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Research on Mechanical Features and AE Characteristic Parameters of Filling Body under Cyclic Loading

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Abstract: An effort is made to study the mechanical features and AE characteristic parameters of filling bodies under repeated loading and unloading, which are common stress paths for the filling bodies of mine, to providing theoretical basis for the monitoring and the bracing of backfilled mine. Material testing machine RMT-150C is used to conduct uniaxial compression experiments on cemented filling body under above-mentioned stress paths and 1MHZ broad-band emission sensor is employed to collect AE parameters prior to the arrival on peak compression strength. The results indicate that comparing to monotonic loading, cyclic loading could elevate the peak stress of filling bodies by about 30%. The stress-strain- accumulative AE number curves of specimens under cyclic loading tells the surge of accumulative AE number on specimens' reaching peak stress, which combining with test process proves the thorough failure of filling body. It is then demonstrated that the surge of accumulative AE number could serve as a reference criterion for judging the failure of filling bodies.

Keywords: *cyclic loading; filling body; mechanical feature; Acoustic Emission*

1. Introduction

Flashing system, compared to other conventional mining system, has manifest several advantages, e.g. leveling up ore recovery rate, cutting down ore dilution rate, fully utilizing existing resources, effectively controlling ground pressure and ground collapse, optimizing surrounding environment of mine, and avoiding internal fire [1]. Special researches have been gradually carried out by scholars and researchers both at home and at abroad to study the application of cemented solid waste filling bodies and acoustic emission technology in engineering and researches: LEMAITRE analyzed the microscopic failure characteristics on the basis of the stress-strain curves of filling bodies under uniaxial compression and splitting tensile stress and established of corresponding damage evolution-considered constitutive equations for cemented filling bodies[2];YU Shibo et al, analyzed the bracing mechanism of cemented filling body with interaction model of surrounding rock and cemented filling body [3]; LIU Zhixiang et al, studied of the mechanical properties and damage features of filling bodies with different mixing proportion [4]; LI Yifan et al, conducted tests on the mixing proportion of cemented tailing filling bodies and analyzed the strength characteristics of the filling bodies with certain mixing proportion [5]; HAN bin et al, proposed a strength determination method for filling bodies and a analysis method for the sensitivity of stochastic parameter on basis of reliability theory [6]; HAN Zhixing researched numerically on the stop structure parameters of upward horizontal slicing method[7]; Obert and Hodgson imposed impact on the proposition of acoustic emission testing and positioning technology of rupturing point by measuring the rock instability during excavation process [8];

In 1960s, United States and Japan, through testing the physical mechanism of AE of different materials, initially applied the acoustic emission technique in the field of engineering material testing [9-11]; Dunegan et al set the foundation for AE testing technique by performing AE frequency test [12]; LI delved deep into the irreversible process of rock's Felicity effect and put forward the close relationship between the load-bearing process of rocks and the acoustic emission Felicity effect of the loading process of rock[13]; TANG et al and Liu et al built the quantative relationship between the strength distribution of rock infinitesimal and AE number by studying the AE of rocks and associated parameters [14-15]; XIE Yong et al, through research and analysis of the AE characteristic parameters of cemented graded tailing filling bodies during its failure process under uniaxial compressive, established damage evolution process of compression failure equation, combining with the damage variables defined by AE accumulative energy ratio, to get a damage constitutive model of filling bodies under the action of uniaxial compression [16].

HE Guicheng et al, conducted mechanical tests and numerical simulation upon cemented waste rock filling bodies with different mix proportions, suggesting that water-cement ratio and cement-aggregate ratio are two critical factors affecting the compressive strength of filling body [17]. ZHAO Lui et al, studied the load-bearing capacity of reinforced roof filling body combining the outcome of on situ tests [18]. LIU Chao et al, prescribed a reasonable mix proportion and a curing temperature of cemented waste rock filling bodies through comparison experiments [19].

In summary, the mentioned-above studies present constructive outcomes for the recognition of the damage parameters and the AE characteristic parameters monotony of filling bodies under monotonic loading. However, there is no integrated and well-acknowledged theoretical system for mechanical features and AE characteristic parameters of filling body under cyclic loading. In this paper, previous studies is based on to research on mechanical features and AE characteristic parameters of filling bodies with the help of cemented filling bodies formed interiorly under cycle loading and unloading.

2. Test equipment and test scheme:

2.1 Preparation of Specimens:

The tailings used and waste stone applied in the BRCFB specimens are all from mine zone. The dimension of the specimens is 150 mm X150mm (Height X Radius). Cement grade is 325. There three particle grading of waste stone in the specimens, i.e. 5 mm-10 mm, 10 mm-20 mm and 20 mm-30 mm. The mix proportion is 1:1:2. All specimens are made in accordance with Test Code for Hydraulic Concrete (SL352-2006) and Specifications for Rock tests in water conservancy and Hydroelectric Engineering (SL264-2007). Ten cemented blocky filling bodies are poured, wherein 4 specimens are for Monotonic loading AE test, 4 specimens for cyclic loading AE test, and 2 for standby application. Table 1and Figure 1 represents the main parameters of the specimens.

Table 1: *Characteristic parameters of sample*

Test piece number	Sample component mass ratio			
	Cement	Water	Tailings	Blocky Rock
A	1	2.15	4	0
B	1	2.15	4	3

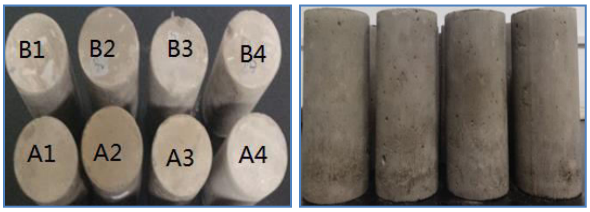

Figure1. *Sample of filling body*

2.2 Test equipment and test method:

RMT-150C servo control system is employed in this test. The test process is shown in figure 2. Displacement controlled loading is adopted, with a rate of 0.002mm/s. The threshold of AE is 35±6dB. To eliminate potential error resulted from the interruption on AE sensors of small particles at the surface of specimens, mild cleaners such as brushes are used and then moderate vacuum insulation grease is applied to the interface between specimens and AE sensors. AE sensors are fixed in the mid-span of the specimen with adhesive belt or rubber band in the prevention of sliding. Specimens should be adjusted to be in line with loading axis. Before data collection, the gauge is checked to ensure the normality of its functions. Meanwhile, AE testing instrument and press machine are turned on to guarantee time consistency.

Cyclic loading AE test is conducted on basis of monotonic loading AE test. Accounting for the fact that filling bodies is subjected to certain compression stress in engineering practice, specimens are kept at 10% of its peak strength at every unloading. The load scheme for the cyclic loading test is: (1). Load the specimen to 20% of its compression strength, and then unload to 10% of its peak strength; (2). Reload the specimen to 40% of its compression strength, and then unload like previous step; (3). 60% of the specimen's compression strength is achieved, and then unload the specimen; (4). 80% of the specimen's peak strength is reached, and then unload the specimen; (5). The specimen is reloaded to its failure directly. AE collector is kept working continuously during this process.

Figure2. *Sample of filling body and test system*

3. Mechanical features of filling bodies:

According to the results of the tests, Figure 3 givens the stress-strain curves for AE tests under different stress paths(A group contains specimens under monotonic loading; B group includes specimens under cyclic loading.); Due to the constraint of space, the corresponding parameters of other specimens are listed in the Table.2.

***Table2:** Physical and mechanical parameters of specimens*

Specimens	wave velocity m/s	Peak stress σ_p/MPa	Peak strain ε_p
A1	2166	3.907	0.0149
A2	2089	4.120	0.0145
A3	2221	3.989	0.0153
A4	2135	3.876	0.0164
B1	2144	4.423	0.0145
B2	2212	4.692	0.0147
B3	2019	4.371	0.0152
B4	2103	4.826	0.0144

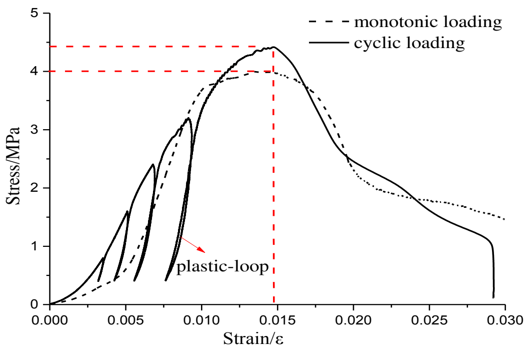

***Figure3.**Stress-strain curves*

Combining Table.2 and Figure.3, when specimens of the same group have wave velocities with slight difference, the internal structures and compressive strength of filling body specimen can be deemed to be basically the same, thus guaranteeing that cyclic loading AE test can refer to the compression strength acquire monotonic loading AE test for classification. According to the peak stress and associated strain provided in Table.2, the average value of peak stress of A group (monotonic loading test) is 3.973 MPa while that of B group (cyclic loading test) is 4.578 MPa. Figure.3 reads: comparing to monotonic loading, cyclic loading could elevate the peak stress of filling bodies by about 30%; strains corresponding to peak stress for these two stress paths is almost close, demonstrating the little impact of stress paths on strain corresponding to peak stress.

By analyzing the constitutive curves of the stress paths under consideration, some phenomena could be found. The loading segment and the reloading segment of the curve for group B almost coincides, presenting no visible overlap area; with the increase of cycles, an manifest circular zone between unloading curve and loading/reloading curve appears, and the unloading curve always lag behind loading/reloading curve, which is to say, the loading/reloading path and the unloading path of cemented blocky rock filling body could not coincides with each other and a one-to-one relationship between stress and strain does not exist. Comparing the full stress-strain curve of the failure process of specimens under the above-mentioned stress paths, it is found that a sharper turn in the peak value zone in the constitutive curve of Group B showed up than that of Group A, indicating a stronger brittleness of filling body specimens under cyclic loading.

4. AE Characteristic parameters of filling bodies:

Accumulative AE number in the failure process of specimens with different stress paths is collected to analyze the AE characteristics of cemented blocky rock filling bodies. Considering the consistency of mixing proportion of Group B specimens, representative specimens are selected to plot the stress-strain- accumulative AE number curve in Figure.4 and the time-vertical force-accumulative AE number curve in Figure.5. For the sake of analysis, only the data of vertical force, time and accumulative AE number before specimens' failure are used.

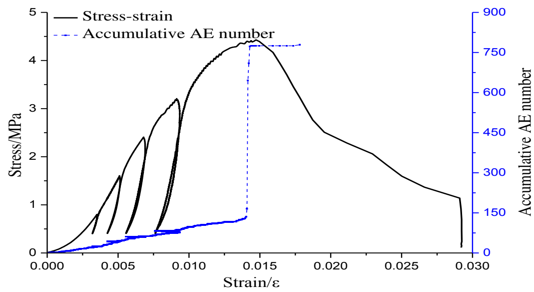

***Figure4.** Stress-strain-accumulative AE number curve*

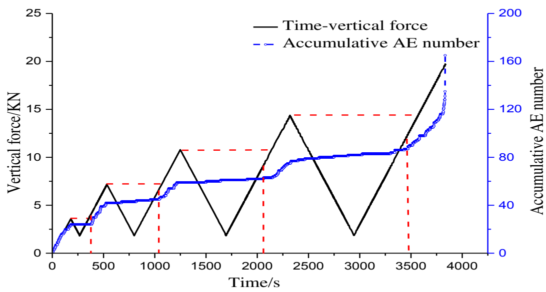

Figure 5. *Time-vertical force-accumulative AE number curve*

Some conclusions could be drawn observing Figure.4. Accumulative AE number experiences a slow increase at the initial stage of loading and levels out when the specimens is unloaded. Accumulative AE number could be viewed approximately as a straight line before the arrival of peak strength, that is, the increase rate of accumulative AE number is basically unchanging. The surge of accumulative AE number when the specimens are at their peak stress indicates the penetration of internal cracks in the specimens, forming macroscopic failure. By comparison with other stage of the test process, it could be known that “avalanche” failure does occur, namely, it is feasible to use AE number to represent the internal failure of specimens.

The time-vertical force- accumulative AE number curve in Figure.5 shows a continuous increase stage is visible in every loading/reloading- unloading cycle. Accumulative AE number climbs up at the initial loading stage, which directly levels up (with omissible increase) when the stress level reaches pre-set value. The first reloading after the specimen is unloaded to 10% of its compressive strength induces no occurrence of AE number initially. For the second loading cycle, AE number does not show up until the stress level of the specimen is close to the maximum load of the first loading cycle. And for the third cycle, AE number is zero until the stress level is about 70% of the set value of the second cycle. For the fourth cycle, AE number is constant at zero till the stress level is about 65% of the set value of the third cycle. In terms of the fifth cycle, the stress threshold of the appearance of AE number is 60% of the set maximum stress of the fourth cycle. It could be concluded that with the increase of cycles, the stress threshold for the occurrence of effective AE number decrease from 100% to 60% of the maximum stress of previous cycle.

5. Conclusion:

1. Comparing to monotonic loading, cyclic loading could elevate the peak stress of filling bodies by about 30%.
2. A sharper turn in the peak value zone in the constitutive curve of Group B showed up than that of Group A, indicating a stronger brittleness of filling body specimens under cyclic loading.
3. By analyzing the full stress-strain- accumulative AE number curve of the specimens, it is known that the surge of accumulative AE number when the specimens are at their peak stress indicates the penetration of internal cracks in the specimens, forming macroscopic failure.
4. From the time-vertical force-accumulative AE number curve in Figure.5, it could be concluded that with the increase of cycles, the stress threshold for the occurrence of effective AE number decrease from 100% to 60% of the maximum stress of previous cycle.

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References

[1] ZHANG Haibo, SONG Weidong and XU Yingxia, Study on the current problem and applied development of backfill mining [J], *GOLD*,v.1,pp.23-25,2010.

[2] LEMAITREJ, How to use damage mechanics[J], *Nuclear Engineering &Design*,v.80 (1), pp.233-245, 1984.

[3] YU Shibo, Yang Xiaocong and Dong Kaichen, Space-time rule of the control action of filling body for the movement of surrounding rock in method of the delayed filling open stoping [J], *Journal of Mining& Safety Engineering*, v.31(3),pp.430-434,2014.

[4] LIU Zhixiang, LI Xibing, DAI Peigen and CAO Ping, On damage model of cemented tailings backfill and its match with rock mass [J],*Rock and Soil Mechanics*, v.27(9),pp.1442-1446,2006.

[5] LI Yifang, ZHANG Jianming, DENG Fei and BAI Shiwei, Experimental study on strength characteristics of tailings cement backfilling at deep-seated mined-out area [J], *Rock and Soi1 Mechanics*, v.26(6), pp.865-868, 2005.

[6] HAN Bin, ZHANG Shengxue, DENG Jian and WANG Xianlai, Determining Method of Backfill Strength for Underhand Drift Cut-and-Fill Stopping Based on Reliability Theory [J], *Journal of China University of Mining & Technology*, v.35(3), pp.372-376, 2006.

[7] HAN Zhixing and WANG Ning, Analysis of structural parameters for dipping at high angle and thick orebody with upward horizontal slicing and filling non-pillar continuous mining [J], *Rock and Soil Mechanic*, v.28(2), pp.367-370, 2007.

[8] HUANG Chengde and LIU Maojun, Review of acoustic emission technique for concrete material [J], *Journal of Guangxi University (Nat Sci Ed)*, v.33(3), pp.220-224, 2008.

[9] WANG Xinhua and JIAO Yulin, Study on wavelet denoising algorithm based on acoustic emission leakage of heaters [J], *International Infoemation and Engineering Technology Association*, v.2(3), pp.21-26 2015.

[10]M. J. Eaton, R. Pullin and K. M. Holford, Acoustic Emission Source Location in Composite Materials Using Delta T Mapping [J], *Composites*

Part A: Applied Science and Manufacturing, v.43(6), pp.856-863, 2012.

[11]WANG Xinhua, JIAO Yulin, NIU Yongchao and YANG Jie, Study on the acoustic emission features of leakage detection assisted by wave guide rods [J],*International Information and Engineering Technology Association*, v.33(2), pp.143-150,2015.

[12]SHEN Gongtian, DAI Guang and LIU Shifeng, Acoustic Emission Testing Progress in China [J], *NDT*, v.25(6), pp.302-307, 2003.

[13]LI C L and Nordlund E, Experimental verification of the Kaiser effect in rock[J]. *Mechanics and Rock Engineering*, v.26(4), pp.333-351, 1993.

[14]Tang C A and Xu X H. Evolution and propagation of material defect s and Kaiser-effect function [J]. *Journal of Seismological Research*, v.13(2), pp.203-213, 1990.

[15]LIUJianpo, LIYuanhui, TIAN Jun, ZHAO Xingdong, LIU Hongtao and GAN Huaiying, Experimental study of temporal and spatial distribution characteristics of acoustic emission during rock fracture based on single-link cluster method [J],*Chinese Journal of Rock Mechanics and Engineering*, v.29(S2), pp.3488-3497, 2010.

[16]Xie Yong, He Wen, Zhu Zhicheng, Liu Xianjun, Liu Hao and Xie Tao, Study on backfill acoustic emission characteristic and damage evolution under uniaxial compression [J],*Chinese Journal of Applied Mechanics*, v.32(4),pp.670-676, 2015.

[17]HE Guichen and LIU Yong, Strength characteristic of cemented waste rock backfills and its application [J], *Journal of Mining &Safety Engineering*, v.30(1), pp.74-79,2013.

[19]ZHAO Kui, WANG Xiaojun, LIU Hongxing, WU Changfu and ZHANG Jinlong, Experimental study of mechanical behaviors of cemented tailings backfill roof with reinforcement [J],*Rock and Soil Mechanics*, v.32(1), pp.9-14, 2011.

[20]LIU Chao, HAN Bin, SUN Wei, WU Jianxun and HU Haiyan, Experimental study of strength of backfillings of cemented rock debris and its application under low temperature condition [J]. *Chinese Journal of Rock Mechanics and Engineering*, v.1, pp.139-147, 2015