International Journal of Mining Science and Technology 24 (2014) 839–845

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

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

Test and application of hydraulic expansion bolts in a roadway under goaf with ultra-close separation

Wang Xiangyu [a,*], Bai Jianbiao [b], Guo Guanlong [a], Yu Yang [a]

[a] School of Mines, Key Laboratory of Deep Coal Resource Mining, Ministry of Education, China University of Mining & Technology, Xuzhou 221116, China
[b] State Key Laboratory of Coal Resources and Mine Safety, China University of Mining & Technology, Xuzhou 221116, China

ARTICLE INFO

Article history:
Received 11 January 2014
Received in revised form 10 March 2014
Accepted 17 May 2014
Available online 17 November 2014

Keywords:
Hydraulic expansion bolt
Coal seams with ultra-close distance
Anchoring force
Roadway under goaf

ABSTRACT

The roof of a roadway under goaf with ultra-close separation consists of thin rock strata and rocks caving in upper goaf. Influenced by the mining of the upper coal seam, the roof is loose and broken, and its integrity is poor. Resin anchored bolts cannot provide an effective anchoring force in such roof conditions. By conducting free expansion tests and field pull-out tests on a hydraulic expansion bolt, this study has analyzed the influencing factors and laws of radial expansion and anchoring force changes in the rod body. This has revealed the anchoring mechanism of such bolts, and has obtained reasonable water injection pressures and suitable drilling diameters (which are 20–25 MPa and 32–35 mm respectively) for the hydraulic expansion bolt (φ28 mm) used in these tests. Based on pull-out tests at different interlayer spacing, the applicability of hydraulic expansion bolts had been verified for controlling the roof of roadways under goaf with ultra-close distance. Combined with the deformation and failure characteristics of the test roadway roof, this paper proposes a united roof-control technology based on the use of hydraulic expansion bolts and advancing intubation for the roof. Engineering practice indicated that the roof of the test roadway did not generate leaking and caving phenomenon, and the amount of roof deformation was controlled to within 150 mm. Maintenance of the roadway roof has been improved significantly, which ensures safe mining in coal seams with ultra-close separation.

1. Introduction

The complexity and variety of coal seams in our country is rare in the world [1–3]. Coal seams with close proximity are distributed widely in China. Highly-intensive mining causes coal reserves of superior quality to decrease sharply in many mining areas. Thus, mining problems in coal seams in close proximity enter into people's perceptions gradually. Compared with mining a single coal seam, the mining of coal seams in close proximity has particular problems in terms of the characteristics of strata behavior, surrounding rock control and technical support of safety. By numerical calculation, building structural mechanics models of the roof, physical simulation tests, etc, Chinese researchers have studied the optimum location of entry, the distribution laws of roof stress, the characteristics of roof catastrophic collapse, etc when the lower coal seam is excavated [4–8]. Also, the distribution law for the surrounding rock and overburden rock migration has been revealed. Meanwhile, foreign researchers have studied and analyzed, systematically, the mining sequence of coal seams, interaction mechanisms, key influencing factors of stress distribution, entry support design, et al. [9–15]. Existing research results have a positive effect on mining of coal seams in close proximity and the design of surrounding rock control under the condition of large spacing between coal seams. However, for ultra-close separation of coal seams, there is still no systematic understanding on both support principles and support countermeasures for the roof of a roadway under goaf with ultra-close separation. Thus, roadway support models are severely limited. When the thickness of the roof (in the roadway under goaf) is less than the length of an ordinary resin bolt, the anchoring part of the bolt will be located in the caving zone above the roof. As there are a larger number of interspaces in the caving zone, a great deal of resin will be forced into these interspaces, which will reduce the compaction rate of resin between rod body and hole wall, and prevent solid stowing of the anchoring agent. The anchoring force of a bolt is unstable and small, inducing roadway maintenance difficulties and influencing normal replacement between mining and excavation directly. Therefore, it is significant for safe mining of ultra-close multi-seam that seeking a new anchoring type and exploring a surrounding rock control technology suitable for roof of roadway under goaf with ultra-close separation.

* Corresponding author. Tel.: +86 13912042606.
E-mail address: wangxiangyu79@126.com (X. Wang).

http://dx.doi.org/10.1016/j.ijmst.2014.10.017
2095-2686/

2. Profile of testing roadway

The transportation roadway of 101 working face in 3# coal seam, Beiyu coal mine, Puxian Hongyuan Group, Shanxi province, was selected as the test site. The mine mainly exploits 2# and 3# coal seams (3# coal seam is beneath 2# coal seam). The average dip angle of the two coal seams is 3°. The thickness and hardness coefficients of 3# coal seam are 3 m and 1.5–2.5 on average respectively. Adopting a downward mining mode, the mine will exploit 2# coal seam and later exploit 3# coal seam. On the basis of exposure by excavation in 3# coal seam, the spacing between 2# and 3# coal seam is small, only about 1.2–2.0 m. Influenced by the mining of 2# coal seam, the roof of 3# coal seam is loose, broken and has poor integrity. As the roof of the roadway in 3# coal seam basically consists of thin rock strata (coal and shale with low strength and developmental cracks) and rocks in the caving zone of 2# coal seam, effective anchoring force may not be achieved by adopting traditional resin anchored bolts to control the roof. The roof will then cave over a large area. The spatial position of the test roadway is shown in Fig. 1.

In order to verify the support effect of resin anchored bolts in the roof of the test roadway, it was decided to conduct a non-destructive pull-out test on left-handed thread steel bolts (HRB335, φ20 mm, L2000 mm) with anchoring extended by resin anchoring agent. If the pull-out force reaches the design value (80 kN), then the pull-out test is stopped as the anchoring force meets the design requirements. The test data are shown in Table 1. It can be seen from the table that, as the roadway roof consists of thin rock strata and rocks in the caving zone of 2# coal seam, a great deal of resin was squeezed into the interspaces during the bolt installation process, which caused the drawing force of the roof bolt to reach about 30 kN. Meanwhile, interlayer spacing, namely roof thickness, measured by borehole imaging amounted to 1.8–2.0 m which was the thickest interlayer spacing in the test roadway. Anchoring performance at the site was inferior, which showed that the anchoring force of the resin bolt was far less than the design value (80 kN). Therefore, the resin anchored bolt was not suitable for supporting the roof in such conditions.

3. Experimental research on hydraulic expansion bolt

The hydraulic expansion bolt (consisting of pot head, check ring, flooding mouth and tray) is a concave tubular rod made of seamless steel tube [16–17]. The outer diameter of the bolt is larger than the drill diameter. The structure of the bolt is shown in Fig. 2.

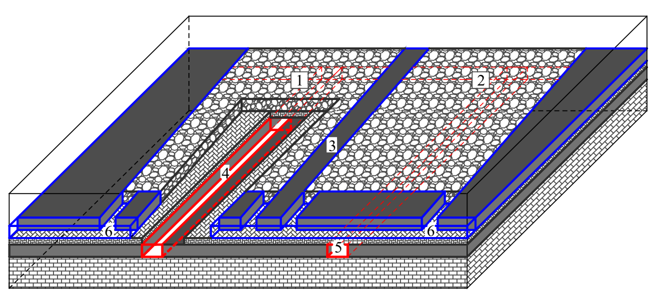
The support mechanism of the hydraulic expansion bolt is described as follows:

(1) Anchoring surrounding rock over the full length

The hydraulic expansion bolt is installed into the borehole, and then high-pressure water is injected into the bolt. When the water pressure exceeds the yield limit of the steel pipe material, the rod body will generate permanent plastic expansion deformation along with the geometry of the borehole, whether the surrounding rock is weak and broken rock or unbroken hard rock [18–20]. The bolt will then be embedded firmly into the surrounding rock of the borehole. By applying a compressive force on the surrounding rock, the hydraulic expansion bolt will achieve the design anchoring force.

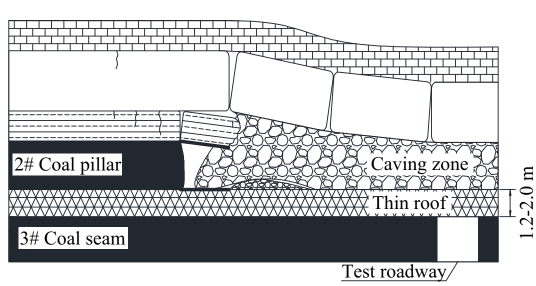
(2) Extruding reinforcement on broken surrounding rock

After high-pressure water has been injected, the pipe wall of the bolt becomes tightly embedded in the surrounding rock, and will exert a relatively high radial pressure on the surrounding rock along the full length of the bolt, which plays the role of extruding reinforcement on the surrounding rock. This role will be strength-



1, Goaf of 201 working face in 2# coal seam; 2, Goaf of 203 working face in 2# coal seam; 3, Section pillar in 2# coal seam; 4, Transportation roadway of 101 working face in 3# coal seam; 5, Return-air roadway of 101 working face in 3# coal seam; 6, Mining roadway in 2# coal seam

(a) Spatial location map of roadway



(b) Roof strata structure of testing roadway

Fig. 1. Spatial location and roof strata structure of testing roadway.