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Experimental investigation of the occurrence of rockburst in a rock specimen through infrared thermography and acoustic emission

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1. Introduction

Rockburst is a nonlinear dynamic phenomenon that rock mass releases large amount of energy instantaneously along the unloading face of excavation.[1] Because of the characteristics of suddenness, destructiveness, unpredictability, rockburst has become a serious disaster for production and safety. The mechanism of rockburst is a difficult subject that has been widely investigated in the fields of mining, tunnelling and underground engineering.[2–6]

In the past, many researchers did research on rockbursts, and accumulated abundant results.[7–20] Appropriate monitoring methods are crucial importance to study the occurrence and mechanism of rockburst. In field monitoring of rockburst, many researchers use some necessary instrument for directly monitoring of engineering rock mass to distinguish whether there is a possibility of rockburst.[21–23] Field monitoring methods mainly include seismic method, drilling cuttings method, microgravity method, etc. Limited by the complexity of geological factors and the induced conditions of rockburst, field monitoring has difficult in capturing the required information. Therefore, it is particularly important to represent the real damage process of rockburst under the condition of laboratory experiment for the study of the mechanism and the influencing factors of rockburst through effective monitoring methods.

Infrared thermography, due to its non-destructive and non-contact testing nature, has been widely used in the field of rock mechanics. Brady and Luong studied the characteristic of fracture process of different rocks through the thermovision.[24,25] Cui and Grinzato investigated the thermal-radiation features of rock under loading.[26,27] Wu and Wang classified the abnormal characteristics of rock failure into three types, which is an important founding for the study of precursors of rock failure.[28] Based on the results of previous studies, Wu did more experiments to study the precursory of rock fracturing and failure.[29] Mineo and Pappalardo studied the cooling behavior of rock samples in laboratory through the analysis of thermograms.[30] Infrared thermography has also been widely used in remote survey. Pappalardo and Mineo proposed a cooling rate index through the thermal imaging campaigns carried out in different climatic conditions, proving that the infrared thermography as an effective remote survey technique.[31] Mineo studied the most unstable areas along the slope with the help of infrared thermography images.[32] Baroň presented a new approach for mapping open cracks and tension fractures within rock slope instabilities and rock cliffs, which resides in high-resolution ground-based and airborne infrared thermography.[33]

Acoustic emission (AE) is another effective monitoring method that can release elastic waves when microcracks are generated in a rock mass.[34,35] Researchers have done much work on AE characteristics in rock engineering in order to investigate mechanic properties in the process of rock failure.[36–38]

Infrared thermography and AE technology has made a lot of meaningful progresses in the process of rock failure, but the research on the mechanism of rockburst based on the infrared thermography combined with AE technology is rarely reported. In this paper, the rockburst of tuffaceous stone is analyzed through the infrared thermography cooperated with the analysis of AE frequency spectrum characteristics. The result is crucial importance to analyze the mechanism of rockburst.

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Table 1
Physical and mechanical properties of tuffaceous samples.

No.	Density (g/cm^3)	E (GPa)	UCS (MPa)	Poisson's ratio
1–1	2.64	14.5	70.31	0.22
1–2	2.65	13.5	71.14	0.21
1–3	2.64	13.4	66.17	0.22

Table 2
Mineral types and contents of tuffaceous samples.

No.	Mineral types and contents (%)				Clay mineral contents (%)
	Quartz	Potash feldspar	Plagioclase	Calcite	
1#–1	30.4	2.8	39.9	3.1	23.5
1#–2	30.8	2.9	39.7	3.0	23.6

2. Engineering geological conditions

The rockburst experiments are focused on the high stress section of a deep and long tunnel project at Changji City, Xinjiang province, China. The buried depth is 770.0 m. The surrounding rock of tunnel is fresh hard rock which is classified as II–III rock.[39] There are eleven faults in the engineering area.

According to the in-situ stress measurement results analysis, the maximum principal stress is horizontal stress, N23°E direction. The stress value ranges from 22.0 to 36.0 MPa. Combined with the engineering geological condition, the rockburst is likely to happen during the tunnel excavation.

The rock samples are tuffaceous sandstone, taken from the borehole ZK202. We used the uniaxial compression experiments to determine the various parameters including elasticity modulus, uniaxial compression stress (UCS), and Poisson's ratio. Contents of clay minerals are one of the most important factors determining the tendency of rockburst. So we used X-ray diffraction to conform contents of clay minerals including quartz, potash feldspar, plagioclase, and calcite. The physical and mechanical parameters and X-ray diffraction results of mineral contents of samples are listed in Tables 1 and 2. Observed by electron microscope scanning, the sample is integrity with some microcracks and cavities developed (see Fig. 1).

Sampled rocks must be processed into standard sample. The standard sample size is approximate 150×60×30 mm^3. Fig. 2 shows one of these samples. In Fig. 2, (a) represents schematic of the sample including loading face (σ_1, σ_2, σ_3) and unloading face, and (b) represents the detail characteristics of the six faces of the tuffaceous sandstone. We can see amounts of white stripes on the surface of the samples.

3. Experimental method

This strain rockburst experiment was conducted using the Modified True-Triaxial Apparatus (MTTA) developed by He,[7] which can provide dynamic loading/unloading independently in three principal stress directions. It is a unique system for rockburst including the main machine, the hydraulic pressure-controlling unit and data acquisition system. Data acquisition system consists of stress-strain collection system, infrared detection system, AE collection system. Infrared images were acquired by an infrared thermography model ImageIR4325. The thermography works in the cooled and a passive modes (no extra heat sources used) at wave length of 3.7–4.8 μm, with measuring temperature range of −10 to +1200 ℃; minimum detection temperature difference of 0.025 ℃; on-line display resolution 320×256 pixels.

During the rockburst experiment, stress was loaded to the rock sample on three directions and six faces using the manual hydraulic loading control system. One surface of the sample can be unloaded immediately from the true triaxial compression condition to simulate the excavation of tunnel. Fig. 3 shows design of stress path being conducted by MTTA.

According to in-situ stress regression curve, the initial confining stress σ_1, σ_2, σ_3 applied on the sample is 16.2 MPa, 15.1 MPa, and 11.1 MPa, respectively. The initial confining stress can simulate the in-situ stress of 622 m. The initial stress is shown in area I, Fig. 3. Keep the initial stress for about twenty minutes in order to let the stress conditions in line with the in-situ stress. The sudden drop of σ_3 can reflect that one surface of the sample is unloaded immediately to simulate the excavation of tunnel as shown in area II, Fig. 3. The sharp increase of σ_1 in area II can reflect the stress concentration after excavation of tunnel. The increased value follows Kirsch formula.[40] Due to the rockburst may not happen at the stress level of 622 m, we will do the repeated experiment at the next stress level by an increase of 200 m reaching to 822 m according to in-situ stress regression curve. The loading-unloading stress design at 822 m depth is shown in area III, Fig. 3.

4. Principles of infrared detection

Radiant exitance in the infrared band can be detected and then transferred into temperature field by infrared thermography. The relationship between the temperature field and the radiant exitance follows the Stefan-Boltzmann law,

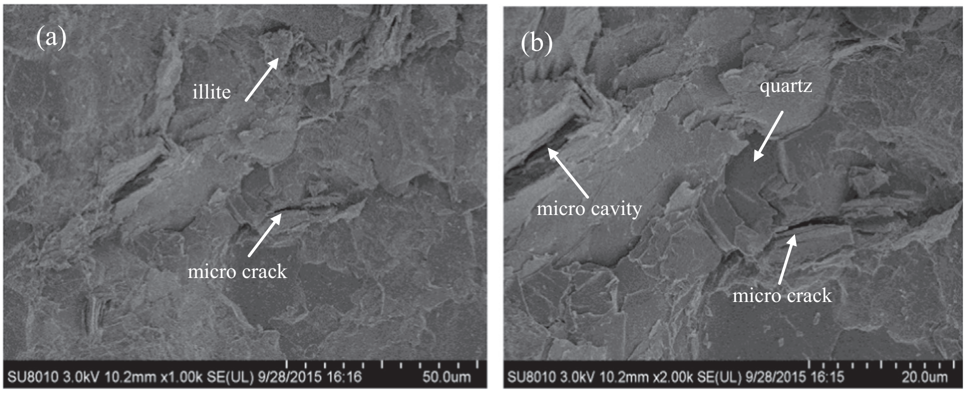

Fig. 1. SEM photos of the tuffaceous sample before the experiment.