Experimental Study on the Characteristics of Acoustic Emission Source of Rock under Uniaxial Compression

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Abstract: One of the main research problems in acoustic emission (AE) monitoring technology is to identify the source of the acoustic emission. Processing the acoustic emission signal is the only way to solve this problem, and then to achieve the purpose of identifying the material destruction mode. Using acoustic emission monitoring technology, the acoustic emission of granite under uniaxial compression was monitored and analyzed, and the coupling characteristics between the acoustic emission signal parameters of granite under different loading rates were obtained. The results show that during the process of rock shear failure, the peak intensity of the rock, the peak value of the absolute energy of acoustic emission, the cumulative amount of acoustic emission and the loading rate showed a positive correlation. The correlation diagram of the AE ringing count and the duration shows a triangular distribution, and as the rock loading rate decreases, the angle of the triangle top angle of the correlation diagram increases. The distribution relationship between the absolute energy of AE and the duration can be fitted using a unary quadratic function, and as the loading rate decreases, the opening of the fitting curve gradually increases, and the width of the correlation graph gradually decreases. The correlation graph of absolute energy and amplitude of AE is linearly distributed, and as the loading rate decreases, the slope of the fitted line of absolute energy and amplitude of AE gradually decreases, and the width of the linear channel of the correlation graph decreases. It is found that there is a good regularity between the correlation graphs of different parameters of the acoustic emission of the rock during the uniaxial compression failure process, which is an effective method to identify the characteristics of the source of the acoustic emission. Therefore, establishing the correspondence between the characteristics of the AE source and the loading conditions will promote the development of acoustic emission technology in the monitoring of the stability of the surrounding rock of underground projects.

1. Introduction

During the rapid release of energy from a local source in a material, the phenomenon of transient elastic waves is called acoustic emission. Under the action of force, rock deformation and crack propagation are important mechanisms for structural failure, and this source directly related to deformation and fracture mechanisms is called the rock's acoustic emission source[1]. At the same time, the elastic wave (acoustic emission signal) produced from the acoustic emission source must contain the characteristic information of the acoustic emission source[2]. The acoustic emission signal is transmitted from the acoustic emission source and propagates through the rock medium. Therefore, it also contains information about the characteristics of the rock itself. In short, the acoustic emission signal is a kind of comprehensive information that includes the characteristics of the wave source,
material and monitoring equipment[3]. Monitoring the acoustic emission signals emitted during the process of crack initiation, propagation and rupture in the rock, and analyzing the characteristic parameters and coupling characteristics of the acoustic emission signal can identify the stress state of the rock[4,5].

With the improvement of computer performance and the improvement of monitoring technology, acoustic emission monitoring technology is widely used to monitor the stability of surrounding rocks at multiple scales. At present, it has been possible to use monitoring technology to obtain acoustic emission signals during the evolution of internal cracks in rocks, and to accurately predict possible damage to rocks based on the obtained monitoring data. The characteristics of acoustic emission of rocks under different stress paths are studied, and it is found that acoustic emission is related to the internal structure of rocks[6,7]. Moreover, the research results of acoustic emission characteristics can be used to determine and identify the deformation stage of the rock [15]. The influence of strain rate on the acoustic emission characteristics in the process of rock deformation and failure can be divided into two problems: the influence of strain rate on the acoustic emission characteristics of rock elastic deformation and fracture instability[8,9].

At present, due to the complexity and heterogeneity of the structure and mineral composition of rock materials at the micro level, more research results have focused on the evolution characteristics of acoustic emission signals in time series. There are few studies on the judgment and recognition mode of acoustic emission sources under different mechanical effects on rocks, and they have not formed regular and common characteristics. This limits the application effect of acoustic emission monitoring technology in engineering monitoring and disaster warning. Therefore, in this paper, by analyzing the acoustic emission signal during the process of rock uniaxial compression failure under different loading rates, the correlation between the characteristic parameters of the acoustic emission signal is studied. It provides a basis for exploring the use of the characteristics of acoustic emission sources to identify rock failure methods.

2. Sampling and methodology

2.1. samples
The granite used in the experiment is about -500m underground in Xincheng Gold Mine, Shandong Province.

The selected rock sample has uniform and fine texture, good integrity and few original defects. The granite material is made into a standard cylindrical specimen with a diameter of 50mm and a height of 100mm, and the flatness of the cross section is less than 0.02mm, and the end surface of the sample is smooth and flat, which meets the requirements of the international rock mechanics test standards.

2.2. Experimental equipment
Uniaxial compression experimental system: The experiment adopted GAW-2000 rock rigid compression tester manufactured by Changchun Chaoyang instrument co. The system, which is composed of a press machine, a DCS controller and a Power Test control program, boasts the functions of closed-loop control, constant load control and load retention. Moreover, the system whose hydraulic oil pump can reach a maximum load of 2000kN is able to realize equal loading, constant-rate loading and force-displacement compound control.

Acoustic emission monitoring system: Acoustic emission monitoring system monitors and collects acoustic emission data in the process of uniaxial compression failure. Acoustic emission adopts PCI-2 multi-channel acoustic emission monitoring system produced by PAC of American physical acoustics company. Rock mechanics testing and acoustic emission testing system are shown in Fig. 1.
2.3. Experimental process

The uniaxial compression test adopts the method of deformation control to load, the loading rate is 0.05 mm / min, 0.01 mm / min, 0.005 mm / min. A total of 3 groups were tested in the experiment, and 3 samples were tested in each group, and continuous loading was performed until the samples were destroyed. If the test results have large dispersion, increase the sample and take the intermediate results with small dispersion for analysis.

At the beginning of the test, the loading system and the acoustic emission monitoring system were turned on at the same time to ensure that the relevant mechanical parameters and acoustic emission parameters were recorded in real time at a uniform time. To eliminate the influence of environmental noise on acoustic emission monitoring data, in the test, the amplification gain was 40 dB, the threshold value was 40 dB, the waveform sampling frequency was 1 MSPS, the retrigger was 256, and the length was 2 K. The acoustic emission sensor selected was an R6 resonant-type high sensitivity sensor with a resonant frequency of 35~100 kHz. In order to reduce the attenuation and distortion of the acoustic emission signal, apply an appropriate amount of coupling agent between the rock and the acoustic emission sensor to ensure the better coupling.

3. Experimental results

3.1. Relationship between strength and strain rate

The stress-strain curves of granite under different loading rates are shown in Figure 2. Although the stress-strain curve characteristics of granite are different under different loading rates, they have
similar characteristics. According to the crack growth process, they can be divided into four stages: compaction, elastic deformation, plastic deformation and post-peak failure.

In order to further compare and analyze the peak stress and strain values of the granite under different loading rates, the results are shown in Figure 3. There is a good statistical law between the loading rate and the rock's ultimate compressive strength and its corresponding strain value. As the loading rate increases, the ultimate compressive strength of the rock increases significantly, and the relationship between the loading rate and compressive strength is an increasing function of the power function. As the loading rate increases, the strain value corresponding to the peak intensity decreases, and the strain value corresponding to the loading rate and peak stress value is a decreasing function of the power function.

3.2. Relationship between strength and AE absolute energy

The absolute energy of acoustic emission is a true reflection of the energy of the acoustic emission impact signal, which can reflect the scale of the internal fracture of the rock. The unit of absolute energy of acoustic emission is attoJoules (aJ), and 1 aJ is equivalent to $10^{-18}$ J. Figure 4 shows the variation curve of stress and AE absolute energy with time during the uniaxial compression of rock under different loading rates.

![Fig.4 The variation curve of stress and AE absolute energy with time during the uniaxial compression of rock under different loading rates: (a) 0.05 mm/min, (b) 0.01 mm/min, (c) 0.005 mm/min.](image)

It can be seen from Fig. 4 that after the peak stress, the AE absolute energy of the rock increases rapidly, indicating that the energy is suddenly released, and the peak of AE absolute energy lags behind the peak of stress. The peak of AE absolute energy is $1.15 \times 10^{10}$ aJ when the loading rate of rock is 0.05 mm / min, and the peak of AE absolute energy is $1.86 \times 10^{10}$ aJ when the loading rate of rock is 0.01 mm / min, and the peak of AE absolute energy is $2.23 \times 10^{10}$ aJ when the loading rate of rock is 0.005 mm / min. It shows that as the loading rate decreases, the peak of AE absolute energy increases. This is mainly due to the reduction of the loading rate, the deformation rate of the rock is reduced, and the energy accumulation is slow. When the rock is suddenly destroyed, the energy is released instantly, resulting in the instantaneous increase of AE absolute energy. The AE cumulative energy value of the rock under different loading rates shows a jump growth law after the plastic deformation stage, which
is mainly due to the rapid expansion of the crack inside the rock at this stage, the increase of the AE absolute energy release, the cumulative energy of the AE occurs jumping increase.

3.3. Relationship between AE counts and signal duration

The correlation graph analysis method is the most commonly used method in the signal analysis of acoustic emission. The signal parameters generated by acoustic emission sources of different natures will have different growth rates, sizes, and ranges. By drawing the correlation diagram between different acoustic emission parameters, the characteristics of the rock acoustic emission source under different loading can be analyzed, so as to identify the acoustic emission source.

Since the values of acoustic emission parameters span multiple orders of magnitude, in order to be more intuitively expressed, a logarithmic scale is used to describe the changing rules of acoustic emission parameters. Figure 5 shows the correlation between the AE count and duration of rocks under different loading rates. From the double logarithmic coordinates of FIG. 5, the count value of the acoustic emission signal with a long duration is large. The distribution of the correlation diagram of AE count and duration showed a triangular distribution, and the angles of the top angles of the triangles with rock loading rates of 0.05 mm/min, 0.01 mm/min, and 0.005 mm/min were 19°, 20°, and 23°, respectively. It shows that under uniaxial compression, as the loading rate decreases, the angle of the apex angle of the triangle of the AE count and duration correlation diagram increases.

3.4. Relationship between AE absolute energy and signal duration

Figure 6 is a correlation diagram between the absolute energy of rock AE and the duration under different loading rates. From the double logarithmic graph in Figure 6, although the rock loading rate is different, the relationship between the absolute energy of AE and the duration is as follows:
At different loading rates, the evolution trend of the correlation diagram of AE absolute energy and duration is the same, indicating that the rock crack propagation evolves in the same way. However, as the loading rate decreases, the opening of the curve of the quadratic equation obtained by fitting the relationship between the absolute energy of AE and the duration gradually increases, and the width of the correlation diagram of the two gradually decreases.

3.5. Relationship between AE absolute energy and amplitude
Fig. 7 is a correlation diagram between the absolute energy and amplitude of rock AE under different loading rates. It can be seen from Figure 7 that despite the different loading rates of the rocks, the correlation points of the AE absolute energy logarithm and amplitude are all distributed in the linear channel and conform to the linear rule.

As the loading rate decreases, the slope of the fitted line of the AE absolute energy logarithm and the amplitude gradually decreases, and the width of the linear channel of the distribution of associated points also gradually decreases.
4. Conclusions

(1) The correlation between the acoustic emission signal characteristic parameters of rocks during uniaxial compression failure under different loading rates was studied. The peak strength of the rock and the peak value and accumulation of AE absolute energy during the compression and shear failure process change positively with the loading rate.

(2) The distribution of the correlation graph of the ring count and duration of the acoustic emission has a triangular distribution. The loading angles of 0.05 mm/min, 0.01 mm/min and 0.005 mm/min correspond to the angles of the apex angles of the triangles being 19°, 20° and 23°, respectively. It shows a trend that the angle of the apex angle of the triangle of the correlation graph gradually increases as the rock loading rate decreases.

(3) The distribution of the corresponding points between the absolute energy of AE and the duration accords with the relationship of the function of unary quadratic. It shows that as the rock loading rate decreases, the opening of the fitting curve gradually increases, and the width of the correlation graph gradually decreases.

(4) The correlation graph of AE absolute energy and amplitude is linearly distributed. The linear slopes corresponding to the loading rates of 0.05 mm/min, 0.01 mm/min and 0.005 mm/min are 0.10749, 0.10481 and 0.10111, respectively. It shows the trend that the slope of the fitted line decreases gradually as the rock loading rate decreases.

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