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Experimental Study on the Characteristics of Acoustic Emission in Damage Evolution Process of Marble under Uniaxial Compressive Load

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Abstract. In order to study the relationship of the damage evolution and acoustic emission fractal of marble under uniaxial compressive load, damage evolution and acoustic emission(AE) character of marble under uniaxial compression are studied using MTS815.04 servo-controlled rock mechanical test system and AEwinE1.86 system. The relationship curves of damage variable and correlation dimension is analyzed. The results show that the value of correlation dimension is great and there are few feature points in the stage of initial damage, and then the values of correlation dimension drastically change and reduce as a whole and feature points increase rapidly in the stage of damage stable evolution and development, finally the values of correlation dimension reduce to the minimum and feature points are intensive in the stage of damage accelerating development. The phenomenon that the value of correlation dimension appear choppy greatly reduce can be thought failure precursor of rock and that the values of correlation dimension reduce to the minimum can be thought the damage of rock basically completed.

Introduction

In recent years, damage evolution of rock becomes a research focus in the rock mechanics, the analysis of rock damage evolution mechanism of the stability of surrounding rock in the construction of practical engineering monitoring and early warning is great significance. The failure process of rock is its internal micro process of crack initiation, expansion and fracture [1]. The fracture has fractal characteristic. By using the traditional mechanical method based on European space has certain limitation, so fractal theory to rock mechanics to study the damage of the rock provides a new method.

Many researchers have done a lot of work in the rock damage evolution and the AE fractal features [2-11]. Research shows that the fractal theory to study rock acoustic emission characteristics can better reflect the rock loading damage internal crack in the process of production and the variation characteristics. It can be applied to characterize the damage evolution of the rock. But at present most

of the studies, most scholars just studied the period before stage of rock loading peak stress with less study on the whole process of rock under load fractal characters.

In view of this, in order to better understand the laws of rock damage evolution and the damage evolution and the whole process of rock damage fractal characteristics. In this paper, the uniaxial sustained load damage evolution process under the condition of marble specimens of AE fractal features are studied.

Marble Acoustic Mission Experiment of Uniaxial Compression

Test load equipment is MTS815.04 electro-hydraulic servo machine and acoustic emission testing system chooses AEwinE1.86 system. For marble specimens in the process of deformation and failure time, stress, strain and acoustic emission parameters such as ringing count were monitored.

According to the data obtained from monitoring of test, get the marble specimens under uniaxial relation of deformation and damage and acoustic emission under the condition of continuous load, as shown in figure 1 to 3. As we can seen from figure 1, the complete stress-strain curve of marble specimen can be divided into three stages, namely compaction stage, stage of elastic deformation and plastic deformation stage. As we can see from figure 2 to 3, at the beginning of the load marble specimens is at the consolidation stage, initial crack closure will produce a small amount of internal acoustic emission events; With continuous loading, stress increases to the peak stress and sample at the elastic stage, internal almost no cracks produced and extended, so only in very small amounts of acoustic emission events; After entered the stage of plastic deformation, unloading stress decreases, and the sample inside began to produce new cracks, acoustic emission events began to increase, crack interaction occurs through gradually formed between macro fracture, acoustic emission events are very active. Continued loading stage acoustic emission counts in maximum stress is less, the stress level began to drop significantly when ringing count maximum level acoustic emission, and acoustic emission events has increased sharply.

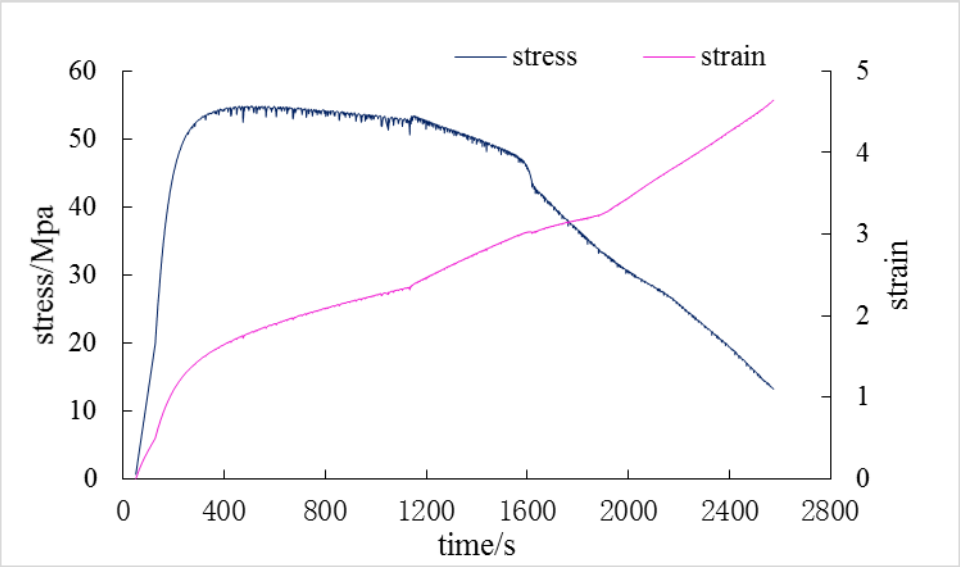

Fig.1 Relation curves between stress and strain of marble under uniaxial compressive load

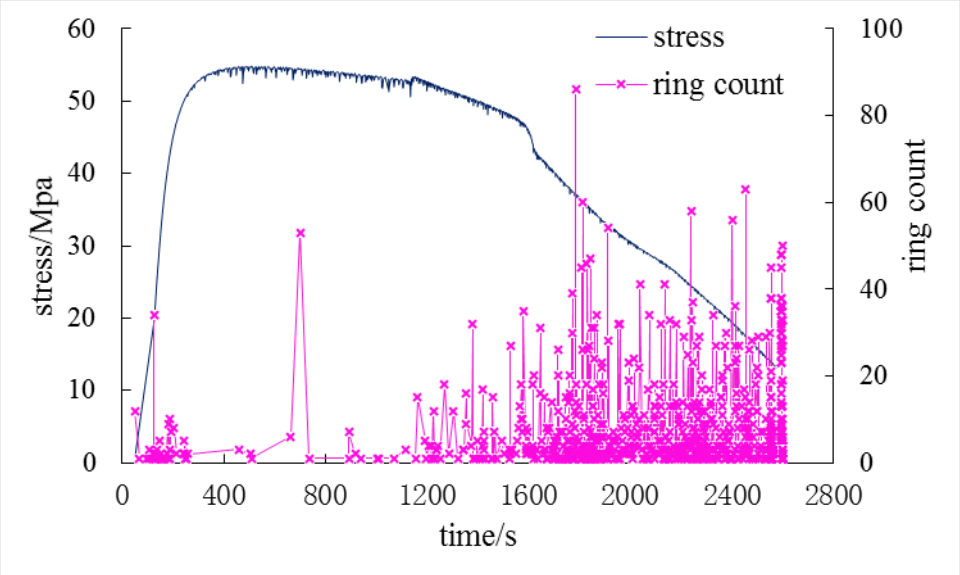

Fig.2 AE ring-down counts-time curve and stress-time curve of marble under uniaxial compressive load

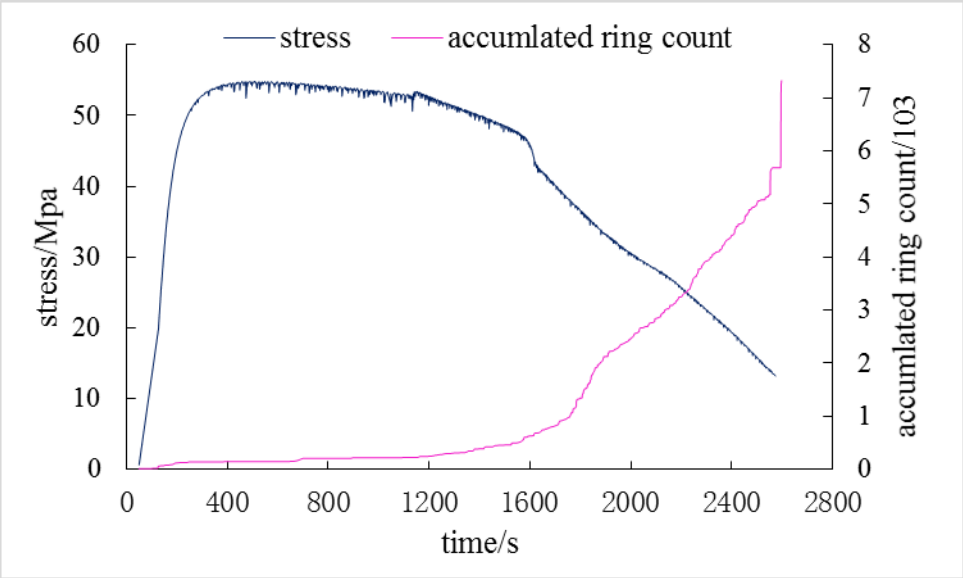

Fig.3 AE cumulative ring-down counts-time curve and stress-time curve of marble under uniaxial compressive load

Damage Evolution Analysis

Based on the Acoustic Emission of Damage Variable Analytic Expression. Liu Baoxian [12] defines damage variable with acoustic emission ringing count and total acoustic emission ringing:

$$D = D_u \frac{C_d}{C_0} = \left(1 - \frac{\sigma_c}{\sigma_p}\right)\frac{C_d}{C_0} \tag{1}$$

Du is damage threshold, C_d is rock damage section of acoustic emission at any time the cumulative ringing count, C_0 is rock damage reaches the critical value of the accumulated acoustic emission ringing count, σ_c is residual strength and σ_p id peak intensity.

So damage model based on acoustic emission ringing count are obtained

$$\sigma = (1 - D)E\varepsilon = \left(1 - D_u \frac{C_d}{C_0}\right)E\varepsilon \tag{2}$$

By formula (2), the acoustic emission at any time when the damage variable and the accumulative ringing count Cd shows correlation change. Using the expression to describe the damage evolution of marble under uniaxial condition.

Damage Evolution Analysis. According to the above damage variable defined method, get the marble strain - damage variable relation curve, as shown in figure 4 (including σ_p = 54.84Mpa, σ_c = 12.18Mpa). According to figure 4, the marble of the damage evolution under the conditions of uniaxial compression can be roughly divided into three stages, the first phase of the initial damage stage, the load to strain reaches 3.0 or so, damage variable change weak approach to zero, although

this one phase stress level has reached the peak stress, marble sample is still in the stage of elastic deformation. The second stage of damage stability evolution stage of development, the strain is about 3.0~4.5, the stress significantly decreases, and damage variable began to steady increase to 0.4 or so. Using plastic deformation stage, the stage of primary crack extension and produce new. The third stage for damage development phase, the strain is about 4.5~4.7, the stress and stability decreases, and damage variable has risen sharply until the damage threshold. At this stage the sample internal crack expanding quickly, well versed in, the main rupture occurred, the macroscopic damage appeared finally.

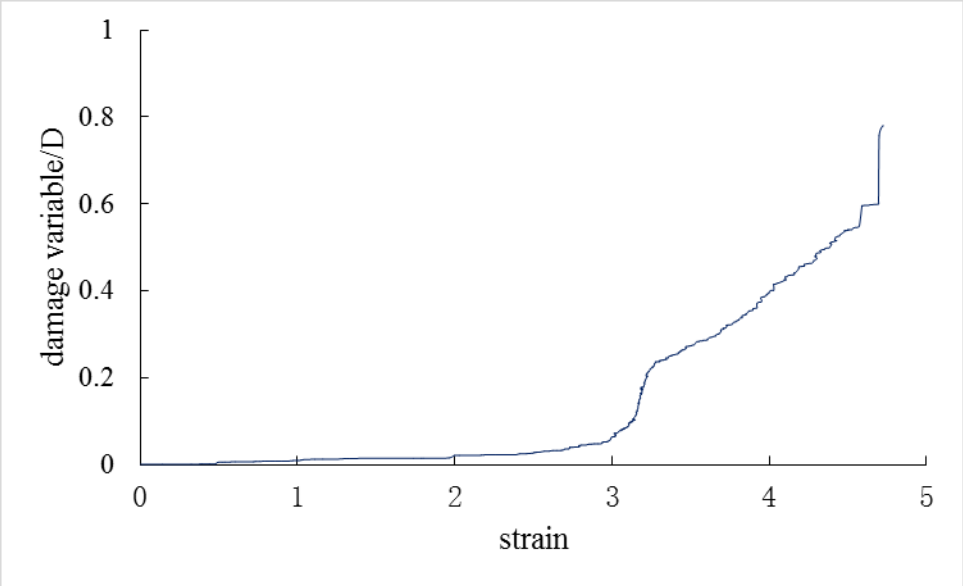

Fig.4 Strain-damage curve of marble under uniaxial compressive load

Acoustic Emission Analysis Correlation Dimension Change

G-P[13]algorithm is used to calculate correlation dimension of the acoustic emission ringing count, its principle and calculation method is as follows.

Test collection of acoustic emission ringing count is one dimensional data. corresponding vector set {xi}(i=1，2，3…，n), construct a m (m < n) three-dimensional reconstruction of phase space R^m, the dimensions of the m for the phase space reconstruction, known as the embedding dimension, take before m number as a vector of m dimensional space, according to the vector set structure N= n-m+j (m<n, j = 1, 2, 3,..., m) of a vector space X_{n-m+j}= $\{X_{n-m+j}\}$, vector by the refactoring

$$X_{n-m+1} = \begin{Bmatrix} x_1 & x_2 & \cdots & x_{n-m} & x_{n-m+1,} \\ x_2 & x_3 & \cdots & x_{n-m+1} & x_{n-m+2} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{m-1} & x_m & \cdots & x_{n-2} & x_{n-1} \\ x_m & x_{m+1} & \cdots & x_{n-1} & x_n \end{Bmatrix} \tag{3}$$

The correlation functions between these vectors as follows: the correlation functions between these vectors as follows:

$$W(\mathrm{r}) = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} H(r - \left|x_i - x_j\right|) \tag{4}$$

H is Heaviside function as the unit step function; r is a given scale.

Heaviside function is:

$$H(u) = \begin{cases} 0, & u < 0 \\ 1, & u \geq 0 \end{cases} \tag{5}$$

In order to avoid dispersion, when r value generally take:

$$r = kr_0 = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left|x_i - x_j\right| \tag{6}$$

Which k is proportional coefficient.

In log-log coordinates n points (logW (r), log (r)) can be achieves, these points are fitting, fitting for the straight line shows that acoustic emission sequence at a given scale has fractal characteristics, the slope of the linear fitting by the absolute value of acoustic emission related parameters of the correlation dimension, namely:

$$\mathrm{E} = \log W(\mathrm{r}) / \log(\mathrm{r}) \tag{7}$$

Using MATLAB software in calculating the correlation dimension of acoustic emission ringing count, 100 regulations calculation of the data length, the first data obtained from the corresponding time and associated dimension values correspond.Take 20 incremental data length.Concrete is divided into four steps:

(1) Determining the embedding dimension m, and according to the embedding dimension of reconstructed phase space;

(2) Determining the size of the r: write command to calculate, using the formula to calculate the r value;

(3) Calculation according to the Heaviside function for values;

(4) Fitting of the income of a series of point (logW (r), log (r)), fitting results for the straight line and the slope of the fitting line absolute value is the E values.

Get under the condition of uniaxial loading marble correlation dimension-time curve is shown in figure 5. According to fractal theory of acoustic emission ringing count correlation dimension change has three conditions: (1) the correlation dimension increase event specimens of small and medium-sized rupture, micro fracture gradual development; (2) the correlation dimension of the decline, suggesting that specimens rupture of big events happen within increases; (3) the correlation dimension fluctuate along with the change of stress level, this shows that acoustic emission events of medium and small proportion bigger, damage of the specimens is given priority to with tiny micro fracture.According to the figure 6 shows that the correlation value with the time of the overall trends to increase circulation reduce and reduce the size of the ups and downs of change.Correlation dimension of the feature points with time gradually increased, initial less, less shows that acoustic emission events, late and more intensive, acoustic emission events are active.To illustrate marble sample loading damage is generated micro fracture rupture is a kind of progressive development to intensive process with big burst incident.

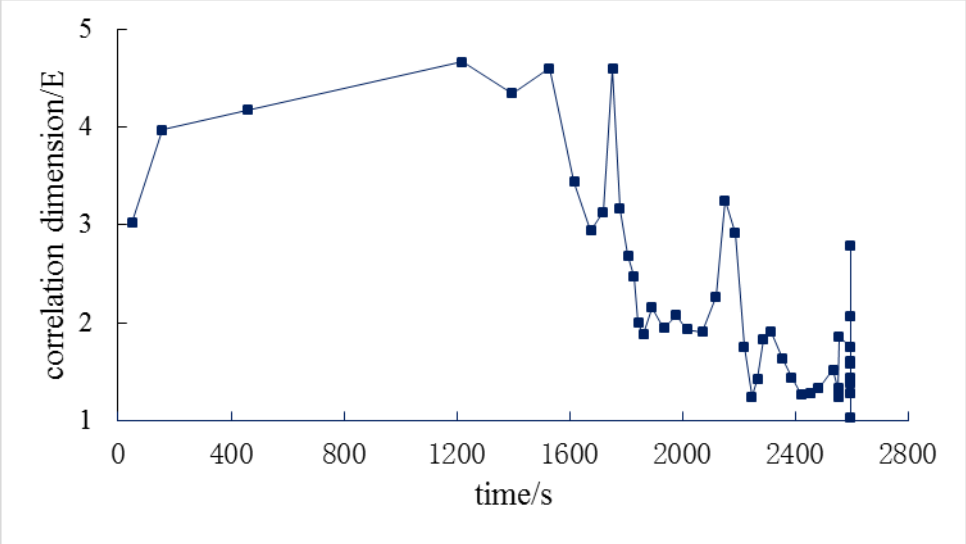

Fig.5 correlation dimension-time curve of marble under uniaxial compressive load

Damage Evolution Process Analysis of Characteristics of Correlation Dimension Changes

According to three stages, the damage evolution of the sample for the correlation dimension and time together and get the marble damage evolution characteristics and the acoustic emission characteristics of correlation dimension as shown in figure 6 to 7.

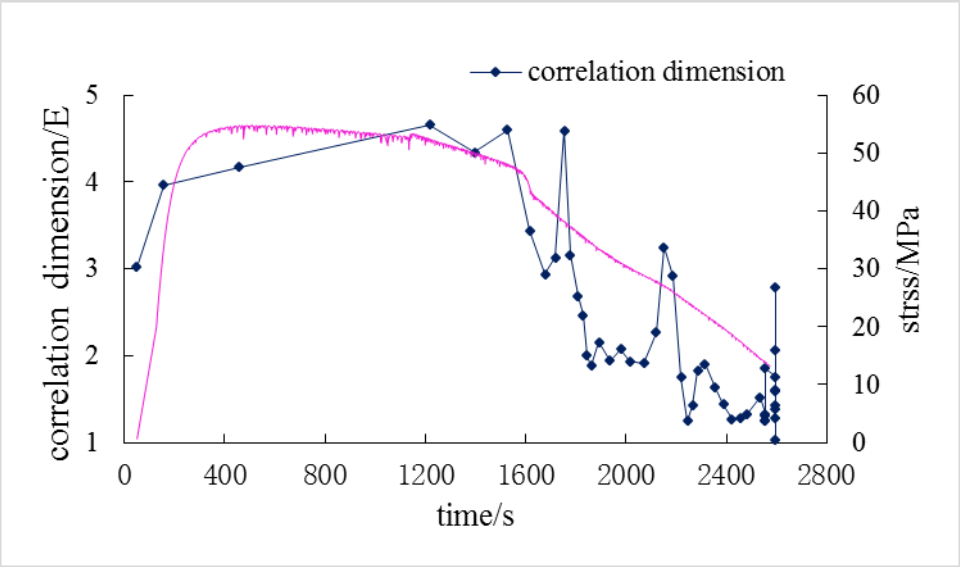

Fig.7 Stress-correlation dimension curve and time curve of marble under uniaxial compressive load

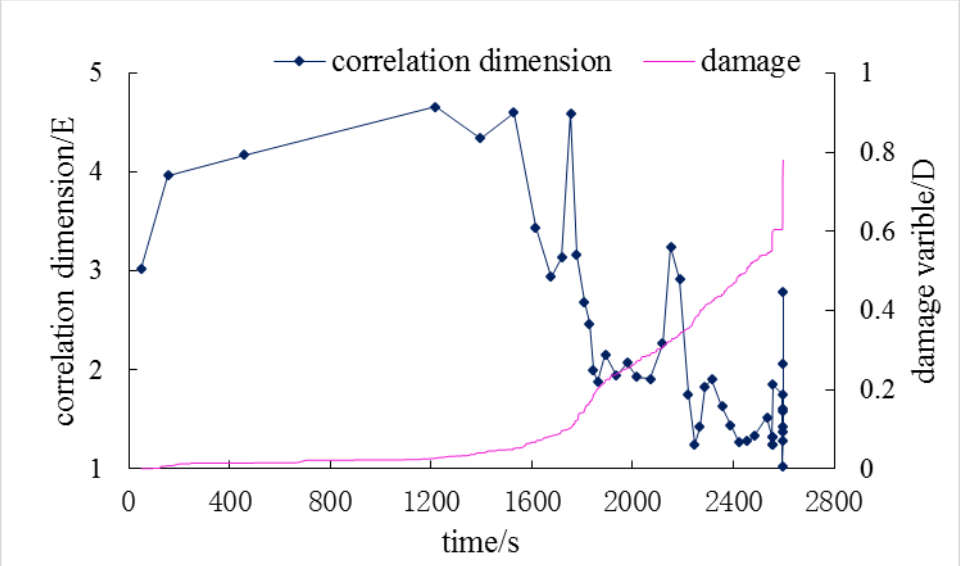

Fig.8 Damage-correlation dimension curve and time curve of marble under uniaxial compressive load

The figure 6 to 7 show that at the initial stage of damage, increase after the peak stress and axial loading stress continues to load, correlation dimension value is larger and the feature points, less damage variable values change increase is not obvious close to zero, internal acoustic emission events less sample shows that the phase, the initial crack by pressure, at the elastic stage;Entered a stage of stable damage evolution, the axial stress began to unload decreases, and the correlation value and change and decreases, and correlation dimension feature point increase in the number of damage variable value increases rapidly, that sample internal acoustic emission events increase, produce new crack extending, and in plastic deformation stage;To damage the accelerated development stage, stable axial stress decreases, and the correlation value increases quickly after sharply reduced to a

minimum and unusually intense feature point distribution, damage variable values spurt to the critical value, shows the active phase acoustic emission, sample internal macro crack produces, basically complete destruction.

Conclusion

Internally generated in the process of rock failure fracture and crack extension will produce acoustic emission events, namely acoustic emission events is a characteristic of rock failure, through uniaxial compression tests of marble failure process under the condition of acoustic emission ringing count correlation dimension analysis study found:

(1) Marble acoustic emission ringing count the value of correlation dimensions increases with time the overall trend of the first cycle increase and reduce, reduce the ups and downs of change after loading damage is micro fracture rupture is a kind of progressive development to intensive process and with big burst incident.

(2) The correlation dimension of the feature points with time gradually increased, initial less, less shows that acoustic emission events, late and more intensive, acoustic emission events are active.So the correlation dimension of feature point intensity reflects the active degree of acoustic emission events.

(3) In the initial stage of damage, the correlation value is bigger and less feature points;After entering damage evolution stable development phase, the correlation values appear drastically changes and reduced, and feature point increase, into the accelerated development stage after injury, the correlation value reduced to the minimum after the jump, and feature point set.Correlation dimension sharply reduced to the minimum after spurt, said sample destruction was basically completed.

(4) Under the condition of uniaxial sustained loading, axial stress increases to the peak and continuous loading, the process of damage variable is almost zero, it wouldn't change correlation dimension characteristic, when the axial stress unloading correlation dimension began to appear larger fluctuation change, damage variable began to increase rapidly, therefore, when the correlation dimension began to appear larger fluctuation change, but at the beginning of the sentence to rock breaking.

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