THERMAL INFRARED CHARACTERISTICS OF ROCK STRATA FRACTURE IN STEEPLY INCLINED AND EXTRA THICK COAL SEAM

by

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In view of the complexity of the rules of rock strata fracture in steeply inclined and extra thick coal seam, the mining method of horizontal section top coal caving was put forward. In this paper, the physical similarity simulation model is established to analyze the movement rules of rock strata. The relationship between the form of rock strata fracture and the thermal infrared radiation is analyzed according to studying the characteristics of the thermal infrared radiation temperature of the rock strata fracture. Meanwhile, the changes characteristics of abnormal area of thermal infrared radiation were mastered, and the precursors of thermal infrared radiation of rock strata fracture were predicted. The results showed that the rock strata fracture form of steeply inclined and extra thick coal seam is related to the mining depth.

Key words: *steeply inclined and extra thick coal seam, similarity simulation, horizontal section top coal caving, thermal infrared radiation, thermo-mechanical coupling effects form*

Introduction

A large number of steeply inclined and extra thick coal seam (SIETCS) were existed in Urumqi, Xinjiang. Due to special environment and the complexity of the rock strata movement rules, more severe mining problems with the increase of mining depth were faced [1-4], such as large suspension of the rock strata caused by natural repose angle of coal and rock mass, large deformation of roadway surrounding rock strata, and the rock burst, *etc*. The horizontal section top coal caving mining method was widely used as an economical and efficient method for mining SIETCS. This method not only improved the mining efficiency, but also formed multi-layer caving space, which aggravated the complexity of the rock strata movement rules and brought serious threat to the safe mining.

Many scholars had systematic research on the disaster problem caused by the rock strata fracture of steeply inclined coal seam and the thermal infrared precursors of rock strata fracture, many beneficial results had been obtained. According to the study of disaster caused by rock strata fracture of steeply inclined coal seam, Ju *et al.* [5] deduced the cantilever beam energy expression of the basic rock strata by analyzing the fracture characteristics of the basic rock strata in horizontal section top coal caving mining of SIETCS. Shi *et al.* [6] analyzed the basic rock strata through the elastic thin plate theory, and obtained the criterion of rock strata fracture. Through the analysis of the mining pressure rules of the working face in steeply inclined coal seam, Shao *et al.* [7] found a protective effect of the temporary structure of the

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overlying strata, which leaded the working resistance of the support would not increased significantly with the increase of section height and mining depth. Since the 1990's, infrared remote sensing had used to study the thermal infrared phenomenon of rock strata fracture [8-11], which had confirmed the obvious changes of thermal infrared in the process of coal and rock mass under stress [12-18]. Based on this, the scholar began to study the thermal infrared precursors of rock strata fracture. Liu *et al.* [19] conducted a systematic study on the thermal infrared radiation (TIR) characteristics of rock under different loading modes, and found that the thermal infrared precursor of rock strata fracture occurred in the plastic deformation stage of micro-fracture development before peak loading. The aforementioned results had made a very beneficial exploration on the changes characteristics of thermal infrared effect of rock strata fracture in SIETCS. However, there were few reports on the application of thermal infrared to the study of the rock strata movement rules in SIETCS.

The main target of the paper is show that the physical similarity simulation model is established to analyze the rock strata fracture form during mining. Combined with studying relationship between the TIR of the rock strata and the rock strata fracture, the changes characteristics of the infrared radiation abnormal area is comparatively studied. The thermal infrared precursor of the rock strata fracture is revealed. Meanwhile, deep holes blasting is carried out on the rock strata of +575 level working face to reduce the concentrated stress, which provided a strong guarantee for the safe minings.

Engineering background

Wudong Coal Mine was located in the northeast of Urumqi. The mine field was about 10.8 km long from east to west, 0.7-2.7 km wide from north to south. The area of coal mine was about 20.3 km^2. The designed production capacity was 6 million tons per year. The north mining area of Wudong Coal Mine was located in the north side of the Badaowan syncline, and the basic structure was a monoclinic structure inclined to the north. The rock strata strike was 67°NE and dip direction was 157°SE, the average dip angle was 45°, the average ground level was about 800 m. The main coal seams in the north mining area were the 43# and 45# coal seams. The main roof thickness of the 43# coal seam was 10-20 m, and the direct roof thickness was 3-5 m. The rock strata were characterized of large thickness and high strength, few fracture and joints, rigidity and difficult caving.

Mining technology of horizontal section top coal caving in SIETCS

The horizontal section top coal caving mining layout of the SIETCS in Wudong Coal Mine is shown in fig. 1. As an economical and efficient mining method, horizontal section top coal caving mining had been widely used in SIETCS. The mining method had the characteristics of high recovery rate, low excavation rate and high economic benefit.

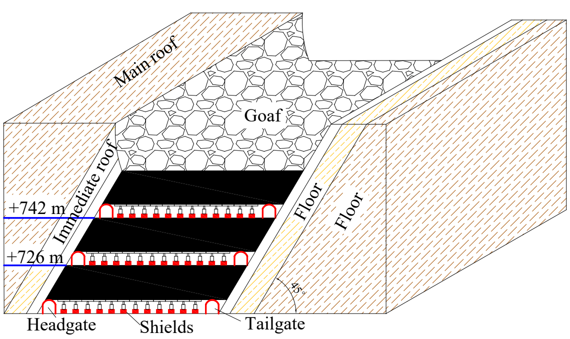

Figure 1. The horizontal section top coal caving mining layout of the SIETCS

The horizontal section top coal caving mining technology was significantly different from the traditional long-wall mining. The horizontal section top coal caving mining working face was arranged along the horizontal line of the coal seam thickness, the short length was approximately equal to the coal thickness (generally no more than 50 m). The average section height was 15-25 m, and the mechanized mining height was 3 m. The horizontal section top coal caving mining method was adopted in the mining technology and the mining ratio was 1:4~1:7.3. However, in the process of the mining, the rules of the rock strata movement were complicated, and the problem of large suspension of the rock strata often occurred. This was mainly due to the particularity of coal seam occurrence, which was closed to the occurrence characteristics of the natural angle of repose of the coal and rock mass. Thus, it posed a serious threat to the safe mining.

Analysis on the infrared thermal of rock strata fracture in horizontal section top coal caving mining

The establishment of physical similarity model

The geological characteristics of the occurrence of steeply inclined coal seam in the north mining area of Wudong Coal Mine were taken as the experimental prototype. Based on the plane stress model test platform, the horizontal section top coal caving mining model test of SIETCS was designed. The geometric similarity constant $C_l = 200$ (prototype: model) of the test was determined according to the purpose of the test and the results of the field investigation. Meanwhile, the model pavement dimension (length×width×height) was 3.0 × 0.2 × 1.75 m. The similar constant of stress $C_\sigma = 300$, the similar constant of bulk density $C_\gamma = 1.5$, the similar constant of strength, elastic modulus and cohesive force were 1.

The monitoring equipment was arranged and the test began after 5~7 days. During the test, the TIR camera was placed 1.5 m in front of the test platform. The main purpose was to obtain the infrared radiation parameters of the rock strata fracture process, to observe and record the temperature information during the disturbance of coal mining. The relationship between TIR characteristics and the form of rock strata fracture under the influence of mining were analyzed.

The TIR adopted continuous real-time operation, and monitoring layout is shown in fig. 2. The model was excavated based on actual mining technology to ensure the accuracy of the test results. In this model, the changes of infrared radiation intensity was caused by the the rock strata movement rules, which were called thermo-mechanical coupling effects [19]. To study the TIR characteristics of model rock strata, it was necessary to analyse the relationship between the model infrared radiation energy and physical temperature. According to Stanfen-Boltzman's law, the relationship of the TIR energy and the physical emissivity was expressed as follows:

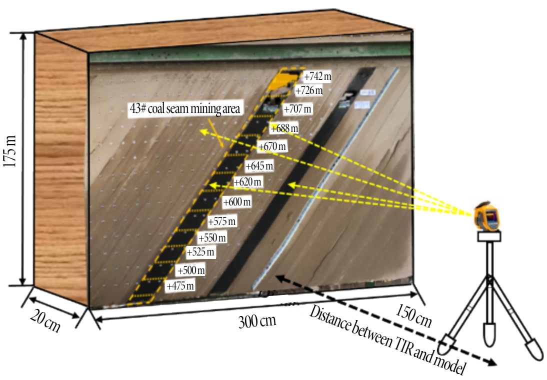

Figure 2. Site mining and monitoring layout

$$W_r = \lambda \mu T^4 \tag{1}$$

where W_r [Wm^{-2}] is the TIR energy of the rock strata when the physical temperature was T, μ – the Stanfen-Boltzman coefficient, T – the physical temperature of rock strata, and λ – the emissivity of rock strata.

Strata fracture thermal infrared characteristics of horizontal section top coal caving with SIETCS

In this physical similarity simulation test, 13 horizontal sections (+742 level~+475level) of 43# coal seam were extracted, with a total extraction height of 141 cm (actual 282 m). It was found that the rock strata fracture form of SIETCS was related to the mining depth, which was generally divided into shallow mining and deep mining. The structural evolution and thermal infrared characteristics of the rock strata during shallow mining are shown in fig. 3. At the initial stage of mining, the rock strata above the working face was stable and did not move significantly, but from the +707 level working face, the rock strata was bent and separated. Due to the slipped of the caving rock strata to the goaf, the suspension length of the rock strata increases easily, which led to tensile fracture.

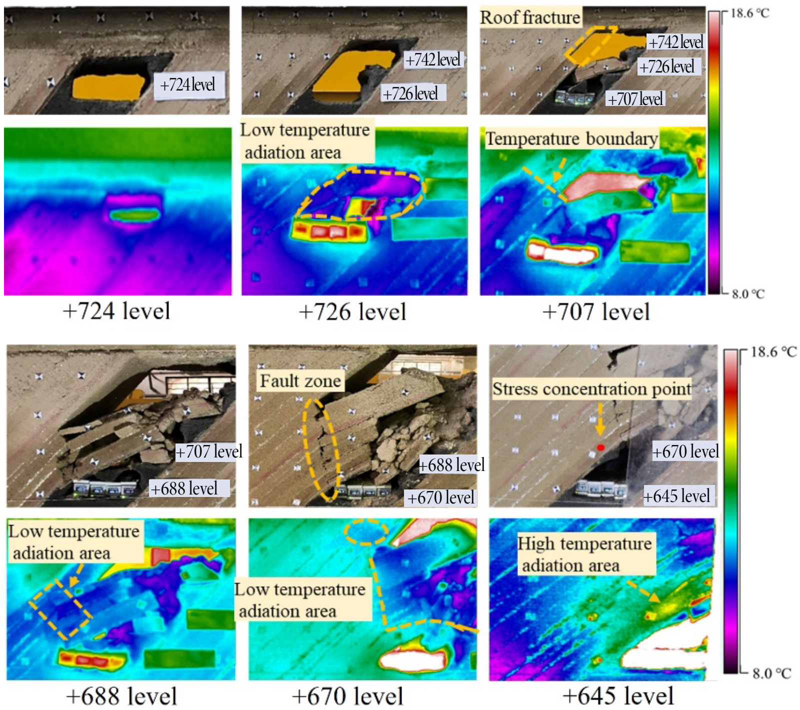

Figure 3. Thermal infrared characteristics of shallow mining of SIETCS

The hermal infrared characteristics of rock strata showed that there was an obvious temperature interface at the location of the shallow mining rock strata fracture. This temperature of location became lower, which mainly caused by the tensile fracture of the shallow rock strata.

The relationship between the structure evolution and thermal infrared characteristics of rock strata during deep mining are shown in fig. 4. When the working face entered deep mining, and it was filled with broken rock strata, which restrained the fracture of the rock strata and led to the increase of goaf space. In +525 level working face, the suspension length of rock strata reached 106 m, which posed a serious threat to the safe mining. The broken rock strata was slipped in deep mining to form a hinged structure with the lower horizontal rock strata,

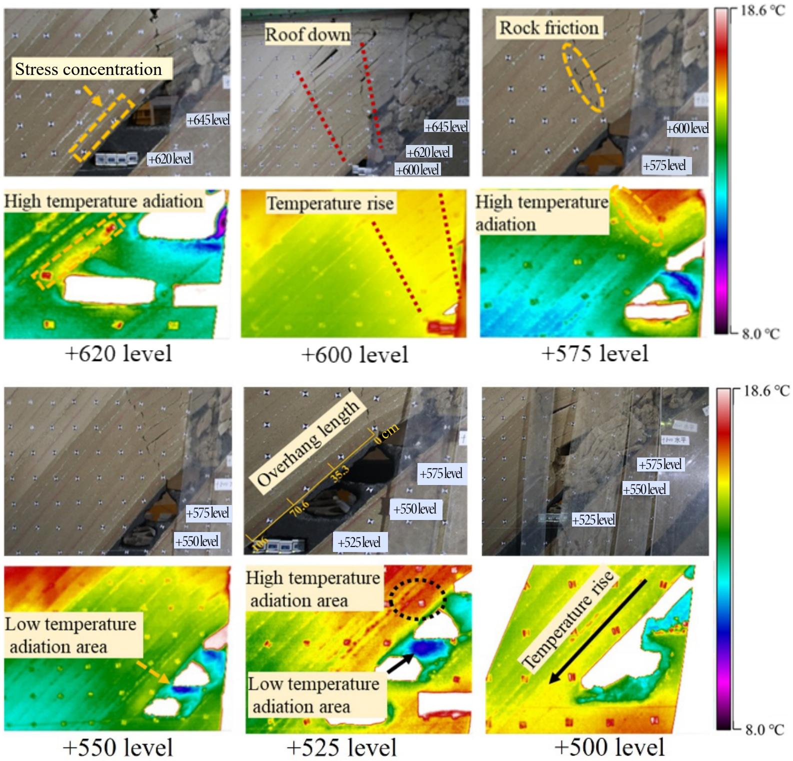

Figure 4. Thermal infrared characteristics of deep mining of SIETCS

which prevented the rock strata from collapsing further. When the loading above the strata exceeded its compressive strength, the temperature of the location of fracture surface would be risen. Meanwhile, the +525 level working face suspended rock strata was formed a temperature gradient distribution feature of *higher temperature - lower temperature - higher temperature* by repeat mining. The temperature increased at the end of the rock strata under compression, while the temperature decreased at the middle of the rock strata during buckling and stretching.

The characteristics of TIR abnormal regional

The rock strata in SIETCS had undergone the evolution process of elastic deformation, plastic deformation and fracture collapse. The corresponding rock strata temperature field reflected the abnormal changes characteristics of the temperature radiation zone, and could be used as an important precursor phenomenon for judging rock strata fractures.

The relationship of the rock strata fracture situation and infrared radiation changes characteristics of the +525 level working face is shown in fig. 5. It was shown that the location of rock strata fracture at 30 m and 62 m during the +525 level working face, which was close to the upper middle of the rock strata. Meanwhile, the fracture situation of +525 level working face rock strata would induce dynamic disaster accidents in the working face. The temperature of the three levels in fig. 5(b) showed an overall downward trend during the mining, but there was a brief rose in the temperature at the location where the fracture was about to occur in the early stage. This trend changes indicated that the rock strata formation was about to fracture.

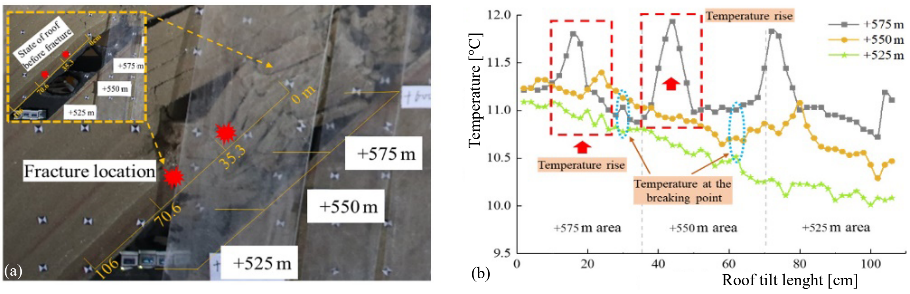

Figure 5. The fracture situation of +525 level working face rock strata; (a) rock strata fracture and (b) infrared radiation changes characteristics

According to the infrared radiation temperature characteristics of +525 level working face rock strata, tensile fracture was occurred at 30 m and shear fracture was occurred at 62 m.

Prevention and control scheme design of rock strata dynamic disaster

According to the change's characteristics of simulation model rock strata temperature, the rock strata of the deep mining might fracture in a large area, which posed a serious threat to the safe mining. Therefore, it was necessary to weaken the rock strata in the north mining district of Wudong Coal Mine. The deep holes-blasting was used to reduce the rock strata concentrated stress above +575 level working face. The specific governance scheme was as follows.

The layout of rock strata deep holes blasting is shown in fig. 6, and the parameters of deep holes-blasting are shown in tab. 1. The rock strata deep holes-blasting was carried out in the middle and upper location of +575 level headgate. The holes were arranged within 50 m behind the +575 level working face. Three holes were arranged in each row. The angle with the horizontal plane was 45°, 75°, and 105°, respectively. The angle with vertical plane was 30°, which was to promote rock strata fracture. The construction length of holes was 40 m. The length of explosive was 30 m. The length of holes sealing was 10 m. The row spacing was 10 m with 5 rows arranged.

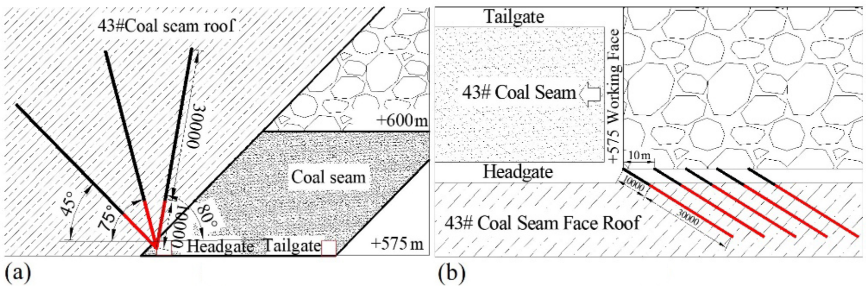

Figure 6. (a) Layout of rock strata deep holes blasting (b) plan of rock strata deep space blasting

Table 1. The parameters of deep holes blasting

Holes number	Holes angle [°]	Holes length [m]	Explosive length [m]	Explosive weight [kg]	Holes sealing length [m]
1#	45 south, 60 east	40	30	236	10
2#	75 south, 60 east	40	30	236	10
3#	105 south, 60 east	40	30	236	10

Conclusions

In the present task, the horizontal section top coal caving mining method was put forward to recovery the SIETCS. According to the geological conditions of SIETCS, the physical similarity simulation model was established to analyze the changes rules of rock strata. The shallow mining rock strata were mainly caused by tensile fracture, and the deep mining rock strata were mainly shear fracture. The long suspension distance of deep mining rock strata was 106 m, which posed a serious threat to the safe mining. Based on characteristics of the TIR temperature of the rock strata fracture, when the rock strata fracture, whose temperature would become lower or higher. The different types of abnormal areas indicated different fracture form of rock strata: The higher temperature indicated shear fracture, the lower temperature indicated tensile fracture. The changes characteristics of TIR could be used as an important precursor of rock strata fracture, and the temperature was risen provisionally before the rock strata fracture. In order to solve the problem of long suspension of rock strata in SIETCS, it was necessary to weaken the hard rock strata in north mining district of Wudong Coal Mine. The deep holes blasting was carried out on the rock strata of +575 level working face to reduce the concentrated stress, which provided a strong guarantee for the safe mining.

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Nomenclature

C_l – geometric similarity constant, [–]
C_γ – similar constant of bulk density, [–]
C_σ – similar constant of stress, [–]
T – physical temperature of rock strata, [K]
W_r – total radiation intensity, [Wm^{-2}]

Greel symbols

λ – the emissivity of rock strata, [–]
μ – Stanfen-Boltzman coefficient, [–]

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