The 6th International Conference on Mining Science & Technology

Acoustic emission characteristic during rock fatigue damage and failure

Xu Jiang, Li Shu-chun, Tao Yun-qi, Tang Xiao-jun, Wu Xin*

Key Laboratory for the Exploitation of South-western Resources & the Environmental Disaster Control Engineering, Ministry of Education, Chongqing University, Chongqing 400044, China

Abstract

In the realm of rock mass project, fatigue failure characteristics of rock under cyclic load have closed realtionship with the long-term stability of rock mass. Acoustic emission (AE) technique can be used to monitor the production of the micro-cracks development and the failure process in the rock test sample continuously and in-real-time, which makes it better than other methods. The experimental results were displayed as follows: AE Count, Energy, Hits roughly have the same characteristics in the rock fatigue damage process. The AE signal of materials such as rock is arised from the damage. Thus, the damage variable expression was established based on AE Count, Energy, and Hits. The accumulative Hits curve was turned into fatigue damage evolution one in this paper, which obviously indicated the characteristic of ‘the three phases development rules’ of irreversible deformation of rock, conforming to the rules of fatigue damage evolution.

Keywords: acoustic emission (AE); fatigue failure; damage; hits

1. Introduction

Rock mechanics plays an important role in the design, construction and performance assessment of various rock engineering fields such as railway and highway tunnels, bridges, hydro- and nuclear power generation, geological hazards prediction and prevention, and surface and underground space utilizations. The failure and damage of rocks is, therefore, one of the most focused research topics in rock mechanics and rock engineering [1].

In the realm of rock mass project, fatigue failure characteristics of rock under cyclic load have closed realtionship with the long-term stability of rock mass [2].

As brittle materials, concrete fatigue damage has been studied more in-depth at present [3-5]. In the realm of rock fatigue research, Ge Xiu-run [6] has proposed the three phases development rules of irreversible deformation of rock under cyclic loading, and regarded deformation as a benchmark to measure the intensity and failure of rock.

AE technique can be used to monitor the micro-cracks development and the failure process in the rock test sample continuously and in-real-time, which makes it better than other methods. AE is also called artificial earthquake, as an important means of nondestructive testing, using acoustic emission technique to study the damage and failure of the material has attracted extensive attention.

At present, however, research on the acoustic emission characteristics of rock under fatigue loading is very limited, only limited to research results of Jiang Yu and Ge Xiu-run [2,6], mainly on Qualitative Analysis, therefore, to study the acoustic emission characteristics and the rules of damage and failure of rock under fatigue loading has important significance.

* Corresponding author. Tel.: +86-23-65111236.
E-mail address: jiangxu@cqu.edu.cn
2. Brief outline of the test

The MTS815 rock mechanics testing system, which is made in USA, has been used in this test. The maximum axial load is 2800 kN, the maximum confining pressure is 80 MPa, and the temperature can be up to 200 °C. It is high-performanced and can work stably.

Acoustic emission test uses PCI-AE-2 acoustic emission system made by American physical acoustics corporation. The acoustic emission system is the PAC’s latest product, which uses the PCI-2 board, can minimize the noise while testing. PCI-2 digital acoustic emission system is a fully digital, multi-channel, computerized testing system. It can display signal amplitude, deposit and show analysed result datum.

The uniaxial intensity test is performed on MTS815 rock mechanics testing system. The rock specimens are sandstone, taken from some project, the dimension of the specimen are φ50×100 mm and are prepared according to experiment standards of ISRM. The specimen is tested at 0.5 mm/min rate of displacement control and confining pressures of 0 MPa.

At the same time, to construct the cyclic fatigue damage evolution equation, the uniaxial compressive fatigue test has been performed. Experimental machine, material, sample specification and sample strength according to the above monotonous loading test are the same as above. The specimen are tested at 100.9 kN/min rate of load control with triangle wave (the elastic deformation stage corresponds to this kind of sandstone static displacement loading state at 0.5 mm/min), the upper limit and the lower limit stress strength ratio are 90% and 45% respectively. Acoustic emission test is synchronized with uniaxial compressive fatigue test.

3. AE characteristic of rock fatigue damage and failure

Fig. 1 is the stress-strain curve of sandstone specimen under cyclic loading, it shows that the stress-strain curve of the rock under cyclic loading of high stress presents plastic hysteresis cycle; in the initial stage, plastic hysteresis cycle are sparsity, in the middle stage, plastic hysteresis cycle is closed, then over again sparsity before the failure, showing such state of sparsity-close-sparsity. It indicates that rock in the process of fatigue pass through the initial stage of instability deformation, the stable deformation stage, and the final stage of accelerated deformation before the failure.

Figs. 2-4 are the time course of AE signal parameters of rock, thus descry that Count, Energy, Hits have roughly the same law in the rock fatigue damage process: the initial stage of instability deformation, AE parameters shows very large change, then, in the stable deformation stage, the AE parameters number are smaller widely, in the final stage of accelerated deformation, the AE parameters number begin to accelerate larger. In the several cycle before the failure, AE parameters are clearly increased, when the crack fracture mode transform from the beginning of macro invisible micro-fracture to the macro-fracture, this has been verified through the CT test of this sandstone under fatigue load. It shows that rock fatigue damage evolution is changed at this time.
Fig. 3. Count-Time

Fig. 4. Hits ratio-Time

Fig. 5 is the curves of the load-time and Hits-time between 1106-1253s (two cycles), It can be seen from Fig. 5 that, in each cycle of the load upper limit, Hits ratio reaches its maximum, while the minimum in each cycle of the load lower limit, AE signal also can be seen when unloading, while, it is almost symmetrical distribution with loading.

Materials such as rock and concrete, because crack in the plastic area is very small, thus the AE energy are smaller than the AE energy of rock due to cracking and expanding of the crack, contrast one another about five or six orders of magnitude. We can approximately consider that the AE signal of such materials is all from the damage [7]. Thus, the damage variable expression may be established based on AE.

Fig. 5. Force and Hits ratio-Time between 1106s-1253s

Damage variable $D$ presents the damage state of the material; it is defined as a ratio of cracking area $A_d$ with the instantaneous apparent total area $A$:

$$\text{(1)}$$

Assuming that the rock material has no initial damage, AE cumulative number is $\phi_m$ while the rock failed. Then, when the damaged section area is $A_d$, the accumulative number of AE is

$$\phi = \frac{\phi_m}{A} A_d$$  \hspace{1cm} \text{(2)}

Then damage variable $D$ is given by

$$\frac{\phi}{\phi_m} = D$$ \hspace{1cm} \text{(3)}

Base on Eq.(3), the accumulative Hits curve can be turned into fatigue damage evolution curve by using Fig. 6. It can be seen from the Fig. 7 that, the fatigue damage evolution curve established by the paper has obviously shown ‘the three phases development rule of irreversible deformation of rock’, being of the characteristic and conforming to the rule of fatigue damage evolution.
4. Conclusions

The stress-strain curve of the rock under cyclic loading of the high stress will present plastic hysteresis cycle: in the initial stage, plastic hysteresis cycle are sparsity; in the middle stage, plastic hysteresis cycle are close; then over again sparsity before the failure, showing such state of sparsity-close-sparsity.

Count, Energy, Hits have roughly the same characteristic in the rock fatigue damage process. We can approximately consider that the AE signal of such materials is arised from damage. Thus, the damage variable expression may be established based on Hits. The accumulative Hits curve was turned into fatigue damage evolution curve in this paper, the fatigue damage evolution curve established in the paper has obviously shown ‘the three phases development rule of irreversible deformation of rock’, being of the characteristic and conforming to the rule of fatigue damage evolution.

It is suggested that more experiments of other types of rocks and coal rock be performed to verify the method in this paper. The extensive understanding of the characteristic as well as the damage and fracture of rock mass engineering could be helpful to deal with some practical problems effectively, such as the damage and fracture of rock groundwork, failures of slope and underground rock mass engineering, and the coal rock damage coupling to gas bursts etc.

Acknowledgements

Supported by National Natural Science Foundation of China(50574108); Key Project of the National Natural Science Foundation of China (50534080).

References