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A new technology for the drilling of long boreholes for gas drainage in a soft coal seam

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ABSTRACT

The geostatic stress, coal mine gas and disturbances produced by external loading can undermine the stability of a borehole and cause the borehole to collapse in a soft coal seam, which results in a poor efficiency of drilling long boreholes and draining gas in a soft coal seam. To improve the efficiency of drilling boreholes and draining gas in a soft coal seam, we propose a drilling technology of protecting the borehole by spraying foam concrete slurry onto the surface of borehole wall during drilling in a soft coal seam. To realize this process, we propose spraying foam concrete onto the borehole wall during drilling with a foldable drill bit and double drill pipes. Based on this new technology, the equipment and the material required for drilling long boreholes in a soft coal seam were studied. Finally, this new technology was tested in the Zhaozhuang mines in the Shanxi Province of China. The test results indicate the following: the process of spraying foam concrete on the borehole wall can relieve borehole collapse; the plant-based foam concrete has good air permeability, and has no effect on the permeability of the borehole wall; and the novel process of drilling boreholes and spraying foam concrete is an effective drilling process, which can relieve borehole collapse, improve the drilling efficiency and improve the draining efficiency.

1. Introduction

Methane is an important greenhouse gas that constitutes 17% of the total anthropogenic greenhouse gas emissions (Su et al., 2005). Underground coal mines are a source of methane (Karakurt et al., 2011), and the methane emission from coal mining mainly results from the exploitation of underground mines (Karacan et al., 2011). Fugitive methane, which is emitted from coal mines worldwide, represents approximately 8% of the world's anthropogenic methane emission (Karakurt et al., 2012). Studies on methane emission from different periods indicate that by 2020, methane emission from coal mining is expected to reach 793 Mt (CO_2 equivalent) (Denman et al., 2007) and to account for 8.9–12.8% of the anthropogenic sources of methane emission (Li, 2014a).

With the increase in the mining depth of coal resources and the growth of coal production in China, controlling coal mine gas disasters as well as reducing methane emission from coal mining are becoming increasingly difficult. The total coal mine methane emission in China was estimated as 135.7 Mt (CO_2 equivalent) in 2005, equivalent to 41.1% of the worldwide emissions (Li, 2014a). According to official statistics, 17 accidents related to coal mine gas occurred in coal mines in China in 2014, leading to the deaths of 117 people.

There are many methods to prevent coal mine gas disasters and reduce coal mine methane emission, such as reducing the pressure of the mining seams and increasing the permeability of the mining seams using high-pressure hydraulic jets, drilling boreholes for gas drainage, infusing water and extracting protective coal seams (Tian and Zheng, 2011; Lu et al., 2009; Díaz Aguado and González Nicieza, 2007). Among these methods, protective coal seams and gas pre-extraction are the two primary gas-disaster-preventive technologies used in China (Fang et al., 2009). However, protective coal seams are very rare in most mines, thus leaving gas pre-extraction as the only solution for preventing gas disasters (Lu et al., 2010). The most important issue to be resolved for the pre-extraction of gas in a soft seam is finding a method to increase the gas extraction area and the gas extraction rate of a single borehole. There are many ways to increase the gas extraction area and gas extraction rate of a single borehole, such as hydraulic jet cutting and hydraulic jet reaming (Shen et al., 2015; Li, 2014b, 2014c). Another problem is the identification of methods for drilling long boreholes in the soft seam. Chinese mines, especially in the western parts of

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China, are faced with boreholes that can only reach a maximum length of 50–60 m. The coal seams in those mines are soft and have a high gas content. The boreholes therefore suffer from instability problems, stuck pipes and extra borehole cleaning requirements. The two primary factors that lead to hole collapse in soft coal seam are the geostatic stress and disturbances produced by external loading. During drilling in a soft coal seam, the geostatic stress, the coal mine gas, the drill bit and the water or compressed air (which is used to discharge coal slag) would undermine the stability of the borehole and cause the borehole to collapse. When drilling a hole in the soft seam and discharging coal slag by water, the particles of the coal's free surface will be moistened. Such moistening weakens the connection among these coal particles, leading to intense degradation of the mechanical properties. McLellan (Mclellan and Hawkes, 2002) presented a theory that indicates that borehole instability is usually related to the combination of controllable and uncontrollable factors. The fallen coal fragments pile up in the hole and prevent the hole from being drilled any further (Bradley, 1979; Rea et al., 2003).

There are two main problems for underground gas drainage by long boreholes in the soft seam. One problem is that drilling long boreholes in the soft seam is difficult, and the other problem is that the protection of the long borehole in the soft seam is difficult. The long boreholes in the soft seam usually collapse in the section of stress concentration and block the passage of gas drainage in a very short time (Haimson, 2007; Whittles et al., 2007). Borehole liners are usually used to protect the borehole in a soft coal seam for gas drainage (Liu et al., 2014). Because a long borehole in a soft coal seam usually collapses before it is completed, inserting borehole liners is difficult after drilling. As a result, the borehole liners are usually inserted during drilling using specialized equipment. There are two main problems with using borehole liners to protect the borehole. One problem is that a large number of borehole liners are consumed and their cost is high. The other problem is that the process is more complex, and sometimes the process of inserting all of the borehole liners cannot be completed; as a result, the liner cannot prevent the borehole from collapsing during drilling. To solve these problems, research is required into the development of new technologies of drilling long boreholes for gas drainage in a soft coal seam.

2. New technology for drilling a long borehole in a soft coal seam

2.1. Introduction to the new technology

To improve the efficiency of drilling boreholes and draining gas in a soft coal seam, we propose a drilling technology of protecting the borehole by spraying concrete slurry onto the surface of the borehole wall during drilling in a soft coal seam. To realize this process, we propose drilling with a foldable drill bit and double drill pipes and discharging the coal slag using compressed air or water. We spray the concrete slurry using the double drill pipes and the nozzles installed in the foldable drill bit during drilling in a soft coal seam. The double drill pipe is made of two steel pipes with different diameters, and the steel pipe with the small diameter is fixed in the steel pipe with the large diameter by a supporting sheet steel. The channel between the two steel pipes with different diameters is used to supply compressed air, and the channel in the steel pipe with the small diameter is used to supply concrete slurry.

During drilling in a soft coal seam, we reinforce the borehole wall by spraying concrete slurry onto the surface of the borehole. To shorten the clotting time of the concrete and increase the permeability of the concrete, we add the accelerator and the plant-based cement foam to the concrete slurry. After finishing drilling, a concrete layer remains on the surface of the borehole. The concrete layer has good mechanical strength, high permeability and low cost; as a result, this technology is able to improve the efficiency of drilling long boreholes and draining gas in a soft coal seam. To prevent the concrete slurry from solidifying in the foldable drill bit and double drill pipes, we syringe the drill pipes with water soon after finishing the drilling. Finally, we fold the drill bit and withdraw the drill pipes and drill bit from the borehole.

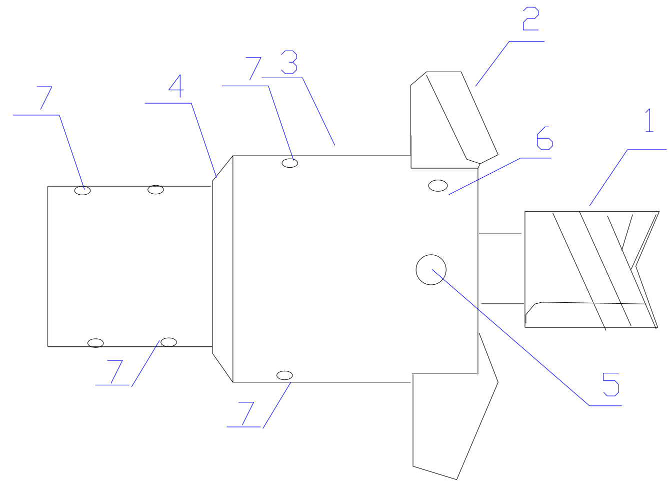

Fig. 1. Foldable drill bit.

2.2. Equipment for the technology

2.2.1. Drill bit

The drill bit used in the proposed technology is foldable. The structure of the drill bit is shown in Fig. 1. In figure, 1 is the small drill bit, 2 is the drilling teeth for the expanding borehole, 3 is the body of the drill bit, 4 is the connector, 5 is the axis of the drilling teeth, 6 is the hole for supplying compressed air, and 7 is the nozzle for spraying concrete slurry. The drilling teeth for the expanding borehole can rotate around the axis. When we withdraw the drill bit from the borehole, the drilling teeth are folded by the resistance from the borehole wall.

2.2.2. Drill pipes

Two drill pipes are used in the proposed technology. The outer drill pipes are made of thicker steel pipes, and the internal drill pipes are made of thinner steel pipes. The outer drill pipes and the internal drill pipes are connected and fixed by a welded steel support. The structure of the drill pipe is shown as Fig. 2, where 8 is the outer drill pipe, 9 is the internal drill pipe, 10 is the welding steel support, and 11 is the connector.

2.2.3. System for the technology

The system for the technology consists of the foldable drill bit and the double drill pipes described above, a rotary sealing joint, tubes for supplying compressed air and concrete slurry, an air compressor, an injection pump and a rig. The air compressor and injection pump are connected with the double drill pipes by the

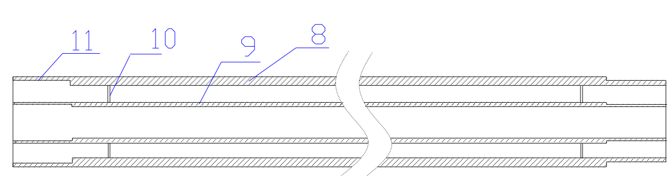

Fig. 2. Structure of the drill pipe.