International Journal of Mining Science and Technology 26 (2016) 609–614

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Research into stope roof control of compound roof by solid backfilling mining

Gao Rui [a,b,*], Zhang Jixiong [a,b], Spearing A.J.S. [c], Li Meng [a,b], An Baifu [d], Hao Deyong [a,b]

[a] School of Mines, China University of Mining and Technology, Xuzhou 221116, China
[b] Key Laboratory of Deep Coal Resource Mining, Ministry of Education of China, China University of Mining and Technology, Xuzhou 221116, China
[c] Western Australian School of Mines, Curtin University, Kalgoorlie 6433, Australia
[d] School of Mining and Safety Engineering, Hunan University of Science and Technology, Xiangtan 411201, China

ARTICLE INFO

Article history:
Received 3 December 2015
Received in revised form 5 January 2016
Accepted 14 February 2016
Available online 24 May 2016

Keywords:
Compound roof
Backfilling mining
Stope
Control

ABSTRACT

Based on the analysis of the failure characteristics and backfilling effect of the compound roof at 1801 backfilling workface in Taiyuan coal mine, China, we propose a method of controlling the pre-subsidence of a compound roof by using pre-stressed bolts to improve the backfilling ratio of the workface so as to maintain the global stability of the stope roof. In addition, PHASE simulation software was employed to analyze the influence law of pre-stressing force, length, and interval on roof subsidence at the workface. On the basis of the numerical simulation results, a model for calculating the pre-stressing force and length of the bolts, the interval between the bolts, as well as roof subsidence at the workface, was established by using SPSS regression analysis software. Moreover, the research results were applied successfully to the 1801 filling workface. According to the monitoring data of roof closure, it was found that the final subsidence value for the goaf roof was 350 mm and the filling ratio at the workface was 86%, which could fully meet the demand for safety production at the workface. The safe and effective control of the stope roof was therefore realized, which achieves the goal of safe and efficient backfilling mining under a compound roof.

1. Introduction

Solid backfilling mining is regarded as one of the most effective technical ways to release the coal under buildings, railways and water bodies ("three unders"). The backfilling materials were transported from the surface to the goaf by utilizing a specific backfilling system, equipment and technology. The dense backfill was pre-formed in the goaf to realize control of the roof [1–4]. The final filling ratio at the workface directly reflects the control effect of overlying rock movement at the workface [5–7].

At present, compound roof faces are widely distributed in coal mines. Most of them are constituted by layers of soft coal or rock stratum which is small in thickness and has poor development and intensity of bedding, joints and fractures. This means that the cohesive force between each layer is weak so that the roof face is often accompanied by separation, subsidence and even failure [8–13]. The compound roof at the workface usually causes serious deformation and failure when it is influenced by the mining disturbance of coal mining machines and the interaction of workface support.

As for backfilling mining under a compound roof, due to the inherent vulnerability of the roof, the pre-subsidence before backfilling is great under the influence of mining-induced stress, which is considered as the main factor influencing stope roof control by backfilling mining. Therefore, it is necessary to reinforce the support of the roof in advance to ensure its stability. On the basis of analyzing the failure characteristics of the compound roof at 1801 workface of the Taiyuan mine area, the authors have analyzed the key factors influencing the control of stope roof control of a compound roof by coal waste backfilling mining in combination with the control of roof subsidence by pre-stressed bolts. Hence, the relationship between face roof subsidence and the features of bolting, such as the pre-stressing force, length, and interval was gained. Moreover, the research results were successfully applied in Taiyuan coal mine to provide a theoretical basis for mining safely under these kinds of geological conditions.

2. Engineering conditions

2.1. Engineering general situation

The corresponding ground elevation for the first mining face for solid backfilling mining at Taiyuan coal mine 1801 workface is

* Corresponding author. Tel.: +86 13813464961.
E-mail address: cumtgaorui@163.com (R. Gao).

http://dx.doi.org/10.1016/j.ijmst.2016.05.012
2095-2686/© 2016 Published by Elsevier B.V. on behalf of China University of Mining & Technology.

+1244 m, while the elevation of the working seam is from +715.514 m to +872.715 m. The other parameters are as follows: the length of the workface is 150 m; the advance length is 1230 m; the dip angle of the coal seam is from 3° to 12° and the designed mining height is 2.6 m. There are fold structures within the range of roof along the advanced direction in the middle of the workface. There is also a compound roof with a thickness of 1.6 m above the coal seam in the range of 1090 m from the open-off cut, which accounts for about 75% of the total area of face roof. In view of the restriction of the maximum support height of the backfilling hydraulic support, mining of the compound roof can cause that part of the coal seam at the workface to be unmined, thereby inducing a low mining rate at the workface. Therefore, the compound roof is not exploited during backfilling mining. The mining section of the workface is shown in Fig. 1. In addition, the normal and maximum water inflows during mining are 75 and 115 m^3/h, respectively.

There are special railways going through the overlying surface of the workface, which is one of the first class protected structures. Based on surface subsidence prediction theory and prediction principles for equivalent mining height [14,15], it is concluded that the face filling ratio is 80% by inversion to control the surface subsidence within a safe range in combination with the protective class of the surface railway [7].

2.2. Engineering rock mass characteristics

The compound roof at the workface is divided into 4 layers with a mean thickness of 1.6 m. In addition, the main lithological character is grey mudstone. The immediate roof is made up of fine sandstone and siltstone, while the floor is composed of taupe clay rock and black charcoal mudstone. Fig. 2 presents the specific characteristics of each coal seam and rock stratum.

3. Failure characteristics and reason analysis of face roof

3.1. Failure characteristics of the roof

The mine pressure on the roof was severe during the production process. The overlying compound roof at the workface broke with different degrees of severity. Large-scale roof falls of the compound roof occurred around the folded structural zone in the middle roof above the coal wall of the workface until it completely collapsed, as well as part of the immediate roof. The caving rock bent the front top beam of the hydraulic supports and finally collapsed into the workface. Meanwhile, the back top beam of the hydraulic supports suffered bending deformation due to overloading. The fall of the broken roof rock in the rear goaf of the workface caused an increase in the gap between backfilling compaction and the roof [16] so that it was difficult to contact the roof for backfilling.

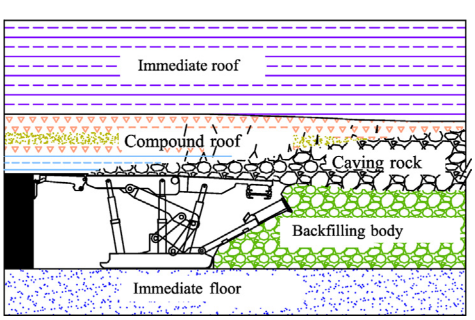

Fig. 1. Mining section of 1801 workface.

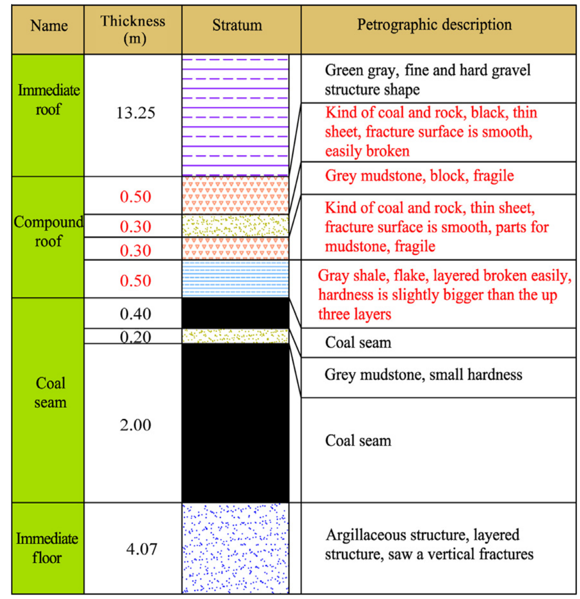

Fig. 2. Borehole histogram of the workface.

3.2. Reasons for severe damage of the compound roof

The self-stability of the compound roof was poor. In addition, the hydraulic supports on the workface interacted with the compound roof due to support stress. With advance of the workface and the mining disturbance by the coal mining machine, the compound roof broke and collapsed ahead of time. The geological conditions on the workface were complex, including the development of fold structures in the middle of the face and high horizontal stress. Also, there were many argillaceous components in the compound roof, which was prone to weathering and separation. Moreover, the roof is apt to expand in contact with water, which finally causes failure. However, water inflow was great during mine production and therefore the self-stability of the compound roof was low, thereby inducing pre-subsidence of the roof.

Falling of the compound roof ahead of time and the bending deformation of the back top beam of the hydraulic supports led to an increasing gap between the backfilling body and the roof and an increase in the distance from the backfilling compaction at the workface to the roof [16], making roof-contact backfilling difficult and thereby reducing the backfilling strength. As a result, the backfilling effect of the workface was influenced. However, the lower the backfilling strength of the face goaf, the more difficult it is to control the stope roof. Furthermore, the instability of the goaf roof resulted in violent movement of the front roof of the workface. These factors therefore created a vicious circle, which meant that it was difficult to effectively control the stability of the stope roof so that the backfilling effect of the workface was greatly influenced. According to the initial production situation of the mine, the actual filling ratio could only achieve up to 70%, which failed to meet the demand of mine safety production.

4. Control mechanism of stope roof by pre-stressed bolts in the compound roof

In order to control the workface roof subsidence to improve the backfilling ratio and maintain the stability of the stope roof, pre-stressed bolts were utilized to control the compound roof. When the compound roof was supported by pre-stressed bolts in advance, the pre-stressing force along the lateral direction produced by a high-strength bolt could effectively increase the hori-