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Arch structure effect of the coal gangue flow of the fully mechanized caving in special thick coal seam and its impact on the loss of top coal

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ABSTRACT

Based on the characteristics of the top coal thickness of the fully mechanized caving in special thick coal seam, the long distance of coal gangue caving, as well as the different sizes of the coal gangue broken fragment dimension and spatial variation of drop flow, this paper uses laboratory dispersion simulation experiment and theoretical analysis to study the arch structure effect and its influence rule on the top coal loss in the process of coal gangue flow. Research shows that in the process of coal gangue flow, arch structure can be formed in three types: the lower arch structure, middle arch structure, and upper arch structure. Moreover, the arch structure has the characteristics of dynamic random arch, the formation probability of dynamic random arch with different layers is not the same, dynamic random arch caused the reduction of the top coal fluency; analyzing the dynamic random arch formation mechanism, influencing factors, and the conditions of instability; the formation probability of the lower arch structure is the highest, the whole coal arch and the coal gangue arch structure has the greatest impact on top coal loss. Therefore, to prevent or reduce the formation of lower whole coal arch structure, the lower coal gangue arch structure and the middle whole coal arch structure is the key to reduce the top coal loss. The research conclusion provides theoretical basis for the further improvement of the top coal recovery rate of the fully mechanized caving in extra thick coal seam.

1. Introduction

Coal is the main energy source in China [1] and thick coal seam reserves account for about 45% of the total reserves. Fully mechanized caving technology is an effective way for mining thick and extra thick coal seam [2–6]. The improvement of the top coal drawing ratio is one of the key difficulties in the fully mechanized caving mining technology [7,8]. The technology of top coal loss in the fully mechanized caving face accounts for 1/2–2/3 of the total loss, and it shows a trend of increase. Therefore, a solution to the technology loss problem is crucial to improvements in the recovery rate of the fully mechanized caving face. The technology loss is mainly caused by the unreasonable coal caving technology mode and parameter. The top coal is the basis for the determination of the coal caving technology parameter and mode. Top coal caving law is the result of many factors. These factors include top coal thickness, the broken fragment size of the immediate roof, the collapsing characteristics of the immediate roof and the support type. The formation and instability of the arch structure in the coal gangue caving flow field is a unique phenomenon [9] which can affect the recovery of top coal and coal quality. With the increase of the thickness of top coal, the range of the top coal and gangue caving flow increases, both the broken fragment dimension of coal gangue and caving flow space changes. This enlarges the probability of the mixing process of top coal and gangue as well as the top coal arching [10], especially under the condition of fully mechanized caving in the special thick coal seam (14–20 m). In order to further improve the recovery rate of top coal and reasonably determine the caving technology parameter, it is necessary to understand the formation characteristics of the arch structure in the coal caving flow process and its influence on coal gangue flow pattern, fluency, and top coal recovery under this condition. Therefore, this paper uses a granular physical simulation experiment to study the arching characteristics of coal gangue in the process of fully mechanized caving in extra thick coal seam and top coal caving and its influence on top coal loss, in order to provide a basis for the reasonable determination of the coal caving technology parameter and the formulation of the technical measures to improve the recovery rate of top coal.

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2. Granular simulation experiment project

According to the similarity theory, under the geological conditions of the No. 8105 coal mining face in the Tashan mine, a granular simulation experiment method was used to study the top coal fragment distribution of the fully mechanized caving in extra thick coal seam with large mining height. The granular simulation experiment method was also used to study the structure effect of coal gangue flow field and its influence on top coal loss law.

The average thickness of the coal seam of the Tashan mine No. 8105 working face is 14.50 m, the mining height is 4.20 m, caving height is 10.30 m, mining and caving ratio is about 1:2.45. The immediate roof is the alternate occurrence layer consisting of magmatic rocks, mudstone and silicified coal with the average height 4.49 m. The basic roof consists of siltstone, fine sandstone, and muddy-conglomeratic sandstone with an average height of 22.93 m. Average dip angle of the coal seam is 4°, the coal mining cycle progress is 0.80 m, and the top coal drawing interval is 0.80 m per cut [11,12].

Theoretical analysis and field tests [13] show that the order of top coal along the thickness direction of the broken fragment dimension is: the lower top coal fragment dimension < middle top coal fragment dimension < upper top coal fragment dimension. According to the results of the field-observed broken coal gangue fragment dimension, the top coal is divided into three layers: upper top coal, middle top coal and lower top coal. The immediate roof is divided into lower immediate roof, middle immediate roof, and upper immediate roof [14]. An experiment was conducted to analyze the caving of top coal flow and the arching law. Different colors and sizes of stones were used to replace all layers of coal, with the addition of clay to simulate smaller particles of coal and rock powder. The testing program is shown in Table 1.

The coal gangue caving mixed experiment model table adopted in the experiment mainly includes a control system, a simple self-moving hydraulic support, a mobile system, and framework. It is 300 cm long, 15 cm wide, and 220 cm tall. The advancing support and coal caving can be automatically carried out by setting the relevant parameters, as shown in Fig. 1. The model bracket height is 40 cm and the field machine mining height is 4.20 cm. Therefore, the geometric similarity ratio of the model and the prototype is $C = 40/420 = 1:10.5$. The thickness of top coal is 10.30 m and the corresponding thickness of top coal in the model is 0.98 m. At the boundary, the simulated coal pillar is 6.50 cm and the open-off cut is 6.00 m.

3. Arch characteristics and types of top coal caving in extra thick coal seam

Through the observation on the coal gangue flow law of the fully mechanized caving in extra thick coal seam during the experiment process, we can see that arching is an important factor that affects the top coal caving in the process of top coal flowing. According to the arching area [15,16], in the caving process of the working surface, the arch structure formed by top coal is divided into three types: the lower arch structure, the middle arch structure, and the upper arch structure. The specific distribution area is shown in Fig. 2.

(1) Lower arch structure: the arch structure is located near the drawing opening, it has the smaller span and high stability, and it is easy to be formed. This is because the space near the drawing opening is the smallest and the large coal mass or coal rock mass is easy to be squeezed by each other to form hinged arch. The lower arch structure contains coal arch and coal gangue arch. The arching material of the coal arch is coal, as shown in Fig. 3a. The arching material of the coal gangue arch is a mixture of coal and gangue, as shown in Fig. 3b.
(2) Middle arch structure: the middle arch structure is located between the caving shield and the top beam. The arch structure can be divided into coal gangue arch structure and pure coal arch structure (Fig. 4).
(3) Upper arch structure: the arch structure is located at the top coal above the support top beam. It is less formed, it has a large span, can form a coal arch, and a coal gangue arch. The stability of the arch structure is lower, the front arch angle is generally located on the top beam of support, the rear arch angle is located on the gangue in goaf, and, therefore, the impact of the swing of support tail beam is small (Fig. 5).

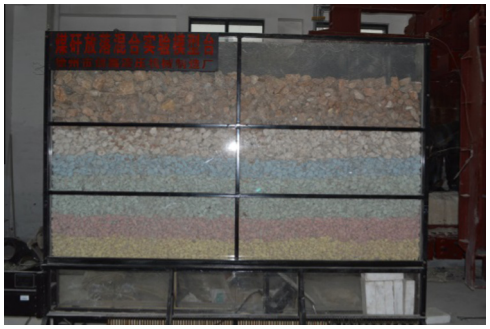

Fig. 1. Combined experiment of fully mechanized coal gangue caving.

Table 1
Similar simulation scheme (mm).

Layer position	Parameter	
	Thickness	Fragment dimension
Upper immediate roof	600	90
Middle immediate roof	400	75
Lower immediate roof	300	70
Upper top coal	326	55
Middle top coal	326	45
Lower top coal	326	27

4. Dynamic random arch effect in the process of top coal caving

4.1. Dynamic random arch characteristics in the process of top coal caving

In the top coal caving process, the flow field fracture surface contracts with the decline of the height. The shrinkage of the fracture surface provides horizontal extrusion pressure between coal gangue blocks which provides the mechanical condition for the block extrusion into arch. Through the experimental analysis of arching characteristics and types in the top coal caving process, we can conclude that the formation of the arch structure has a

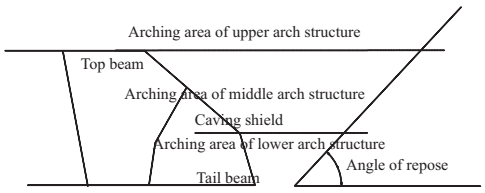

Fig. 2. Three different types of arch structures.