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Error Analysis of Limestone Acoustic Emission B-Value under Uniaxial Compression

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Abstract: *By conducting uniaxial compressional acoustic emission tests on limestone, the characteristics of the acoustic emission b-value throughout the process of rock fracture and the analysis of b-value calculation errors were investigated. The results show that a threshold of 50 dB and a step length of 7 dB resulted in the smallest error in the b value, where b = 1.07 and the fit R2 = 0.946. When the step length is 1dB, the b-value error is minimised at a starting amplitude of 50dB, where b=1.13, R2=0.886. Both have relatively small errors and b values close to 1, the b value for rock damage. In the dynamic b-value graph over time, the b-value tends to increase in the early stages and is accompanied by a low energy signal from the micro-rupture. In the later stages of compression, an acoustic emission signal with extremely high energy values appears, accompanied by a sharp decrease in the b-value. This indicates that large-scale cracking is beginning to occur within the limestone, producing high energy and amplitude values, which is reflected in the trend of decreasing b-values. At the peak of energy and stress, the b-value drops to close to about 1, at which point the limestone is destroyed. This provides a reference for the study of rock damage using acoustic emission b-values.*

Keywords: *Limestone, Acoustic emission, B-value; Uniaxial compression, Error analysis*

1. Introduction

Material damage releases acoustic emission signals to the outside. The use of acoustic emission techniques to study material damage can reveal the mechanism of damage within the material and even predict the damage to the structure in advance, providing early warning to prevent damage from catastrophic events[1]. A large number of scholars have used acoustic emission techniques to study materials such as coal[2], concrete[3] and wood[4]. One of these materials, rock, as a brittle material has also been studied by a large number of scholars using acoustic emission techniques[5-8].

The study of rock damage using acoustic emission techniques is often characterised by several characteristic parameters, of which the distribution characteristics of the amplitude (i.e. the b-value) have attracted a great deal of scholarly interest. The b-value was originally proposed and used in seismological studies by Gutenberg et al[9]. The b-value is also widely used in the study of rocks because of the similarity between the energy signal released when a rock breaks and the energy signal released by an earthquake[10-13]. The b-value is often calculated using the maximum likelihood and least square method. The least square method is a better way to calculate the b value. When calculating the amplitude using the least square method, errors often arise due to the limitation of the starting amplitude and step length division. Therefore, this paper presents a statistical analysis of limestone b-value errors under uniaxial compression using the least square method with limestone.

2. Materials and Methods

2.1. Experimental Equipment and Materials

The loading system is the HYAS-1000C triaxial rock testing system with a maximum axial load of 100 t. The accuracy and range fully meet the experimental requirements. DS5 acoustic emission system. instrument parameters and settings are shown in Table 1. The material for this experiment was a limestone specimen with dimensions of a 50mm x 100mm cylinder. The accuracy of the specimen is: the parallelism deviation of the two ends of the specimen shall not be greater than 0.1mm; the deviation of the diameter of the two ends of the specimen shall not be greater than 0.2mm[14]. The two end faces of the specimen

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should be perpendicular to the axis of the specimen. The before and after specimens for the test are shown in Figure 1.

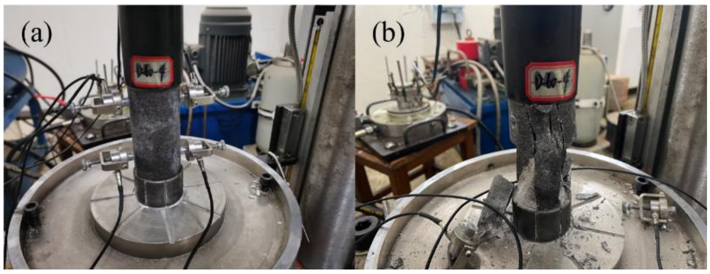

Figure 1: a Pre-test specimen; b After-test specimen

Table 1: Parameters of AE system

Test parameter	Set value
Continuous data pass rate	65.5MB/s
Waveform data pass rate	48 MB/s
Threshold for detection	50dB
Preamplifier gain	40dB
Sampling frequency	3MHz

2.2. Experimental Methods and Procedures

Uniaxial compression experiments were carried out on limestone specimens and the entire compression process was divided into two stages. In the first stage, a small force was applied to the component to hold it in place and the acoustic emission signal was not collected at this stage, thus avoiding the interference of the signal generated by the friction between the press and the specimen in the first stage with the final experimental results. The second stage was loaded by displacement loading at a rate of 0.003mm/s. A total of four sensors were placed on the surface of the specimen, with glue applied to the contact positions of the sensors and the components for coupling and fixing, see Figure 1a for the arrangement. The acoustic emission signal is acquired with a threshold for detection of 50 dB, a preamplifier gain of 40 dB and a sampling frequency of 3 MHz.

3. Results and Discussions

3.1. Energy-Amplitude

Figure 2 shows the limestone acoustic emission energy spectrum. Figure 3 shows the limestone acoustic emission amplitude graph. The whole experiment lasted 500s. The graph shows a good agreement between energy and amplitude, with high energy tending to correspond to high amplitude and an overall very consistent trend between the two. Between 0 and 100 s, only a small amount of acoustic emission signal is generated, which corresponds to the dense stage of the compression of the limestone. After 100s, low amplitude and energy signals begin to appear and trend upwards until the limestone is destroyed at around 500s at this time both energy and amplitude reach their peaks. subtitle.

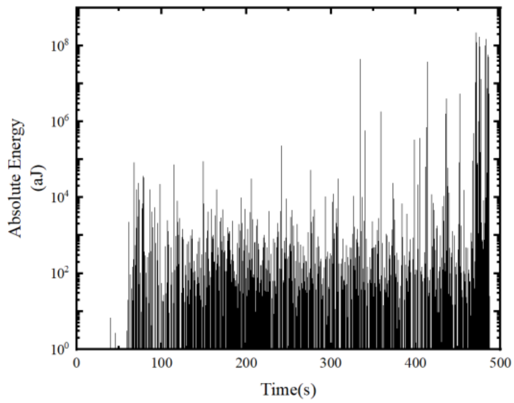

Figure 2: Acoustic emission energy spectrum of limestone

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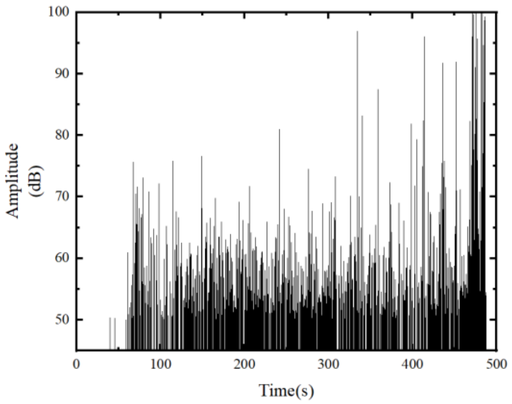

Figure 3: Amplitude - Time

3.2. Error Analysis for Different Step Lengths

The concept of b-value originated from seismological studies, where Gutenberg et al[9]. pioneered the idea that the relationship between earthquake frequency and magnitude satisfies the equation:

$$Log_{10}^{N}=a-b*M \quad (1)$$

Where M is the magnitude of the earthquake, N is the corresponding number of earthquakes and a is a constant. It was found that the characteristics of the distribution of acoustic emission events during rock compression have some similarity to the mechanism of seismic evolution, and the acoustic emission b-value parameter was thus derived and calculated as follows:

$$Log_{10}^{N}=a-b*(AdB/20) \quad (2)$$

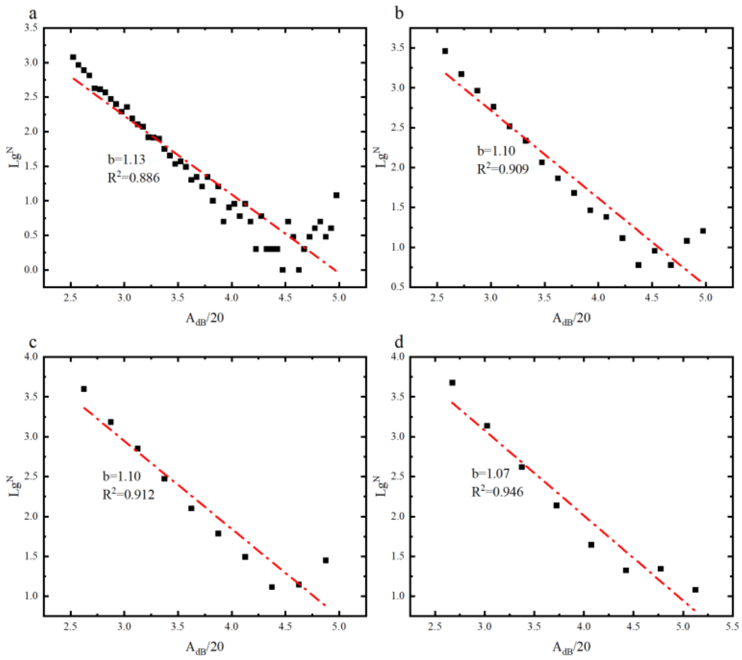

Figure 4: Acoustic emission amplitude-frequency distribution for different step lengths a 1dB b 3dB c 5dB d 7dB

Where: AdB is the maximum amplitude of the acoustic emission event. The b-value is calculated using the least square method. The amplitude-frequency distribution of the three acoustic emissions is characterised in Figure 4, and its absolute slope is the b-value. The starting amplitude is 50dB and the step lengths are 1dB, 3dB, 5dB and 7dB in that order. The b-values for the four are 1.13, 1.10, 1.10 and 1.07 respectively, showing a decreasing trend and gradually approaching the rock damage b-value of 1.The fits are 0.886, 0.909, 0.912 and 0.946 respectively. It is easy to see that the fit also increases gradually. Therefore, a step length of 7 dB is appropriate when calculating the b-value of the acoustic emission from limestone. The reason for this is that the amplitude of the acoustic emission signal does

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not increase uniformly, but there is a sudden increase in a large number of high amplitude signals at the point of imminent destruction. Therefore, when choosing a larger step length, the higher amplitude signals can be combined with the lower amplitude signals in the same group, thus reducing the error. A large number of scatter points in the graph corresponding to the horizontal coordinates 4.5-5 are the high amplitude signals generated during the damage.

3.3. Error Analysis of Different Starting Amplitudes

Figure 5 shows the characteristics of the amplitude-frequency distribution of acoustic emissions for different starting amplitudes at 1 dB step length. The starting amplitudes are 50dB, 51dB, 52dB and 53dB, with b-values of 1.13, 1.12, 1.10 and 1.09 respectively, showing a decreasing trend and approaching the rock damage b-value of 1. The accuracy rates were 0.886, 0.879, 0.872 and 0.862 respectively, with a decreasing trend. Therefore, a lower starting amplitude should be chosen when calculating the b-value for acoustic emissions from limestone. Although the rock produces a large number of high amplitude signals when it is on the verge of destruction, it also produces a large number of low amplitude signals before it is on the verge of destruction. If the starting amplitude is low, a large number of low amplitude signals will be under-counted, resulting in large errors.

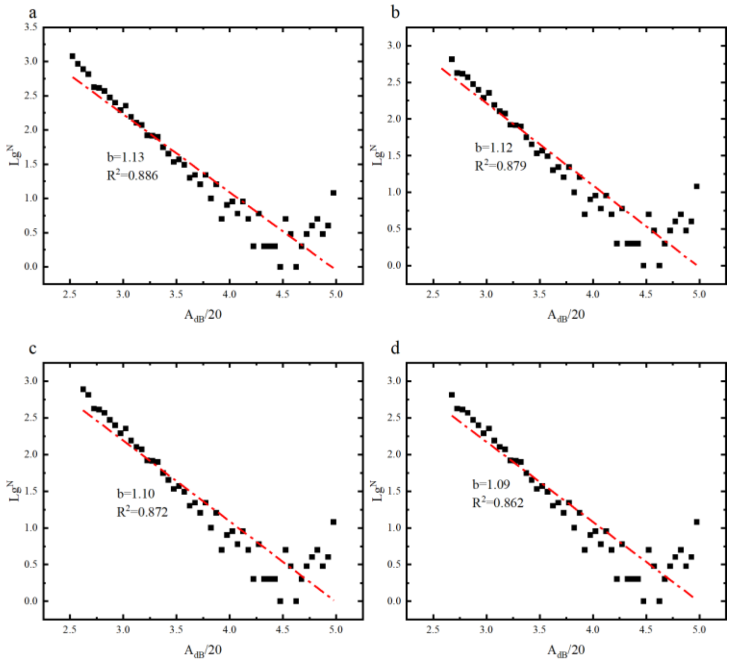

Figure 5: Acoustic emission amplitude-frequency distribution for different starting amplitudes a 50dB b 51dB c 52dB d 53dB

3.4. Dynamic B-value Analysis

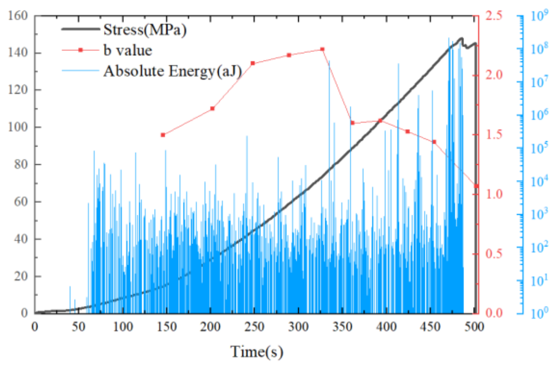

Figure 6: Curves of stress, b-value and energy of acoustic emission with time

The loading process is divided into 10 stages according to the stress level reached, with a starting amplitude of acoustic emission of 50 dB and a step length of 7 dB. Based on the results of the above

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analysis, the cumulative acoustic emission b values for each stress stage can be obtained, and the damage inside the rock at different stress stages and the variation characteristics of the acoustic emission b values can be analysed, as shown in Figure 6.

The b-values trended upwards in the early part of the period and remained at a high level. This is due to the small-scale microstructure that also occurs in the early stages. This can also be seen in the energy diagram in Figure 2, which is predominantly an acoustic emission signal with very small energy values. In the later stages of compression, acoustic emission signals with very high energy values appear, accompanied with a gradual decrease in b-values. This indicates that large-scale cracking is beginning to occur within the limestone, producing high energy and amplitude values. At the energy peak, the b-value drops to about 1, at which point the limestone is destroyed.

4. Conclusions

(1). In the acoustic emission signals generated during limestone fracture, high energy values often correspond to high amplitude values, with both energy and amplitude reaching maximum values when the rock is destroyed.

(2). When calculating the b-value, larger step length and a lower starting amplitude should be chosen for a relatively small error.

(3). In the dynamic b-value graph over time, the b-value shows a trend of increasing and then decreasing. When the limestone completely fails, the b-value drops to about 1. This provides a reference for the use of b-values to study rock damage.

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