International Journal of Mining Science and Technology 24 (2014) 853–858

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

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

Failure mechanism of Mesozoic soft rock roadway in Shajihai coal mine and its surrounding rock control

Yuan Yue *, Zhu Yongjian, Wang Weijun, Yu Weijian

School of Energy and Safety Engineering, Hunan University of Science and Technology, Xiangtan 411201, China
Hunan Provincial Key Laboratory of Safe Mining Techniques of Coal Mines, Hunan University of Science and Technology, Xiangtan 411201, China

ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form 18 March 2014
Accepted 29 May 2014
Available online 24 November 2014

Keywords:
Mesozoic soft rock
Failure mechanism
Constant resistance with large deformation support
Control measures
Collaborative bearing

ABSTRACT

In view of the buckling failure caused by large deformation of Mesozoic soft rock roadway in Shajihai mining area, such as serious roof fall, rib spalling, floor heave, etc., based on the detail site investigation, theoretical analysis, mineral composition test, microstructure test, water-physical property test and field experiments were carried out. And we revealed the compound failure mechanism of Mesozoic soft rock roadway in Shajihai mining area, namely the molecule expansion-shear slip of weak structural plane-construction disturbance. On this basis, the coupling support technology whose core is constant resistance with large deformation bolt was proposed. The feature of this supporting technology is that a new type of structural composite material was used, which makes the supporting system not only has the ideal deformation characteristics, but also has high supporting resistance. Thus the fully release of plastic energy within surrounding rock and reasonable control of the thickness of the plastic ring were realized. Then the differential deformation between the surrounding rock and support was eliminated by the secondary coupling support of bolt–mesh–cable, and the bolt with high strength was applied in the base angle to control floor. Eventually the collaborative bearing system of surrounding rock–support was formed. Through field tests the validity and rationality of support was also verified.

1. Introduction

Soft rock in coal mine is the key part of soft rock engineering, due to the complex geological environment and the special mechanical properties, the governance of soft rock becomes a major problem which puzzles China's coal production and construction in the long-term [1–5]. Shajihai coal mine is a typical large mine in western China, the coal-bearing strata within this area belong to the Mesozoic Jurassic strata. The major lithology includes argillaceous siltstone, fine sandstone, sandstone, mudstone, silty mudstone, of which the diagenesis is poor, and the strength is very low, while the soften coefficient varies from 0.03 to 0.44, so that the rock is easy to soften. Because the roof of B_{13-2} coal seam is weak and loose, so roof fall occurs easily. Furthermore, expansive floor heave in large areas occurs when mudstone and silty mudstone within floor encounter water. The phenomenon of nonlinear large deformation failure takes place during driving for haulage gate of 01 working face, such as roof fall, rib spalling and so on. The top beams of the U-shaped steel bracket generate significant sinking and bending deformation, while the legs get close to each other severely. The major lithologies of surrounding rock within main shaft are sandstone and shale rock, as well as the auxiliary shaft and vertical air shaft. The average strength of surrounding rock is less than 8 MPa, and the joints and fissures are well developed, which lead to the performance of rock with friability and expansibility. Therefore, the surrounding rock belongs to typical compound Mesozoic soft rock. During the first phase construction of the coal mine, varying degrees of engineering damage including roof separation, roof fall, sidewall convergence, floor heave, etc., occurred, which seriously threaten the safety of the mine construction, and severely impact the construction speed of the coal mine. So that, the problem of soft rock roadway supporting need to be solved urgently to ensure the safety of mine construction, and to create favorable conditions for the smooth operation.

Great progress for support issues of soft rock engineering under difficult and complex conditions has been made at present, and different supporting theories and techniques has been formed [6–12]. However, some limitations still exist in these supporting technologies, such as the narrow scope of application, the low efficiency of construction, high cost, poor comprehensive benefits and so on. Judging from the data access, only water conductivity tunnels of hydraulic engineering with shallow depth which belongs to Ter-

* Corresponding author. Tel.: +86 18673287007.
E-mail address: yuanyuekafu@163.com (Y. Yuan).

http://dx.doi.org/10.1016/j.ijmst.2014.10.019
2095-2686/

tiary soft rock in Xinjiang region were studied [13–15]. But the Mesozoic soft rock with larger buried depth has not been studied, and there is almost no governance research for engineering instability of soft rock roadway within Shajihai mining area, nor the supporting theory and technology yet to follow. In this paper for the large deformation failure problems of the Mesozoic soft rock roadway within Shajihai mining area, comprehensively using various methods, we attempt to reveal the deformation and failure mechanism of surrounding rock, and to propose appropriate control measures and design scheme for surrounding rock, which would be applied to the project site.

2. Engineering situations and geological characteristics of surrounding rock

2.1. Engineering situations

Shajihai coal mine located in the northwest of Junggar Basin coalfield in Xinjiang. The area of mine field is 68.26 km^2, of which the coal resources reserves are 1.817 billion tons. The coal-bearing strata with the strike of NE-SW, dip of SE, dip angle of 7 to 28° of this mine field mainly include Sangonghe group, Xishanyao group, Toutunhe group of the Jurassic in Mesozoic. The comprehensive development way including two inclined shaft and one vertical shaft is adopted. And the mine is divided into three levels. Currently the first level is developing. During the roadway driving, large deformation destruction problems such as serious roof fall, rib spalling, and bracket failure occurred, as shown in Fig. 1.

2.2. Geological characteristics of surrounding rock

The major lithology of strata in this area includes sandstone, fine sandstone, argillaceous siltstone and mudstone. Fine sandstone and sandstone mostly filled with mud appear granular structure or massive structure, which can be found lots of parallel plate or wedge-shaped cross-beddings. Additionally, this kind of rock with the softening coefficient varying from 0.03 to 0.44 is very soft, and the water-abundance is good. The mudstone with poor cementitious and strong expansion appears grayish black and massive, which easily collapses and muddies when encountering water. In addition, the joints and cracks of rock are well developed. The mechanical characteristic of rock within this region is that the strength of sandstone is less than that of mudstone, while the strength of mudstone is lower than that of coal. Moreover, the mine water inrush is high, and the cumulative thickness of the aquifer reaches 110 m, which is a greater challenge for safe construction of roadway.

The results of electron microscopy scanning (as shown in Fig. 2) and the mineral composition test show that microcracks, micropores with good connectivity in mudstone are well developed, while the pore distance reaches about 10–50 μm. Compared with mudstone, the overall structure of sandstone and fine-grained sandstone is more complete, and the width of microfracture is smaller.

Clay minerals in siltstone account for 43.2%, among them the content of swellable clay mineral (I/S mixed layer) reaches 42%. Clay minerals in sandstone account for 40%, among them the content of swellable clay mineral (I/S mixed layer) reaches 44%. While clay minerals in mudstone account for 65.7%, among them the content of swellable clay mineral (I/S mixed layer) reaches 60%. It can be seen that from the above results, the integrity of roadway surrounding rock is poor due to the well developed joints and fractures. Under the engineering disturbance, the degree of crushing on rock mass will increase. Meanwhile, the surrounding rock with high content of clay minerals will swell and disintegrate when encountering water, which can seriously weaken stability of the roadway, and cause a variety of rock deformation and failure.

3. Failure mechanism of soft rock roadway with large deformation in Mesozoic

Through the field survey, numerical calculations, laboratory tests and field tests, combined with analysis of test results, the failure mechanism of Mesozoic soft rock roadway in Shajihai coal mine is obtained.

(1) Molecular expansion mechanism

The results of the mineral composition test show that the content of expansive clay minerals (I/S mixed layer) in sandstone, mudstone and sandy mudstone within this area is high, which can reach 40–60%. Illite–smectite mixed layer crystal is composed of many parallel unit cells. Due to low joining force between the unit cells water molecules can enter cell gap. Moreover, the unit cell can be exchanged ions with water, which can increase the chance of water molecules entering. After the water molecules get into the cell gap, cell spacing increased, leading to the surge of rock volume [3]. Therefore, after the interaction between the surrounding rock and water molecules in the air or in the spraying water and gushing water, swelling and disintegration occurred, resulting in a significant reduction of strength. In addition, due to the superposition of the expansion stress caused by volume increasing and the rock stress, stress concentration becomes more significant. Then the weak parts of surrounding rock generate damage and rupture firstly. Because the support system is difficult to adapt to large deformation of surrounding rock, with the further development of deformation, support system gradually failed, which evolved into the overall damage of roadway.

(a) Loose and expansive surrounding rock (b) Failure of rib spalling (c) Serious roof fall

Fig. 1. Deformation and failure of the roadway.