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Cross-borehole hydraulic slotting technique for preventing and controlling coal and gas outbursts during coal roadway excavation

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ABSTRACT

Coal and gas outbursts comprise the predominant hazards in Chinese coal mines. A large number of accidents have occurred during coal roadway excavation. In this study, we propose the application of a cross-borehole hydraulic slotting technique for preventing and controlling coal and gas outburst disasters during coal roadway excavations. In this technique, a high-pressure water jet is applied in a coal body to cut a slot. This helps to increase the permeability of the coal seam, improve the gas-extraction efficiency of the borehole, and prevent and control coal and gas outburst disasters during excavations. In the field test in which hydraulic slotting was employed, the average mass of coal that was discharged from a slotted borehole is 8.2 t; the weight of the largest discharged mass is 16 t. The diameter of the slotted borehole is 12.87 times the diameter of a conventional borehole, which effectively improves the borehole's influence range. After half a month of gas extraction, the average gas-extraction concentration for the slotted borehole is 26%, whereas the average gas-extraction concentration of the conventional borehole is 7%, that is, the gas-extraction concentration for the slotted borehole is approximately 3.7 times the gas-extraction concentration of the conventional borehole. After four months of gas extraction, the residual gas content and gas pressure for the 11091 transportation roadway satisfy the requirement of the State Administration of Work Safety. A conventional borehole requires a minimum period of six months to prevent and control outbursts, whereas a slotted borehole requires a minimum period of four months. These results suggest that the technology can improve the efficiency of gas drainage, reduce the gas drainage time, and is a potential application for preventing and controlling future gas disasters.

1. Introduction

The coal industry serves an important role in the protection of China's rapid economic growth. However, an increased demand for coal has created increases in the mining depth, gas pressure, and gas content in coal mines. The mining depths of some coal mines in central and east China now reach between 800 m and 1200 m; the vertical stress of the coal seams is in the range of 22–33 MPa, the gas pressure and gas content can reach 6 MPa and 22 m^3/t, respectively (Liu et al., 2014), which resulted in a deterioration of the mines and an increase in gas disasters, especially coal and gas outburst disasters (Cheng et al., 2009; Lin et al., 2011; Li and Saghfi, 2014; Wang et al., 2014a,b). Many reports have suggested that a large number of coal and gas outburst accidents occur during coal roadway excavation (Lu et al., 2011; Cheng et al., 2012; Hu et al., 2012; Frank et al., 2013; Yang et al., 2014; Zhou et al., 2015). To ensure mine safety and efficient production, effective measures must be undertaken to control the occurrence of gas disasters. Many scholars have conducted extensive research on the prevention and control of gas disasters and reported useful conclusions (Beamish and Crosdale, 1998; Lu et al., 2010; Aziz et al., 2011; Trubetskoy et al., 2011; Torano et al., 2012; Szlązak et al., 2014; Li et al., 2014; Yan et al., 2015). Despite these studies, gas disasters have not been completely eliminated. During multi-seam mining, the coal seam without outburst danger should be selected as the initial mining seam. By mining this seam, the danger of coal and gas outbursts in the adjacent seam is significantly reduced (Wang et al., 2013a). Due to the lack of a protection seam in a high-gas single coal seam, the gas is extracted prior to mining to reduce the gas content

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and gas pressure, which effectively reduces the risk of coal and gas outbursts (Noack, 1998).

Gas extraction in advance is crucial for preventing coal and gas outburst disasters in a high-gas single coal seam during coal roadway excavation, which effectively reduces the gas content of the coal seam. The maximum drainage of gas in a coal roadway can be accomplished by drilling an in-seam borehole in the working face of a coal roadway [Fig. 1(a)] or drilling a cross-borehole from a rock roadway to a coal roadway [Fig. 1(b)]. In the first method in gas-rich single coal seams, workers directly drill the borehole in the drivage face, which exposes them to a significant risk. In the second method, however, the rock roadway serves as a security barrier. This method has limited construction difficulties and is comparatively safer; thus, it is employed in many coal mines. To guarantee the effectiveness of a gas disaster control system, the engineering construction systems and gas-extraction system must concurrently operate in both time and space. Despite long extraction times, the amount of extracted gas is very low due to low gas permeability in Chinese coal seams. Therefore, the coal seam requires significant structural changes to improve the efficiency of the gas-extraction process and reduce the gas-extraction time (Zhou et al., 2012). A solution to improve the extraction efficiency of coalbed gas is to increase the permeability of the coal seam (Karacan et al., 2011). Many studies were performed to identify a method that exhibits high efficiency for the extraction of gas from high-gas low-permeability coal seams (Gentzis and Bolen, 2008; Ozdemir, 2009; Zheng et al., 2012; Massarotto et al., 2014). Some of the methods for enhancing the permeability of coal seams include hydraulic fracturing, hydraulic punching, and deep hole pre splitting blasting. (Zhang et al., 2004; Mu et al., 2013; Wang et al., 2013b, 2014c; Hao et al., 2014; Vishal et al., 2015). Although these methods have produced desired results, they have certain limitations (e.g., uneven pressure relief or a complicated process).

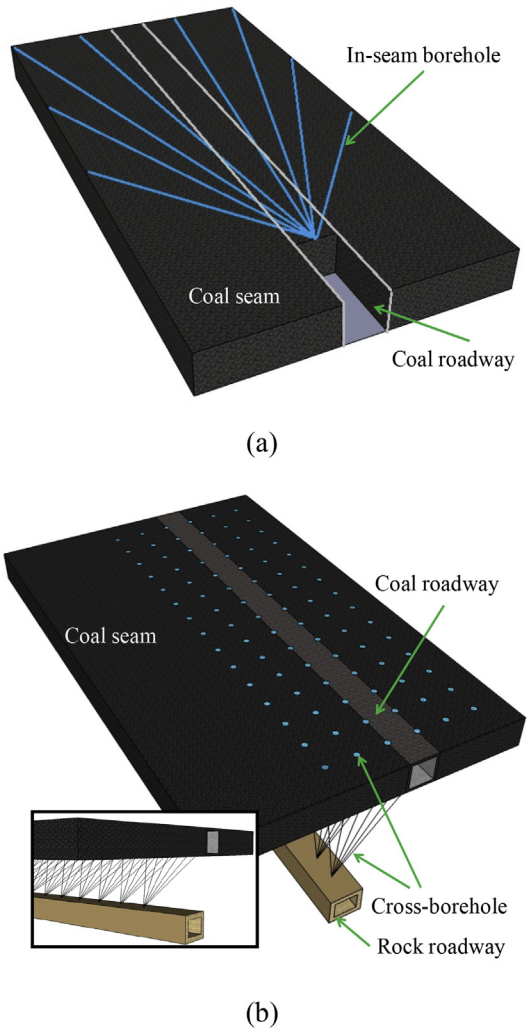

Fig. 1. Extraction of gas in a coal roadway. (a) Drilling an in-seam borehole in the working face of a coal roadway; (b) Drilling a cross-borehole from a rock roadway to a coal roadway.

Hydraulic slotting involves the use of a high-pressure water jet in a coal body to cut slots and achieve pressure release. Thus, this method is relatively advantageous for the generation and expansion of fracture. In the last few decades, high-pressure water-jet technology has achieved substantial progress. It is environmentally friendly and has numerous applications in various industries (e.g., automotive, aerospace, medical, and food industries; Summers, 1995; Etchells, 1997; Kulekci, 2002; Folkes, 2009). The mining industry was one of the early users of this technology. Yao (1991) conducted a study to explore the potential use of water jet as an efficient and economical cutting tool in rock and coal excavation. Li et al. (2000) examined the use of a collimated abrasive water jet assistant for tunnel construction; the application of hydraulic mining associated with this water jet technique has already been attempted in China (Xia et al., 2008; Li, 2014). Hydraulic slotting based on the water-jet technique to increase the permeability of a coal seam has been investigated by some scholars with promising results (Lin et al., 2007; Li et al., 2008). The implementation of hydraulic slotting in a coal seam can improve its porosity and increase the number of cracks, which helps to improve the permeability of a coal seam and subsequently improve the gas-extraction efficiency (Lu et al., 2009; Lin et al., 2010; Shen et al., 2012).

Considering the coal and gas outburst disasters that occur while excavating coal roadways in a high-gas low-permeability single coal seam, we propose the application of a cross-borehole hydraulic slotting technique to increase the permeability of a coal seam. This technology can substantially improve the efficiency of gas extraction, reduce the time required for extraction of gas from a coal roadway, and significantly reduce coal and gas outburst disasters during the excavation of a coal roadway. In addition, the technology also facilitates the efficient mining of the working face, because the coal roadway is used for transportation and ventilation while mining in the working face. If the coal roadway is not efficiently completed, the working face cannot be mined.

2. Fundamentals and technical process of the cross-borehole hydraulic slotting technique

2.1. Fundamentals of the cross-borehole hydraulic slotting technique

In the cross-borehole hydraulic slotting method, a cross-borehole is drilled from a rock roadway to a coal roadway, which is prepared for digging, and high-pressure water is used to cut slots in the coal seam in the cross-borehole. During this process, large amounts of broken coal are discharged from the borehole, which results in the formation of a large space in the coal seam. This space increases the exposure area of the original coal and provides additional space for expansion–deformation of the coal. Lateral expansion–deformation of the coal is significantly improved, and the volume strain of the coal is calculated as