivity. Researchers and operators have studied control measures for rock or coal burst for decades. Current control techniques can be classified into two groups: preventative controls and mitigating controls. The preventative controls are usually implemented at the start of underground mines to avoid occurrence of coal bursts by optimising the mine design, while mitigating controls are applied as risk mitigation measures to minimise the risks of coal bursts.

3.1. Preventative controls

Preventative controls, or mine design optimisation to prevent coal bursts, include mine layout design, pillar design, and protective seams in multiple seam mining. These control measures aim to avoid high static stress concentration and reduce the magnitude of dynamic events induced primarily by strata breaking. Therefore, during mining activities, the accumulated strain energy would distribute more evenly around the excavations after the implementation of preventative controls. In this section, gateroad design, critical pillar design and other layout designs are discussed.