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A novel active prevention technology for borehole instability under the influence of mining activities

Cheng Zhai [a, b], Yanming Xu [a, b, *], Xianwei Xiang [a, b], Xu Yu [a, b], Quanle Zou [a, b], Chao Zhong [a, b]

[a] State Key Laboratory of Coal Resources and Safe Mining, Xuzhou, China
[b] School of Safety Engineering, China University of Mining & Technology, Xuzhou, China

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ABSTRACT

Coal bed methane (CBM) drainage is an efficient method used to control gas hazards. Nevertheless, borehole instability is prone to occur under repeated disturbances by external stress from mining activities. Consequently, the collapsed coal blocks the gas-flow channel to further induce several gas drainage problems, including low gas concentration and flow, poor drainage result, etc. Due to these problems, screen pipes were installed in this work to provide active support in order to prevent borehole instability. Initially, the effect of mining activities on borehole stability was analysed. Subsequently, we explored the instability characteristics and corresponding acoustic emission (AE) properties of a non-supported borehole and a borehole stabilized by internal active support. These boreholes were drilled in the lab sample instead of the real coal sample. Moreover, the abilities of the holes to resist disturbances due to external stresses were compared. When the stress reached 10 MPa, the non-supported borehole was completely destroyed, whereas the actively supported borehole only slightly deformed. As the stress continuously increased to 14 MPa, a deformation of 15 mm was detected along the radial direction of the actively supported borehole. Additionally, an analysis of the dynamic changes in the strain on the screen pipe surface, the AE time–sequence parameter and location information indicated that the maximum AE event count and energy dissipation rate of the supported borehole at 14 MPa were 44% and 23% lower, respectively, than the corresponding values for the non-supported borehole at 10 MPa. Thus, the support increases the ability of the borehole to resist disturbance by at least 40%. Furthermore, the locating points and energy rate appeared to temporally cluster at coal-yielding or failure stage. Hence, the supporting effect of the screen pipe on the coal around boreholes at the crushing stage is significant. The internal support to the borehole provides a positive confining pressure for the coal in the fracture zone to improve the coal's residual strength. Depending on the support from the screen pipe, the coal can mesh to remain in place and thus prevent collapse, which improves the stability of the borehole.

1. Introduction

Coal bed methane (CBM), a by-product from the mining of coal, has been considered the main source of disasters in coal mines since the first documented coal mine gas explosion occurred in the United States in 1810 (Flores, 1998). Currently, hazards caused by gas account for more than 60% of major and extremely serious coal mine accidents. However, CBM is also a form of clean energy. The heat value per cubic meter of CBM is equivalent to that of 1.13 kg gasoline. The effective extraction and utilisation of CBM are of great significance in reducing air pollution and saving energy (Lunarzewski, 1998; Li et al., 2013; Zhou et al., 2014a; Zou et al., 2014a, b; 2015). The average mining depth in China is nearly 700 m and continues to extend downward at a rate of 10–20 m per year (Cheng et al., 2013a; Liu et al., 2014a). The occurrence of CBM, therefore, become more complex and further threaten coal mine safety. Thus, the National Coal Mine Safety Supervision Bureau of China enacted the “Provisions of the prevention of coal and gas outburst” regulations in 2014 to prevent gas accidents. These

* Corresponding author. State Key Laboratory of Coal Resources and Safe Mining. Xuzhou, Jiangsu, China.
E-mail address: cumtxym@163.com (Y. Xu).

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regulations highlighted the necessity of regional methane control measures by mining protective coal seams or regional CBM pre-drainage. CBM drainage is the most efficient method to control the gas hazards of high-gas-content coal seams (Gentzis et al., 2009; Li et al., 2015; Liu et al., 2015a, 2015b). The quantity of CBM drainage in China was 17 billion m^3 in 2014, which consisted of 13.3 billion m^3 of CBM drainage from underground coal mines. Therefore, underground coal mine drainage remains the primary method for CBM drainage. The gas pressure and content can be reduced by constructing numerous CBM drainage boreholes in each coal seam, which can decrease the possibility of gas disasters and facilitate the clean utilisation of CBM (Liu et al., 2014a; Ni et al., 2014). However, coal seams with a high gas content in China are very deep and subject to high ground stresses. In addition to the influence of mining, instability failure is more likely to occur in boreholes under repeated disturbance from external stress. In such a case, the collapsed coal blocks the normal gas-flow channel, which hinders CBM drainage and causes low concentration low gas concentration and flow, poor extraction result, *etc*. Thus, borehole stability is considered a key factor that influences gas extraction. If a borehole collapse is serious, the service life of the boreholes for gas drainage decreases and gas pre-drainage in the seam fails to meet production requirements. In addition, eliminating accidents, such as coal and gas outbursts, is difficult due to existing blind zones in gas drainage systems. Borehole instability restricts the effectiveness of gas management measures in coalmines and significantly affects the production and cost of gas.

The working face $F_{15\text{-}13031}$ of the No. 13 Coal Mine in Pingdingshan, China, was examined. In this mine, the gas concentration decayed to 13% from 75% in 10 days during CBM drainage. Moreover, the average gas extraction flow of each borehole fell from 0.23 m^3/min to 0.07 m^3/min. During the late mining stage, the gas concentration at the working face exceeded the limiting gas concentration. These data suggest that the drainage effect failed to satisfy the requirements of safe and efficient production. A borehole observation instrument was employed to observe instability-induced deformation in boreholes. This monitoring indicated that borehole shrinkage or collapse occurred in areas with borehole depths ranging from 13 m to 35 m (see Fig. 1).

Extensive research has attempted to maintain the stability of a borehole and improve its gas extraction efficiency, including studies of factors that influence borehole stability (Ghajari et al., 2013; Lavrov et al., 2014) and studies of instability mechanism (Papamichos, 2010; Taheri et al., 2014) and studies of preventive measures (Gaede et al., 2013; Ozkan et al., 2015; Yan et al., 2013; Zohreh et al., 2014). Yao et al. (2010) and Han et al. (2014) indicated that the borehole stability is mainly influenced by the following: the extent of softening and mechanical strength of the coal, the gas pressure, ground stresses, and the lateral pressure coefficient, among others. Based on these borehole instability mechanisms, Haimson (2007) investigated failure modes using a scanning electron microscope and analysed the micro-mechanisms underlying borehole instability. Incipient failure in the form of dilatant micro-cracking in the zones of the highest compressive stress concentration around the borehole was identified as the common failure mode. Zhai et al. (2012) analysed the borehole instability mechanism in a soft outburst coal seam and proposed that the stress in the rock surrounding the roadway and the secondary stress around the borehole are primarily responsible for the instability and failure of boreholes in soft coal. On this basis, a regional curing, pore-forming method was proposed. To prevent borehole instability, Zhao et al. (2009) experimentally investigated the critical conditions for borehole deformation instability of granite under high-temperature and high-pressure conditions. Their findings guide borehole stability and maintenance measures under high temperatures and high pressures. Based on many field and experimental simulations, Qu et al. (2011) found that borehole stability is subject to a time delay effect in cleat-rich coal seams and deduced the formula for the stabilisation time of a borehole wall under a certain stress. Liu et al. (2014a) showed that borehole stability can be maintained by installing a liner in the borehole. The advantages and disadvantages of PE and PP liners were tested and compared to guide the selection of the density and diameter of these meshes. Xue et al. (2015) proposed an assembly of various casing pipes in boreholes to improve stability. Moreover, a monitoring trial was carried out to investigate the effect of borehole configuration on the stability and gas production rate at the Zhuji coal mine in China. These studies are significant to the control of borehole instability as well in the improvement of gas drainage effects. Although borehole stability and gas drainage have been extensively studied by traditional means, few studies have examined borehole instability mechanisms and the deformation characteristics of boreholes in soft coal seams under the influence of mining activity. In addition, methods to resist external stress-induced disturbances also warrant exploration.

Therefore, the borehole instability mechanism and failure of the No. 13 Coal Mine in Pingdingshan, China, were analysed. Given that a roadway needs support, a method relying on active support in boreholes was proposed to control borehole instability deformation. The instability characteristics and acoustic emission (AE properties) of a supported and unsupported borehole were then experimentally investigated. Based on the experimental results and the existing sealing materials and devices in use at the No. 13 Coal Mine in Pingdingshan, a method based on combining the curing of the borehole outlet with active support in the borehole was proposed to control borehole instability. The price of the ordinary polyvinyl chloride (PVC) screen pipe is about 0.5 dollar/m in China. Although this approach increases a little unit cost of borehole

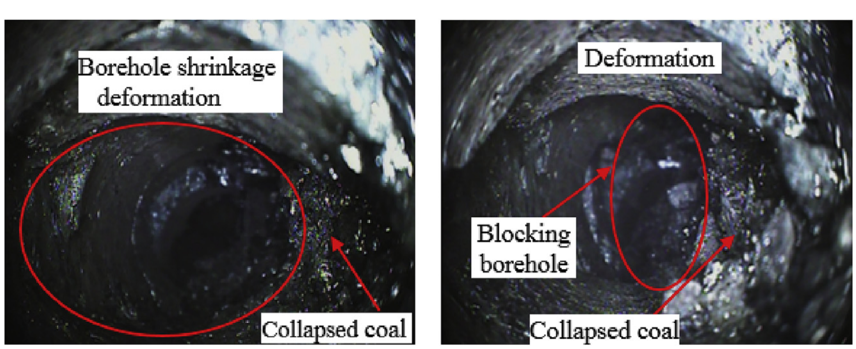

Fig. 1. Borehole deformation, or failure condition, as recorded by a borehole observation rig.