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Acoustic emission characteristics and stress release rate of coal samples in different dynamic destruction time

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A B S T R A C T

Considering the importance of the prediction of rock burst disasters, and in order to grasp the law of acoustic emission (AE) of coal samples in different dynamic destruction time, the SH-II AE monitoring system was adopted to monitor the failure process of coal samples. The study of the change rule of the AE numbers, energy, '*b*' value and spectrum in the micro crack propagation process of the coal samples shows that as dynamic damage time went by, AE presented high-energy counts and the accumulated counts increased during the compression phase. The AE energy and cumulative counts increased during the elastic stage. The AE blank area increased gradually and the blank lines were more and more obvious in the molding stage. The AE counts and energy showed a trend of decrease in the residual damage phase. AE '*b*' values gradually became sparse, and the large scale cracks percentage compared with micro cracks decreased and the degree of damage decreased. The AE frequency spectrum peak went from the residual damage phase to the molding phase, and finally it was nearly stable, besides the bandwidth of the main frequency is gradually narrowed. Also, the frequency peak changed from single peak frequency to bi-peak frequency and to the single peak frequency. Uniaxial compressive strength is more sensitive than the elastic modulus to dynamic damage time.

1. Introduction

In recent years, the consumption of coal has been increasing, along with economic development and improvements in exploration equipment and technology. Exploration speed is increasing at about 12–20 m in depth per year. Many mines have entered the deep exploration period, and the original simple geological condition has changed into a very complicated one. Besides, rock burst occurs more and more frequently with an increasing degree of damage. Rock burst is a phenomenon in which the elastic energy stored in the coal rock releases so suddenly, quickly and drastically that the coal rock bursts with quickly released elastic energy. Considering the conditions for the phenomenon, the storage of energy is the prerequisite and basis for rock burst, and the energy release speed influences the strength of the impact. Essentially, energy and time are the main controlling elements. Almost every exploration technology and method cannot avoid causing rock burst. In the same mine, and in areas with a similar geological situation, some areas may have the impact, while others may not. As can be concluded from the above, rock burst is one of the physical and mechanical properties of coal rock, and determines the amount of energy and the damage strength. The inherent property of a coal mine is called the burst tendency; judging the strength of the burst tendency of coal layers is the necessary requirement for rock burst prediction. The indicators for judging the burst tendency include: the dynamic damage time, the elastic energy index, impact energy index, and uniaxial compressive strength. The physical significance of dynamic damage time is the time needed in the energy release by coal rock failure. There are numerous joints, macro holes and cracks. When the coal sample is under uniaxial compression, there is stress concentration in the defect areas and the macro cracks extend, releasing energy in the form of elastic waves. This kind of phenomenon is called acoustic emission (AE). Studies show that AE carries a lot of internal information of coal rocks. Thus, the internal failure law of coal can be deduced by analyzing the AE of coal rocks. In different damage time periods, their burst tendency differs. With the same amount of energy, the longer the period, the lower the release speed and the greater the possibility of causing impact danger. Therefore, the dynamic damage time and burst tendency are in inverse proportion. Difference in burst tendency is one of the properties of a coal body. Elastic waves released in the failure process of coals with different properties have certain AE parameter features.

Domestic and foreign professors have made some achievements in the study of rock failure through monitoring AE. Shkuratnik et al.

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[1] and others have determined the AE characteristics of rock failure through experiments on coal rocks using different loading methods. Li et al. [2] carried out a comprehensive evaluation of burst tendency by experiments on coal samples with different burst tendencies to get the prediction information for rock burst. However, due to the large difference among the coal samples, the experimental results are not suitable for regular study. Yang and Mao [3] carried out uniaxial compression tests on coal samples with burst tendency so as to study the changes of energy efficiency and '*b*' value. Ning et al. [4] divided the loading failure process of rock with a burst tendency into five stages, and discussed the AE characters of each stage. He et al. [5] analyzed the feasibility of predicting rock burst using AE by analyzing the relation between rock burst and AE. Pan et al. [6] proposed three indices to identify the burst possibility, and combined it with the traditional index, so that the reliability and conciseness of the identification result was improved. Tan et al. [7] proposed four AE patterns prior to a burst based on a ground test, and analyzed the preventative effect on rock burst by shock blasting. Wang and Sun [8] concluded that the shorter the damage time, the less the energy used in damaging samples, and the more the energy is transformed into kinetic energy. Su et al. [9] determined the burst tendency of coal samples, and determined a correlation among the four indices. Lu et al. [10] derived the law of AE and electromagnetic radiation by studying the burst tendency of different combinations of roof, coal sample and floor. Zhang et al. [11] proved, through studies, that dynamic damage time is one of the rational indices for burst tendency. Li and Lv [12] studied the relation between AE and rock burst by rock burst mechanics. Wang et al. [13] carried out failure experiments on different combinations through uniaxial compression, and analyzed the characteristics of AE and micro-shock signals using amplitude and frequency spectra. Xiao et al. [14,15] carried out uniaxial and triaxial compression tests on coal samples, and determined the law of amplitude and energy of AE during the process when coal samples lose stability. Xiao and Liu [16] carried out uniaxial and triaxial compression tests on coal samples with gas drainage boreholes to analyze the relation between the law of coal failure and AE. He proved the changing law of the elastic and molding zones during the coal failure process by numerical tests on COMSOL Microsoft. Wang et al. [17] carried out numerical modeling of the development process of rock bursts, and reached the conclusion that unloading leads to a quick release of energy and rock burst. Ai et al. [18] determined the law of energy release and AE of the failure process of coal samples under different loading speeds.

The above studies are mainly concerned with monitoring the rock burst tendency by AE, while studies on dynamic damage time, which is one of the main factors, are limited within the range: Strong Burst ($DT \leqslant 50$ ms), Weak Burst (50 ms < $DT \leqslant 500$ ms), and No Burst ($DT > 500$ ms). There are few reports of studies on joints connecting different dynamic damage times. Therefore, this paper describes studies on the AE characteristics of coal in different damage time periods using the conciseness and reliability of monitoring crack extension and energy release by AE. The internal relations between dynamic time and AE counts, energy, '*b*' value, frequency spectrum, uniaxial compressive strength, elasticity modulus and stress release speed are found, which sets up a theoretical basis for a deeper study of coal rock burst tendency.

2. Experimental

2.1. Coal sample selection and preparation

A mine in Heilongjiang has experienced the phenomenon of rock burst during exploration. The coal quality varies considerably. In burst tendency tests in different areas of this mine, dynamic damage time changes vary from strong burst period, weak bust period to no burst period, and the time steps are long. Therefore, the coal in this mine is suitable for experiments. In order to maintain the shape of coal samples, pneumatic picks are used to take similar coal cubes with each side length of over 25 cm from typical coal walls. There should not be any obvious joints or cracks in the coal samples. Since interior coal has many joints and cracks, rounded samples are difficult to obtain. Thus the coal samples are processed into 50 mm × 50 mm × 100 mm standard samples along joint layers, according to international requirements, and their accuracy also meets international requirements.

2.2. Equipment and processing methods

A TYJ-500KN electro-hydraulic servo rock rheology change test system is used to load coal samples in the experiments. The system can be used to collect real-time stress and strain data and to draw curves. The experiment loads the coal samples by using loading control with a loading speed of 0.5–1.0 MPa/s. The whole-day monitoring system SH-II produced by an American physical acoustic company is used in AE collection. The collecting frequency is 1 MHz; pre-amplifier gain is 40 dB; threshold value is 45 dB. Four Nano30 sensors (with 125–750 kHz frequency band) are used. AE probes are set on the centers of four sides of coal samples. The void between coal sample and sensor is coupled by Vaseline. The probes are set in a fixed position. Before the experiment, lead-break experiments are carried out on different areas of the samples to investigate any positioning effect, and the coupling effect is automatically tested by the material acoustic features matrix. The experimental system is shown in Fig. 1.

3. Experiment analysis of coal AE in different damage time periods

In order to study the AE characteristic of coal samples at different dynamic damage times, uniaxial compression AE experiments were carried out on 15 samples, among which Experiment DT-4 was unsuccessful. AE hitting counts, energy efficiency, '*b*' value, frequency spectrum uniaxial compressive strength, elasticity modulus as well as stress release speed were studied. Table 1 shows testing indices in dynamic damage time. Fig. 2 is the curve for dynamic damage time counting. Because the differences among these samples during dynamic time are small, 7 typical samples are chosen by time, including DT-8, DT-12, DT-9, DT-7, DT-6, DT-13, DT-11.

3.1. Analysis of different dynamic damage time counting and AE energy

In this section, the feature of AE counting and energy efficiency is described. From the perspective of AE strength and energy release, combined with the stress-strain relationship, this section examines the relationships between every index in a four-dimensional co-ordinate system. In Fig. 3a, (1) the number of balls represents AE counts, and their colors represents energy. Picture (2) shows the amount of energy. In Fig. 3a–d, f and g are placed according to the length of dynamic damage time from short to long.

AE counts and energy are different in different dynamic damage times with different stress-strain change processes. Stress-strain reflects damage of the coal body. Fig. 3 shows that the failure of coal samples can be divided into five phases: ① Initial compression phase; ② Compression phase; ③ Elastic deformation phase; ④ Plastic deformation phase and; ⑤ Failure residue phase. Due to

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