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Review

A review of mechanism and prevention technologies of coal bumps in China

Yaodong Jiang [a,b,*], Yixin Zhao [b,c], Hongwei Wang [a], Jie Zhu [a]

[a] School of Mechanics and Civil Engineering, China University of Mining and Technology, Beijing, 100083, China
[b] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Beijing, 100083, China
[c] School of Resources and Safety Engineering, China University of Mining and Technology, Beijing, 100083, China

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ABSTRACT

Coal bump refers to a sudden catastrophic failure of coal seam and usually can cause serious damages to underground mining facilities and staff. In this circumstance, this paper focuses on the recent achievements in the mechanism and prevention techniques of coal bumps over the past five years in China. Based on theoretical analysis, laboratory experiment, numerical simulation and field test, the characteristics of coal bumps occurrence in China's coal mines were described, and the difference between coal bumps and rockbursts was also discussed. In addition, three categories of coal bumps induced by "material failure" were introduced, i.e. hard roof, floor strata and tectonic structures, in which the mechanism of coal bumps induced by geological structures was analyzed. This involves the bump liability and microstructure effects on bump-prone coal failure, the mechanism of coal bumps in response to fault reactivation, island face mining or hard roof failure. Next, the achievements in the monitoring and controlling methods of coal bumps were reviewed. These methods involve the incorporated prediction system of micro-seismicity and mining-induced pressure, the distributed micro-seismic monitoring system, energy absorption support system, bolts with constant resistance and large elongation, and the "multi-stage" high-performance support. Finally, an optimal mining design is desirable for the purpose of coal bump mitigation.

1. Introduction

Coal mine bump has been recognized as one of the most serious and dangerous hazards in underground mining all over the world (Jiang et al., 2009, 2012, 2014a; Zhao and Jiang, 2010; Jiang and Zhao, 2015). It could lead to a sudden and violent failure of coal mass, release of large amount of elastic energy, rock or coal bumps into the tunnel, damage to the equipment and facilities, and injuries to the miners. It has been a major concern for more than half a century. Although much effort has been made to control and mitigation of coal bumps, coal bumps are still frequently reported in underground mining and even more for deep coal mining across the world. For example, in USA nine miners were killed and six were injured by two serious coal bumps accidences in Crandall Canyon coal mine, Utah in 2007 (Wikipedia, 2007) and two miners lost their lives in a coal bump in the Brody Mine, West Virginia in 2014 (Todd and Newsome, 2014). In Australia, two miners were also killed and the mining machine was damaged by a coal bump in Austar coal mine in 2014 (ABC Radio Australia, 2014). In China, the frequency of coal bumps increases with the mining depth. Statistical results show that coal bumps were only reported in 32 China's coal mines in 1985. However, more than 147 China's coal mines had experienced coal bumps by the end of 2014, such as the Chengshan coal bump incident of Jixi mining district in 2008, Yuejin coal bump incident of Yima mining district in 2010, and Qianqiu coal bump incident of Yima mining district in 2011 (Jiang et al., 2014a).

To date, numerous investigations have been carried out to analyze the mechanism of coal bumps and various theories have been proposed involving the theory of strength, stiffness, energy, and bursting liability (Jiang et al., 2014a), etc. These theories can be generally divided into three categories:

* Corresponding author.
E-mail address: jiangyd@cumtb.edu.cn (Y. Jiang).
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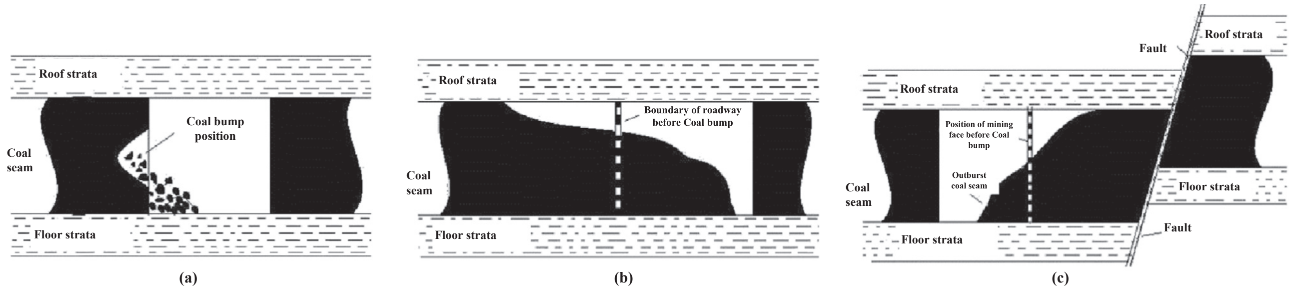

Fig. 1. Scheme of coal bumps classification (Jiang et al., 2014a; Jiang and Zhao, 2015). (a) Coal bump induced by material failure; (b) Coal bump induced by hard roof or floor; and (c) Coal bump induced by instability of tectonic structure.

(1) Coal bumps caused by "material failure". The theory holds that the physico-mechanical properties are the key issues in the development of coal bumps.
(2) Coal bumps induced by complex tectonic structures around the bump-prone zones.
(3) Mining-induced coal bumps.

The studies of coal bumps in China were initiated in the 1960s and major achievements (Jiang et al., 2014a; Jiang and Zhao, 2015) have been made over the past five decades. In 2009, the "Fundamental research on mechanism and prevention of coal mine dynamic disasters at great depth", granted by the National Basic Research Program Project (973 Project), was launched in China. In 2010–2014, four key scientific issues related to coal bumps were proposed, i.e. geological conditions and quantitative analysis method, properties and engineering behaviors of discontinuous rock masses under dynamic loading, temporo-spatial distribution of mining-induced stresses and accumulated elastic strain energy, and coal bumps prevention technology.

This paper aims at reporting the achievements of "973 Project" related to the coal bumps and providing an overview of the coal bump phenomena and the current research progress in China. The achievements are used to illuminate the mechanism of coal bumps induced by tectonic structures and the monitoring and controlling technologies of coal bumps.

2. Classification of coal bumps

Coal bump is a dynamic phenomenon and can cause sudden and severe damage to underground mining, which basically occurs in a form of instantaneous release of elastic deformation energy within surrounding rock mass of mining tunnel or face, characterized by loud noise and thrown out of large quantity of rock or coal mass. Coal bumps usually have the following features: (1) no visible macro-precursors occur prior to coal bumps; (2) they are difficult to be predicted in terms of time, position and intensity before occurrence; and (3) other dynamic disasters can also be induced, such as gas outburst, gas explosion, and water inrush (Jiang et al., 2014a).

The characteristics of coal bumps and various classification methods for coal bumps are extensively studied. Pan et al. (2003) classified the coal bumps as the types of rock compression, roof fracture and fault reactivation. He et al. (2005) considered the coal bumps with two types, i.e. "single" energy and "compound" energy in the mining space where the accumulation of elastic energy takes place. Qian (2014) suggested that coal bumps could be divided into sliding coal bump resulting from fault-slip and strain energy bump resulting from failure of coal masses. According to various classification criteria proposed, the methods can be generally divided into two categories: (1) based on the position of the coal bump occurrence, it can be classified into coal seam bump, roof bump and floor bump; and (2) based on the sources of energy, coal bumps involve three types, i.e. gravity induced, tectonic structure induced, and gravity-tectonic induced coal bumps.

As shown in Fig. 1, Jiang et al. (2014a), Jiang and Zhao (2015) pointed out that coal bump is a nonlinear dynamic mechanical process of strain energy gradually accumulated and abruptly released. According to the bump patterns and associated factors, coal bumps could be classified into three categories with respect to site-specific geological conditions:

Type I: Coal bumps are induced by material failure. During the excavation of tunnels or longwall panel, cracks in coal and rocks can initiate, develop, propagate and penetrate. When the ultimate strength of surrounding rock or coal mass is reached, coal bump could happen.

Type II: Coal bumps are induced by hard roof or floor. Large stiffness differences between roof/floor strata and coal seam can be frequently observed when the coal bumps occur (Zhao et al., 2010, 2014; Zhu et al., 2014; Rostami et al., 2015). The hard roof or floor may release accumulated strain energy instantly during mining process. In this case, coal bumps or horizontal movement of coal mass toward the tunnel may occur.

Type III: Coal bumps are induced by tectonic structures. For rock strata characterized by strong tectonic structures, huge elastic energy can be accumulated in the regions adjacent to the tectonic structures during the long-term geological evolution. The fault reactivation induced by mining nearby may also lead to the occurrence of coal bump.

In practice, as mining proceeds, high in-situ stress can result in instability and reactivation of faults, release of high stress and possible occurrence of coal bumps. The degrees of damage caused by coal bumps of Types II and III are greater than that of Type I. For instance, the coal bump reported in Qianqiu coal mine in China was induced by the fault F16. Jiang et al. (2013) conducted a physical experiment and simulated the process of fault instability. Modeling results suggested that immediately before fault reactivation, the normal and shear stresses on the fault surface increased rapidly and then the fault slip occurred instantaneously. Therefore, it has been a major concern that the coal bumps are induced by tectonic structure for deep coal mines under high tectonic stress. In addition, the coal bumps of Types II and III may also occur during island face mining, and coal pillar recoveries in association with hard roof.

3. Mechanism of coal bumps induced by geological structures

Previous investigations show that geological features are the main issues in terms of coal bumps (Shepherd et al., 1981; Wang et al., 2012, 2013; Xu et al., 2015). The features of geological setting from micro- to macro-scale involve the liability of coal bumps, the tectonic structures, the hard roof or floor strata, and the specific mining characteristics such as coal pillar or island face. Among these issues, the coal bump proneness plays a main role in