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Study on acoustic emission characteristics of concrete freeze-thaw damage

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ABSTRACT

Acoustic emission(AE) technology is a dynamic nondestructive testing technology, which is widely used in structural health monitoring and nondestructive testing. In this paper, based on the AE monitoring method, studies the variation laws of mass loss rate, first wave amplitude and AE characteristic parameters of concrete with different freeze-thaw cycles, and analyzes them with the correlation parameter method. The test results show that with the increase of the number of freeze-thaw cycles, the concrete surface spalling is more serious, the mass loss rate increases, and the amplitude of the first wave decreases, indicating that the internal cracks of the concrete are more obvious and the damage is more serious. The amplitude of AE shows obvious periodicity with the number of freeze-thaw cycles, which is mainly due to the combined action of water migration stress and frost heaving force in the specimen. The analysis results of amplitude energy correlation parameters show that the damage degree of concrete under different freeze-thaw cycles is directly proportional to the amplitude and energy of AE. The results of this paper provide a theoretical reference for the study of concrete dynamic damage.

1. INTRODUCTION

As a basic building material widely used in civil engineering, concrete will cause varying degrees of freeze-thaw damage with the bad service environment[1,2,3,4,5]. Freeze-thaw damage will reduce the basic mechanical properties of concrete structure, shorten its bearing capacity and service life, and seriously endanger the safety of concrete structure[6,7,8]. Therefore, it is very necessary to effectively monitor the in-service concrete structure [9,10].

At present, there are many studies on the mechanical properties of concrete under freeze-thaw cycle, but there are relatively few studies on the combination of freeze-thaw cycle and AE. Peng et al. [11] studied the mechanical properties of concrete under uniaxial and biaxial dynamic compression after freezing-thawing cycle. Huang et al. [12] studied the dynamic splitting tensile damage characteristics of concrete after freeze-thaw deterioration, and analyzed the effects of freeze-thaw cycle times and strain rate on the splitting tensile strength and energy absorption capacity of concrete. Qiu et al. [13] studied the compression damage characteristics of coal gangue concrete after freeze-thaw cycle, and dynamically analyzed the damage characteristics of it in the whole process of compression failure. Zhu et al. [14] studied the effect of the coupling of freeze-thaw damage and sustained load on the bond properties of various concrete through a series of loading, freeze-thaw cycle and bond slip tests. Yuan et al. [15] conducted an experimental study on the changes of concrete pores under freeze-thaw cycle by using X-ray CT.

In this paper, by studying the AE characteristic test of concrete freeze-thaw damage, the influence law between the number of freeze-thaw cycles and AE characteristic parameters is obtained, and the influence law of concrete specimens after different freeze-thaw cycles is measured by AE method, which provides a new theoretical support for concrete freeze-thaw damage.

2. TEST SCHEME

2.1 RAW MATERIALS AND MIX RATIO

The cement used in the test was PO42.5 ordinary Portland cement, the sand was intermediate standard sand, and the water was ordinary tap water. The test object was 70 × 70 × 70 mm C30 concrete cube specimen, and the water-cement ratio was 0.5. In order to test the damage of concrete under different freezing-thawing cycles, 4 groups of control specimens were set up, among which 1 group was the control specimen. Table 1 shows the mix of C30 concrete.

Table 1. The mix of C30 concrete

Ingredients	Cement	Water	Sand
Quality/kg	0.675	0.3375	2.025

2.2 TEST EQUIPMENT AND METHOD

The test adopts the concrete rapid freezing-thawing test machine produced by Beijing Naiheng testing equipment technology development Co., Ltd (NJW - HDK - 9), as shown in Fig. 1(a). Freezing-thawing test according to the ordinary concrete long-term performance and durability test method standard, after 24 days of standard curing, the specimen was immersed in water for 4 days, and then the rapid freeze-thaw cycle test was carried out. The three groups of specimens were subjected to freezing-thawing cycles for 25, 50 and 75 times respectively, and the control group specimens were placed in the standard curing room.

The AE acquisition system adopts the AE instrument (PCI-2) produced by American physical acoustics company, with pre-amplification gain of 40 dB, threshold value of 50 dB and sampling frequency of 1 MHz, and vaseline was selected as the coupling agent, and the AE signal was collected for 30 h, as shown in Fig.1 (b).

The Nielsen Hsu pencil lead break (PLB) method with 0.5 mm pencil core was simulated at the center of the circle [16,17], PLB was carried out along the surface of the concrete at an angle of 30º, the lead core was extended by 2.5 mm, and the AE system was used to collect the signals of concrete specimens under different freezing-thawing times.

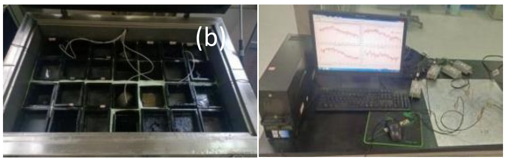


Fig. 1 Main instruments of test

3. TEST RESULTS AND ANALYSIS

3.1 ANALYSIS OF EXPERIMRNTAL PHENOMENA

The surface characteristics of concrete under different freeze-thaw cycles were shown in Fig. 2 below. It can be seen that compared with the control specimens without freezing-thawing cycle, the surface morphology of concrete specimens with different freezing-thawing cycles has slight differences. After 25 freeze-thaw cycle concrete specimen surface appear small circular holes, the surface of the sample was rough with less slurry peeling. After 50 and 75 freeze-thaw cycles, the concrete surface spalling was more serious, part of the fine aggregate was exposed, and the block falls at the edges and corners of the specimen, and the number of circular holes increases obviously.

Fig. 2 Concrete surface under different cycles

3.2 VARIATION OF SPECIMEN PARAMETERS

The mass loss rate was the main parameter to evaluate the frost resistance of concrete, which can represent the frost resistance of concrete. The calculation formula was shown in formula 1.1:

$$W = \frac{G_0 - G_n}{G_0} \times 100\% \qquad (1.1)$$

Where: W is the mass loss rate of the test piece after freeze-thaw cycle; G_0 is the initial mass of the test piece before the freeze-thaw cycle (kg); G_n is the mass of the test piece after n freeze-thaw cycles (kg). Fig. 3 shows the mass loss rate under different freeze-thaw cycles. It can be seen that the mass loss rate of concrete specimen first increases and then decreases with the increase of freeze-thaw cycle times, when the number of freeze-thaw cycles was small, the damage was mainly concentrated on the surface of the specimen, and the damage and peeling of the surface material leads to the reduction of the quality. With the increase of the number of freeze-thaw cycles, the freeze-thaw damage will transfer from the outside to the inside, and the surface material will peel off less, but the internal material will not peel off. At the same time, the peeling of the surface material will lead to the increase of the surface pore size, the infiltration of water into the concrete specimen, the increase of the overall moisture content of the specimen, and the increase of the quality of concrete.

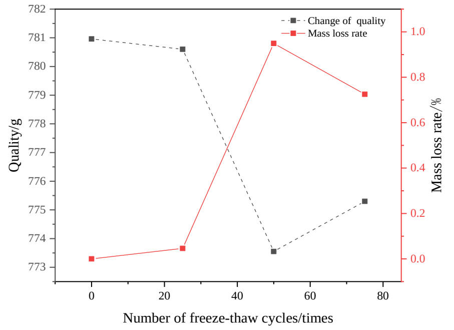


Fig. 3 Mass loss rate under different freeze-thaw cycles

The internal defects of concrete were detected by AE wave to characterize the freezing-thawing damage of concrete specimen. Fig. 4 shows the amplitude under different number of freeze-thaw cycles. It can be found that the amplitude of the specimen without freeze-thaw cycles was the highest. With the increase of the number of freeze-thaw cycles, the amplitude gradually decreases from the initial 0.3 V to 0.07 V, with an attenuation of 76.7%. It shows that the internal pores of concrete were hyperplastic in the freezing-thawing cycle, and the increase of pores leads to a large increase in the internal gas and water content. Energy dissipation occurs in the process of acoustic wave passing through the concrete specimen, and the propagation path also changes, resulting in only a small part of the acoustic wave transmitted by the sensor. The amplitude of acoustic wave decreased obviously in the first 50 freezing-thawing cycles, it shows that the crack propagation was obvious and the damage was serious in this stage.

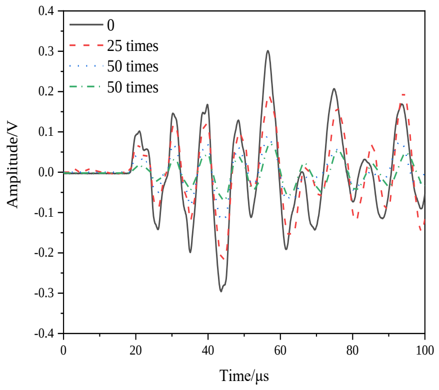


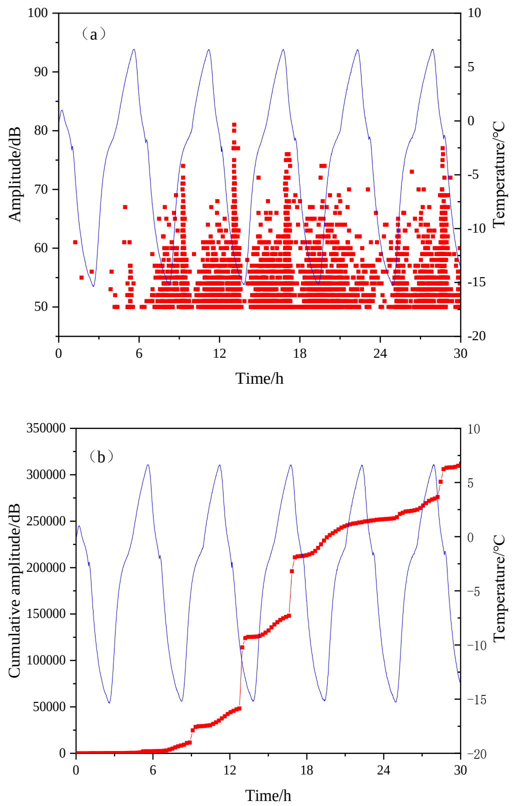
Fig. 4 Amplitude under different number of freeze-thaw cycles

3.3 AE PARAMETE ANALYSIS

AE instrument automatically collects and records AE characteristic parameters of concrete under freezing-thawing cycle. In this paper, amplitude and energy were selected for analysis. Fig. 5 shows the AE amplitude and cumulative amplitude of concrete specimens changing with time and temperature under different freezing-thawing cycles. It can be seen from fig. 5 (a) that AE parameter has obvious periodicity, was about 6 h. In the initial cooling stage, the amplitude was small, less than 60 dB, and the AE amplitude increases near 6 h, it shows that the activity intensity of AE source inside concrete increases at this stage. From the analysis for 12-18 h, it can be seen that the highest amplitude was 83 dB near 0 ℃, indicating that large cracks were generated inside at this time, which was mainly due to the damage of concrete caused by expansion force. When the temperature drops from 0 ℃ to - 15 ℃, the maximum amplitude reaches 77 dB, indicating that the expansion stress in concrete was further at this stage. Water crystallization in the specimen leads to slow growth of rate of expansion stress and low AE amplitude. When the temperature rises from - 15 ℃, the amplitude was about 50-72 dB. Because a large amount of water in the concrete was frozen, part of the water migrates to the AE signal generated by stress. Fig. 5 (c) and Fig. 5 (e) have similar freeze-thaw cycles.

It can be seen from fig. 5 (b) that the curve of the overall increases, the temperature of 5 ℃ down 0 ℃, the cumulative amplitude increases slowly, mainly due to the weak stress wave caused by water migration in the concrete. When 0 ℃ drops to - 15 ℃, the cumulative amplitude rises rapidly. It may be due to the joint action of expansion and migration stress. When - 15 ℃ rises to 0 ℃, the cumulative amplitude remains basically unchanged, and when 0 ℃ rises to 5 ℃, the cumulative amplitude rises slowly, indicating that the crack generation speed was small .

It can be seen from Fig. 5 (d) and Fig. 5 (f) that the regularity was lower than that of the first 25 cycles, but the overall cumulative amplitude was higher, indicating that more cracks occur at this time.



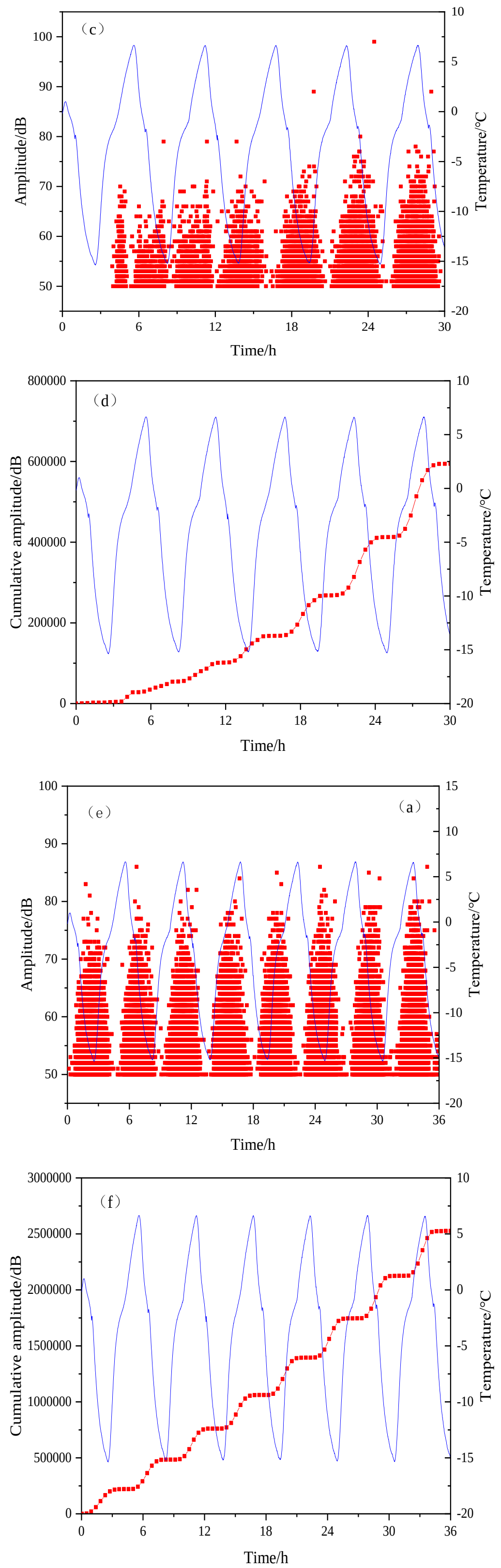


Fig. 5 (a), (c) and (e) are amplitude and temperature time curves of freezing-thawing cycles 25, 50 and 75 times respectively. (b), (d) and (f) are the cumulative amplitude and temperature time curves of freezing-thawing cycles for 25, 50 and 75 times respectively

3.4 CORRELATION ANALYSIS OF SIGNAL PARAMETERS

Correlation analysis method was a common method for AE signal analysis. The waveform characteristic parameters of any two AE signals can be analyzed as correlation graph. By making the correlation diagram of different parameters, the characteristics of AE sources can be analyzed. According to the correlation parameter diagram, the variation rule of AE signals of concrete in the freezing-thawing process can be obtained, and the correlation diagram of amplitude and energy of different freezing-thawing cycles can be drawn, so as to better study the AE characteristics of concrete specimens under freezing-thawing cycles.

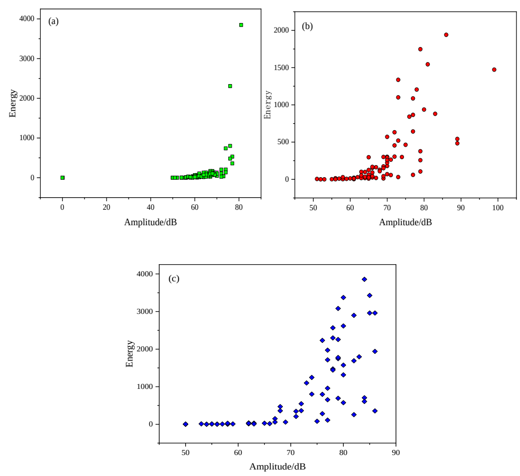


Fig. 6 Amplitude-energy correlation diagram under different freeze-thaw cycles

Fig. 6 shows the amplitude-energy correlation diagram under different freezing-thawing cycles. It can be seen that energy increases with the increase of amplitude, indicating that freezing-thawing damage signals with high amplitude have the characteristics of high energy. Moreover, with the increase of the number of freezing-thawing cycles, AE signals were more obvious, with higher energy and amplitude, and serious freezing-thawing losses. When large cracks occur, AE signals have a amplitude of more than 90 dB and an energy of more than 2000.

4. CONCLUSION

(1) Different freeze-thaw cycles times were compared with the specimens without freezing-thawing cycle, the surface has larger difference, quality loss significantly, with the increase of freeze-thaw cycles, freezing-thawing of the specimens quality loss increases first then decreases, showed that freezing-thawing cycle was a process from surface to inner.
(2) With the increase of freezing-thawing cycles, the amplitude of the first wave are decreases, indicating that the internal crack was more obvious and the damage was more serious.
(3) AE parameters of freezing-thawing cycle have obvious periodicality, and the freezing-thawing damage was mainly due to the comprehensive effect of water migration stress and frost heaving force inside the specimen, but the influence of the latter was much higher than that of the former.
(4) The damage of specimens under different freezing-thawing cycles was closely related to the amplitude and energy, and the damage degree of specimens was directly proportional to the amplitude and energy.

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