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Three-dimensional experimental study of loose top-coal drawing law for longwall top-coal caving mining technology

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A B S T R A C T

Based on the loose medium flow field theory, the loose top-coal drawing law of longwall top-coal caving (LTCC) mining technology is studied by using self-developed three-dimensional (3D) test device. The loose top-coal drawing test with shields and the controlled test without shields are performed in the condition without any boundary effect. Test results show that shields will cause reduction in drawing volume of coal in the LTCC mining. The deflection phenomenon of drawing body is also observed in the controlled test, which is verified that the deflection of drawing body is caused by shield. It is found that the deflection angle decreases with increasing caving height, with the maximum value of α_{tail} and the minimum value of 0. In addition, the formula to calculate the drawing volume is proposed subsequently. The deflection of drawing body is numerically simulated using particle flow code PFC^{3D} and the proposed formula to calculate drawing volume in LTCC is also verified.

1. Introduction

Longwall top-coal caving (LTCC) mining technology is a productive and economical method to extract thick coal seams, and thus is widely used in many coal mines in China (Wang, 2009; Wang et al., 2014). Although some hypotheses on top-coal drawing process were proposed (e.g. Wang and Fu, 2002; Wang et al., 2004, 2010, 2014; Unver and Yasitli, 2006; Vakili and Hebblewhite, 2010; Karekal et al., 2011), the top-coal drawing law still remains unclear in the process of top-coal drawing, which is one of the limitations of improving the recovery ratio of the top-coal. The loose medium flow field theory is one of the most important hypotheses in terms of the slope shield tail beam and the shield periodic step advance. However, the shield and the advance make the drawing process of top-coal and metal ore very different (Wang and Fu, 2002). Many researchers analyzed the effects of the shield of top-coal caving technology. Wu and Zhang (2001) proposed a new concept of the relation between shield and surrounding rock in the LTCC faces. Nan et al. (2002) analyzed the effect of the parameters of top-coal caving shield on the recovery ratio. Yan et al. (2002) proposed a method to determine the shield capacity using the LTCC mining technology. However, most studies did not consider the combining effect of the shield and spatial shape of drawing body. Moreover, some tests on the LTCC technology were merely concentrated on two-dimensional (2D) cases (Jiang, 1990; Bai et al., 2001; Wang and Fu, 2002; Zhai, 2002; Wang et al., 2004). Unfortunately, the 2D simulation cannot truly reflect the movement law of loose top-coal and fragmented rock along the coal seam dip direction. Thus we cannot understand the three-dimensional (3D) drawing law of loose top-coal in longwall caving mining method only from 2D simulation.

In this study, based on the loose medium flow field theory, we conduct the loose top-coal drawing test with shields and controlled test without shields by using self-developed 3D test device for the LTCC mining. As for the controlled test, the effects of other factors during the test are ignored but the effect of shields on the loose top-coal drawing law in top-coal caving is analyzed. Meanwhile, the PFC^{3D} models are established to verify the results obtained from 3D physical model test.

2. Loose medium flow field theory

During the process of coal face advancing of the LTCC panel, the top-coal and immediate roof above the shields are basically broken and can then be regarded as loose media. Thus the caving top-coal moving and drawing process complies with the law of loose medium flow. As shown in Fig. 1, the drawing opening of the shield is the free boundary for the loose media composed of loose coal and

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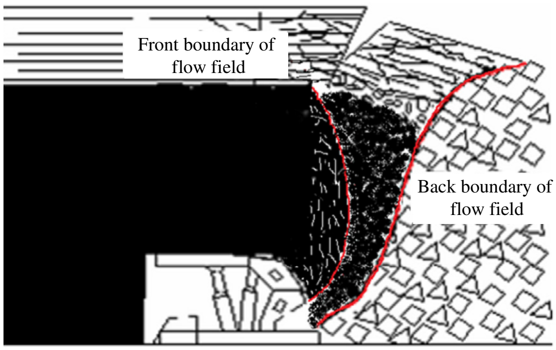

Fig. 1. Theoretical model of loose medium flow field.

loose immediate roof. The interaction forces between particles of the loose media can be released in the opening. The loose media above and behind the shield will move towards the drawing opening along the path of minimum resistance, and a motion field which is similar to traction flow will be formed in the loose media. Such moving and drawing process of top-coal is called as the loose medium flow field model (Wang and Fu, 2002; Wang et al., 2004, 2010, 2013, 2014).

3. 3D similar simulation tests on loose media

3.1. Test device

The physical model tests are conducted using self-developed 3D test device in top-coal caving laboratory at China University of Mining and Technology (Beijing) (CUMTB). Fig. 2 shows the test device with dimensions of 1000 mm × 500 mm × 600 mm.

3.2. Materials

The geometrical ratio of the shield prototype to physical model is 20:1, and the height of caving shield (Fig. 2b) is 100 mm. The materials used in this study are shown in Fig. 3. Loose coal is simulated by black granite particles, with diameter of 5–10 mm, friction angle of 36.1°, and density of 1712 kg/m^3. The loose immediate roof is simulated by white marble particles with diameter of 10–20 mm, friction angle of 37.7°, and density of 1782 kg/m^3. The thicknesses of loose coal and immediate roof in the test are 300 mm and 200 mm, respectively.

3.3. Layout of marked particles and test schemes

The particles are marked to analyze the flowing characteristics of loose media and locate the spatial shape of drawing body. In order to keep the same flowing characteristics as the materials used, the marked particles are selected from the materials used with diameter of 5–10 mm. The different ID number on each marked particle is given to represent its coordinate (Wang et al., 2003; Tao et al., 2009). The marked particles are located every 30 mm in height direction along 4 planes (X, Y, $X+45°$ and $X-45°$) during the process of filling materials in the test box, as shown in Fig. 4.

As for the controlled test, two schemes are designed as models 1 and 2. Model 1 is the loose top-coal drawing test with shields, and the test box with shields is shown in Fig. 5a. Model 2 is the controlled test without shields, as shown in Fig. 5b. Each model test is done for three times to reduce the influence of test error.

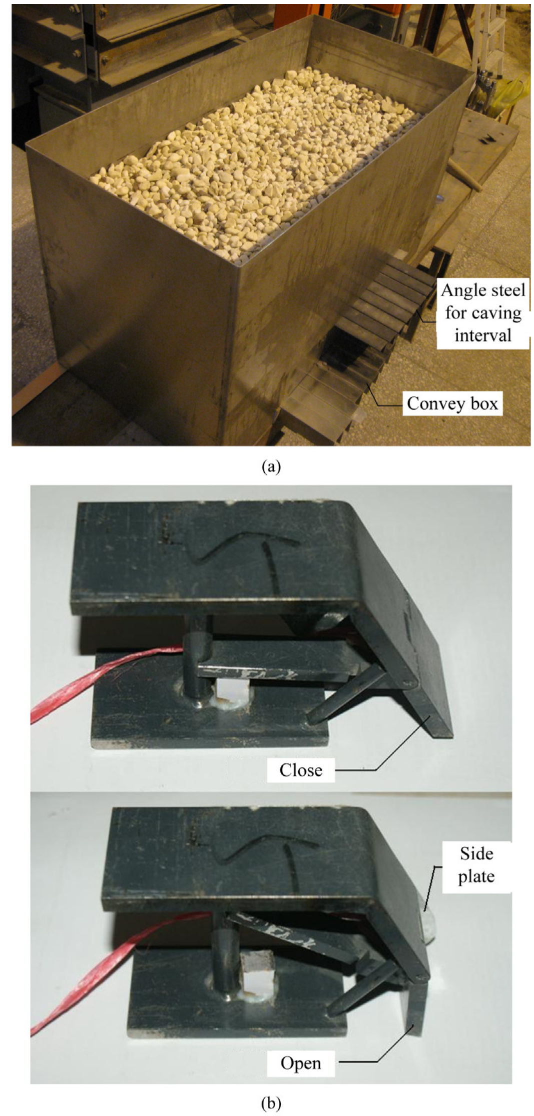

Fig. 2. The 3D test device: (a) overall diagram of test device; (b) caving shield.

4. Test results and analysis

The 3D similar simulation tests can represent the top-coal drawing process. After comparing and analyzing the results of two physical models, the key point is to study the impacts of shields on the drawing volume (i.e. the volume of drawing body) and the developing process of the drawing body.

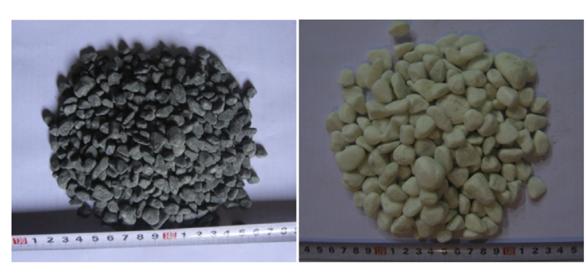

Fig. 3. Materials used for physical model tests: (a) loose coal; (b) loose immediate roof.