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Damage evolution model of cemented tailing backfill based on acoustic emission energy

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Abstract. Tailings cemented backfill is widely used in the production activities of mine management goaf, and it is also one of the main technologies to realize green mining and safety production. In this paper, the cyclic loading and unloading test of cemented tailing backfill is carried out based on acoustic emission technology, the evolution trend of AE energy in the loading process is analyzed, the damage variable based on AE energy is defined, and the damage evolution equation of cemented tailing backfill based on AE energy is established, and the quantitative relationship between AE energy and damage energy release rate is explored. It provides basic research basis for bearing process analysis and failure prediction of cemented backfill in mine site.

Key words: tailings cemented backfill; cyclic loading and unloading; damage characteristics; AE energy.

With the development of mining to the deep, the filling mining method can effectively improve the ore recovery rate and reduce the ore dilution rate, so the filling mining method is widely used [1]. But with the development of mining to the deep, with the frequent occurrence of the accidents of filling body instability, it brings a huge threat to the underground safety production activities, and causes the filling body instability damage and even collapse. It is precisely because the filling body in the process of long-term stress loss, the internal damage continues to accumulate, and finally leads to the instability damage. Therefore, it is very important to study the damage and instability prediction of backfill.

From the point of view of energy, Li Zhongyou et al [2-5]. Analyzed and described the deformation and failure behavior of quasi brittle materials, and made remarkable achievements. The damage forms are various and the changes are different, but they all have a common characteristic, that is, they are all irreversible processes that need to dissipate energy. Therefore, it is feasible to study the influence of damage on the degradation of macro mechanical properties from the energy dissipation characteristics in the process of material deformation and failure, and establish the damage constitutive model. Wang Chuangye et al. [6-7] Selected brittle red sandstone for acoustic emission uniaxial test, the damage variable obtained by single parameter ring counting can well reflect the characteristics of rock damage evolution. Based on the comparison between the stress curve of Weibull distribution and the measured stress curve, Cao Anye's test fitting equation can better reflect the damage evolution process of rock



samples during uniaxial loading, especially under high loading rate [8]. Based on the relationship between the cumulative number of acoustic emission events and stress, the damage evolution model is derived by Xu Fuwei, which can better reflect the damage evolution law of materials in uniaxial compression [9]. Zizheng Zhang introduced the unloading coefficient of confining pressure to describe the damage evolution characteristics of rock mechanical properties [10].

1. Cyclic loading unloading acoustic emission test of cemented tailing backfill

1.1. Test material

The graded tailings used in the test are all from the vertical sand bin of Dahongshan Mining Area. See Table 1 for the basic physical parameters of graded tailings in Dahongshan Mining Area. See Table 2 for the results of chemical composition analysis and mineral composition analysis by chemical element calibration method combined with X-ray diffraction and scanning electron microscopy. As the grading tailings in Dahongshan Mining Area is relatively fine, the mechanical vibration screening method will cause the loss of some fine-grained components, so the water screening method is used in the test, and the results of the test measured grading tailings size in Dahongshan Mining Area are shown in Table 3

Table 1. Basic physical parameters of graded tailings

density/ (kg/m ³)	Bulk density / (kg/m ³)	Compactness	Voidage	Median particle size /μm	Weighted average particle size /μm
2.897	1.467	0.506	0.494	131	139.29

Table 2. Chemical components of graded tailings

component	FeO	SiO ₂	Al ₂ O ₃	CaO	MgO	Cu	Ag ^a	S	Other
%	23.03	41.09	13.53	5.79	4.65	0.023	1.71(g/t)	0.045	10.83

Table 3. Particle size distribution of graded tailings

Particle size/μm	>560	560~295	295~246	246~97	97~74	74~50	50~37	<37
cumulative yield /%	0.67	1.42	12.00	61.75	80.70	97.48	98.85	100

1.2. Test scheme

The loading mode of this cyclic loading and unloading test is that the first stage is loaded to 50% of its uniaxial compressive strength, and the loading and unloading are carried out in equal amplitude cyclic for three times. The second stage is loaded to 60% of its uniaxial compressive strength, and the same three equal amplitude cycles are unloaded to 20% of its uniaxial compressive strength. By analogy, increase the uniaxial compressive strength by 10% for each stage and cycle three times with equal amplitude until failure (see Figure 1).

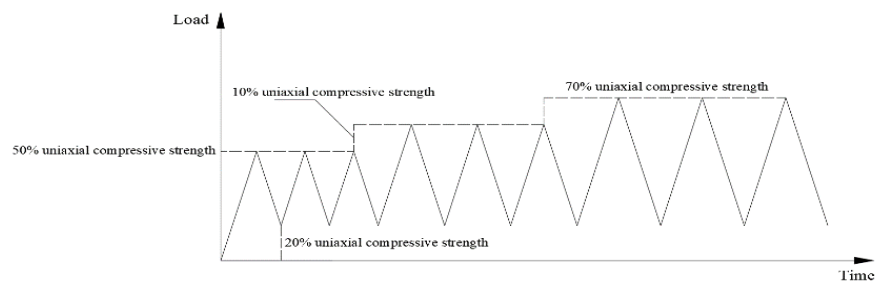


Figure 1. Schematic diagram of cyclic loading and unloading mode

2. Test results and analysis

2.1. Acoustic emission energy characteristics of cemented tailing backfill under cyclic loading and unloading

Under the action of external force, the internal defects or inhomogeneous areas of solid materials will produce stress concentration, which will lead to the generation and expansion of micro fracture. At the same time, the accumulated strain energy will release rapidly in the form of elastic wave. The stress wave is generated at the same time of energy release, which is called acoustic emission (AE). The schematic diagram of acoustic emission is shown in Figure 2.

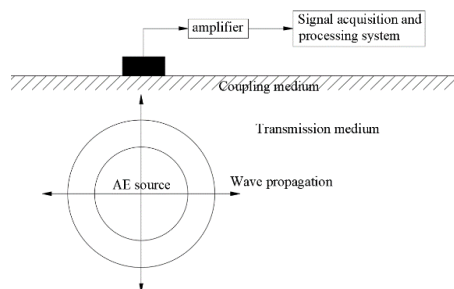


Figure 2. Schematic diagram of acoustic emission

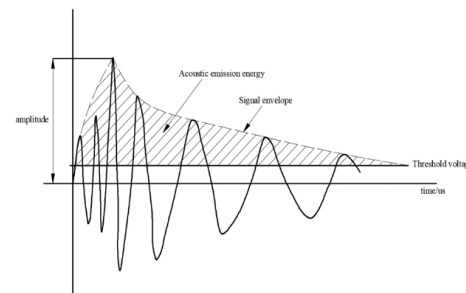


Figure 3. Simplified waveform AE energy diagram of AE signal

The failure of filling body is the result of the joint action of energy release and dissipation. Energy dissipation makes the filling body deteriorate and its mechanical properties decrease, while energy release causes the overall instability failure of the filling body. Therefore, energy is an important index to measure the instability and failure of backfill. Acoustic emission energy refers to the energy released by the partial filler received by the acoustic emission probe due to damage, which can be expressed as the area surrounded by the signal envelope and threshold voltage in Figure 3.

The relation curve of stress time energy count obtained from the test is shown in the figure below.

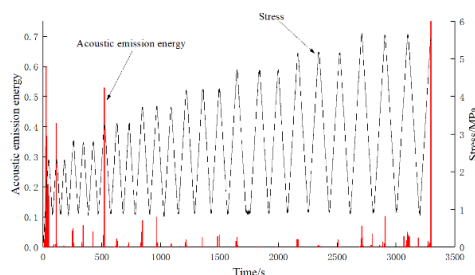


Figure 4. Stress-time-AE energy curve

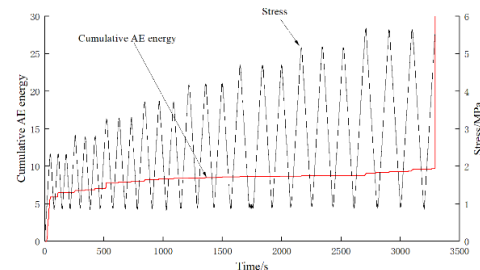


Figure 5. Stress-time-cumulative AE energy curve

It can be seen from Fig.4 and Fig.5 that the cumulative acoustic emission energy develops in a step-by-step manner over time. When loading and unloading at the same stress level, the cumulative acoustic

emission energy is almost unchanged, that is to say, when the upper limit stress of loading and unloading in one cycle is not greater than the upper limit stress of the previous cycle, the acoustic emission hardly occurs; It can also be seen from the figure that when the stress level increases, there is an obvious acoustic emission phenomenon, and the cumulative ring count and cumulative energy count rise a step, which further proves that the filler also has Kaiser effect. In addition, we found that both the AE energy count and the ring count show a trend of "violent → calm → violent" with the process of cyclic loading and unloading. From the above figures, it can be seen clearly that when most of the fillers are close to failure, there is a quiet period of AE. Therefore, the failure of the backfill can be predicted according to this quiet period of acoustic emission.

2.2. Relationship between cumulative energy of acoustic emission and damage evolution

Based on the cumulative energy of acoustic emission, the damage variable D of filling body is defined.

$$D = \frac{\sum_{i=1}^{\text{current Cycle}} Y_i}{\sum_{i=1}^{\text{damage Cycle}} Y_i} \quad (1)$$

Through a large number of loading and unloading tests, the relationship between the cumulative energy Y of acoustic emission and the damage variable D of cemented tailing backfill is shown in the table below. Take the sample of backfill with cement content of 270kg/m^3 , mass concentration of 72%, as an example.

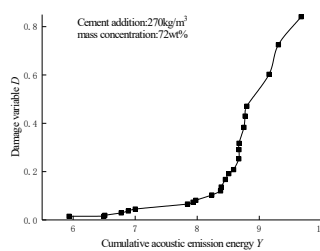
Table 4. Calculation results of 270kg/m^3 -72% of test piece D-Y

Cycle times	1	2	3	4	5	6	7	8
Cumulative damage variable D	0.014	0.015	0.018	0.029	0.037	0.045	0.066	0.073
Accumulated energy of acoustic emission Y	5.935	6.497	6.51	6.775	6.89	7.002	7.844	7.933
Cycle times	9	10	11	12	13	14	15	16
Cumulative damage variable D	0.081	0.103	0.120	0.136	0.167	0.191	0.208	0.253
Accumulated energy of acoustic emission Y	7.977	8.234	8.376	8.387	8.454	8.509	8.587	8.67
Cycle times	17	18	19	20	21	22	23	24
Cumulative damage variable D	0.291	0.317	0.383	0.430	0.471	0.603	0.725	0.841
Accumulated energy of acoustic emission Y	8.673	8.674	8.753	8.773	8.8	9.158	9.309	9.676

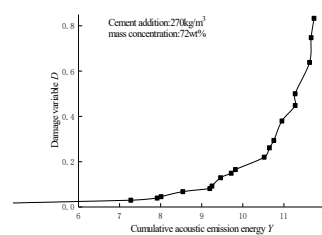
The relation curve between the cumulative acoustic emission energy Y and the damage variable D of the filling body is shown in the figure below.

From figure 6, it can be seen that the cumulative damage variable and cumulative energy of acoustic emission of tailing cemented backfill also conform to the Weibull probability distribution, which can also be described by Weibull probability distribution. Therefore, the damage evolution equation based on cumulative energy of acoustic emission of tailing cemented backfill is established:

$$D = 1 - \exp\left[-B(Y - Y_0)^{\frac{1}{n}}\right] \quad (2)$$



(a) 270kg/m^3 -72%



(b) 270kg/m^3 -74%

Figure 6. D-Y relation diagram

In formula: B , N is the material parameter

The fitting curve of damage variable D and accumulated energy y of acoustic emission of tailing cemented backfill under uniaxial cyclic loading and unloading conditions is as follows.

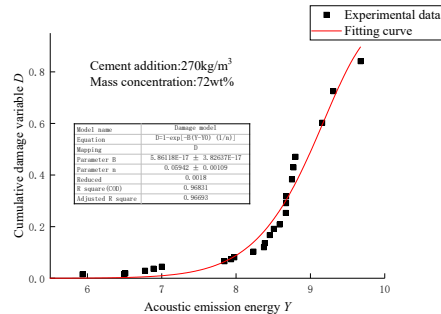


Figure 7. Fitting curve of damage evolution model

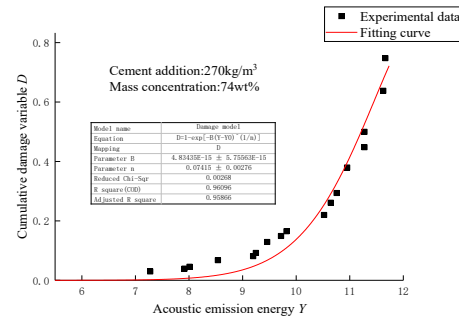


Figure 8. Fitting curve of damage evolution model

It can be seen that the fitting results have high accuracy and small error, so the relationship can accurately reflect the relationship between cumulative damage variable and acoustic emission energy of tailings cemented backfill, which has certain applicability.

2.3. Characteristics of fractal dimension of acoustic emission of backfill under uniaxial cyclic loading and unloading

There are many kinds of fractal dimensions. At present, there are Hausdorff dimension, capacity dimension, box counting dimension, information dimension and so on.

In this paper, the box dimension D_b is used to describe the fractal dimension characteristics of acoustic emission parameters of cemented tailing backfill under cyclic loading and unloading conditions.

Let $A \in H(R^n)$, where R^n is Euclidean geometric space, which is covered by a closed square box with a side length of $1/2^n$, where $N(a)$ represents the number of boxes contained, and the box counting dimension D_b can be expressed as follows.

$$D_b = \lim_{n \rightarrow \infty} \frac{\ln N_n(A)}{\ln(2^n)} \quad (3)$$

If the fractal dimension D_b decreases gradually, the order degree of the acoustic emission process of the filling body increases gradually. If the fractal dimension D_b increases gradually, it shows that the acoustic emission process of the filling body tends to a random "chaos" state.

3. Conclusions

1). Through the acoustic emission test of the tailings cemented backfill under the condition of cyclic loading and unloading, through the processing of the test data, we can see that the acoustic emission energy count of the tailings cemented backfill has obvious stages, that is, when the upper limit stress of the cyclic loading and unloading is not greater than the upper limit stress of the previous cycle, almost no acoustic emission occurs; When the stress level increases, there is an obvious acoustic emission phenomenon, and the cumulative energy count rises one step, which proves that the filler also has Kaiser effect.

2). Based on the accumulated energy of acoustic emission, the damage evolution equation of cemented tailing backfill is established. After fitting, the effect is good and it has certain applicability.

3). Fractal method is used to analyze the fractal characteristics of acoustic emission of tailings cemented backfill under uniaxial cyclic loading and unloading conditions, and the fractal dimension of energy of tailings cemented backfill under uniaxial cyclic loading and unloading conditions is analyzed. Through comparative analysis, the failure of filling body is a process of dimension reduction. The sharp reduction of fractal dimension indicates that the large-scale instability failure of filling body is coming.

Therefore, the sharp reduction of fractal dimension of filling body energy can be used as the criterion for the instability failure of filling body.

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