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A new research system for caving mechanism analysis and its application to sublevel top-coal caving mining

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ABSTRACT

The study of top-coal drawing characteristics is key to improving the top-coal recovery ratio and to reducing the waste of coal resources in longwall top-coal caving (LTCC) mining. This paper introduces a Boundary-Body-Ratio (BBR) based research system established by the authors following a long-term detailed study of the top-coal drawing mechanism. For BBR system, a simplified parabolic model is proposed to describe the development process of the boundary of top-coal in normal top-coal drawing cycles, where the drawing body is a cut variant ellipsoid (CVE) that can be described by the modified Bergmark-Ross model. A method for improving the recovery ratio and reducing the rock mixed ratio of top-coal by selecting reasonable drawing technique parameters and controlling the shape of the boundary of the top-coal is given for the BBR system. Based on the BBR research system, the drawing mechanism for loose top-coal in sublevel top-coal caving (SLTCC) in steeply inclined coal seams is studied for different sublevel heights and drawing direction conditions using distinct element numerical calculations and loose top-coal drawing experiments. The results show that the boundary curve of top-coal can be fitted by a parabola and that the drawing body remains as a cut variation ellipsoid in SLTCC, as is the case for a flat coal seam. The convex point of the boundary of the top-coal moves toward the goaf with increasing sublevel height, which would result in the incomplete development of the top-coal drawing body. The drawing extent index decreases linearly with increasing sublevel height, and the top-coal recovery ratio decreases after an initial increasing phase. Approximately 90% of the residual coal in the current sublevel will not be extracted during the drawing process of the next sublevel. Drawing from the floor to the roof expands the overlap area between the drawing body and the boundary of the top-coal, improving the recovery of the top part of the top-coal. Such a drawing sequence decreases the coal loss near the floor by 38.2% compared to drawing from the roof to the floor and greatly increases the resource recovery ratio.

1. Introduction

China's first longwall top-coal caving (LTCC) mining panel face was installed in the Puhe coal mine in Shenyang in June 1984.[1] As a result of its low roadway excavating ratio, good adaptability to variations in seam thickness and high productivity, LTCC is rapidly finding expanded use for extracting thick coal seams in China.[2,3] Over the course of its long-term use in practice, a series of significant achievements such as LTCC with a large cutting height, LTCC in large dip angle seams and sublevel top-coal caving (SLTCC) in steeply inclined ultra-thick seams have been made as a result of new innovations.[4] However, the low-level recovery ratio of top-coal represents one of the major problems encountered during the application of LTCC. The unpredictable flowing and moving path of loose top-coal in such thick seams makes it very difficult to control the drawing process by miners. This leads to a top-coal recovery ratio of approximately 65–75% in certain ultra-thick coal seams, resulting in a huge waste of coal resources. Because LTCC will continue to be the one of the major methods for extracting thick coal seams in China in the future, the flow and drawing characteristics of loose top-coal in LTCC should be thoroughly studied to optimize the drawing technique and improve the recovery ratio of top-coal.

Loose top-coal drawing characteristic research focuses on the flow characteristics of loose top-coal during the drawing process. The research object is limited to loose top-coal, which can be regarded as flowable loose media. This loose top-coal flows out through the opening in the tail canopy of the shield supported by

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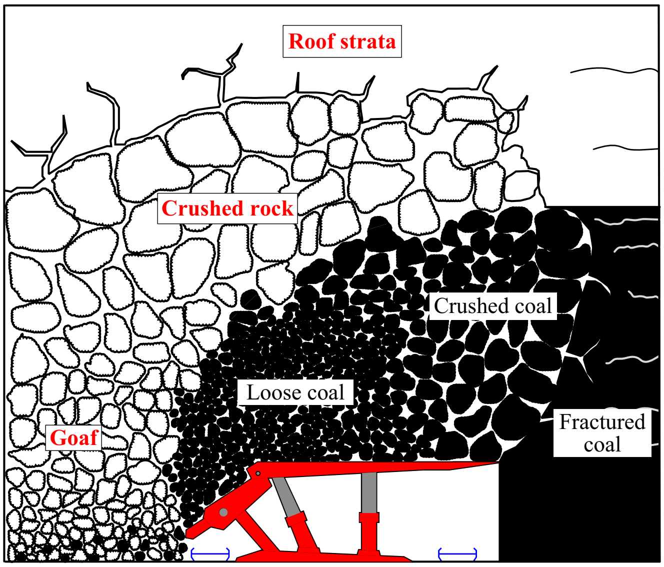

Fig. 1. The conceptual model of top-coal fracturing and drawing in LTCC.

gravity (see Fig. 1). Although some block of coals may randomly roll and slide, the flow of a substantial amount of loose top-coal remains continuous from a macro point of view. Therefore, the drawing law of top-coal can be studied using the distinct element method.

In China, research on top-coal drawing characteristics began in the 1990s. Concerning theoretical research, the concept of the top-coal drawing ellipsoid was proposed based on ellipsoid theory from metal mining.[5] The drawing body formed during the drawing process was modeled as an ellipsoid whose major axis equals the height of the drawing body. In addition, the drawing body is surrounded by a loose ellipsoid, in which the loose top-coal becomes increasingly loose.

In early laboratory studies, the loose material experimental method was borrowed from the study of metal mining, and various researchers conducted 2D loose material experiments without shield supports to simulate the top-coal drawing process.[6,7] Prof. Wang found that the shield plays a very important role in the drawing process of top-coal. His group has developed several types of experimental shields with heights of 100–200 mm since 2000,[8,9] with which loose top-coal drawing experiments with shields were conducted for the first time, and the effects of the shield presence and shield motion on the drawing characteristics were studied. The loose medium flow field theory was proposed based on a large number of experiments,[9,10] and a 3D simulation and testing device for loose top-coal drawing was developed.[11] Additionally, the top-coal tracking device was developed and used in field observations of top-coal recovery ratios in many LTCC panels in China [12–14].

Concerning numerical simulations, the Distinct Element Method (DEM) represents the main method used to study the flow and movement of loose top-coal. The Particle Flow Code in 2 Dimensions (PFC^{2D}) was employed in numerical simulations in early studies.[2,15–18] 3D numerical simulations of the top-coal drawing process were fist conducted using PFC^{3D}, and the spatial shape of the drawing body was obtained by Wang et al. [19].

Most early studies focused on the drawing body and the top-coal recovery ratio, whereas the boundary of top-coal was ignored due to limitations of the experimental and numerical methods. However, the shape of the drawing body is controlled by the boundary of the top-coal, which is the boundary condition for the development of the drawing body. Simultaneously, the shape of the boundary of the top-coal is also influenced by the development of the drawing body. In addition, the value of the recovery ratio and the rock mixed ratio of top-coal represent the external behaviors of the interaction between the drawing body and the boundary of the top-coal. Therefore, the top-coal drawing characteristics cannot be fully understood through an independent study of simply one or two factors unless these four factors are studied together. The BBR research system was established based on these considerations [20].

In this paper, the BBR research system for top-coal drawing characteristics in LTCC mining is introduced, and the interrelationship between each factor in the system is described in detail. Based on the BBR system, the top-coal drawing characteristics of sublevel top-coal caving mining in steeply inclined thick coal seams are analyzed in depth, and reasonable sublevel heights and drawing techniques are suggested to improve the resource recovery ratio.

2. BBR research system

The BBR system focuses on the four factors and their interrelationships to obtain a deeper understanding of the loose top-coal drawing mechanisms. The first "B" represents the boundary of the top-coal (the boundary between the coal and rock), the second "B" represents the drawing body of the top-coal (the spatial zone composed of the top-coal blocks drawn out in the initial position prior to the current drawing procedure), and "R" represents the recovery ratio and rock mixed ratio of the top-coal. This system was recently proposed by Prof. Wang Jiachen based on loose medium flow field theory.[20] Fig. 2a shows the meaning of each factor of the BBR research system.

The basic concept of the BBR research system is that by analyzing the shape of the boundary of top-coal and the development process of the top-coal drawing body, we find ways to improve the recovery ratio and reduce the rock mixed ratio of top-coal. Fig. 2b shows the relationships among the four factors of the BBR system.

In the BBR system, the boundary of the top-coal is visible and constantly changing during the top-coal drawing process, whereas the drawing body of the top-coal is invisible and obtained using a reverse analysis following the drawing process. On the one hand, the shape of the drawing body is controlled by the boundary of the top-coal. On the other hand, the shape of the boundary of the top-coal is also influenced by the development of the drawing body (see Fig. 2b). These two factors represent internal factors of the BBR system, and their interaction determines the recovery ratio and rock mixed ratio of top-coal, which represent the external behaviors of the BBR system. Reducing the waste of coal resources

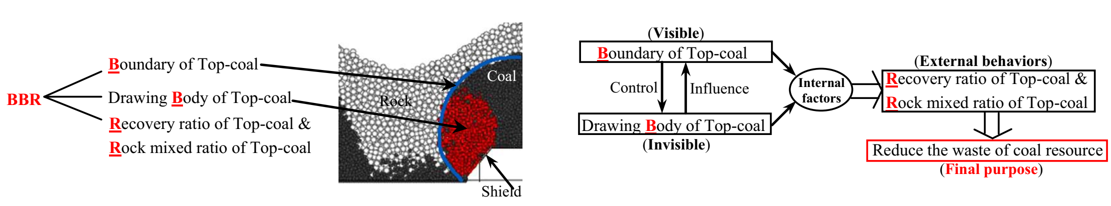

Fig. 2. The BBR research system (a) The meaning of each factor; (b) Relationships among four factors of the BBR system.