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Experimental study on fracture process of concrete by acoustic emission technology

Abstract. *Acoustic emission is a method widely used for real time monitoring of the structural condition of materials. In this paper, the uniaxial compression tests will be carried out to acquire the correlation between the characteristics of acoustic emission signals and that of the concrete strength parameter. In the fracture process of concrete, acoustic emission, which is detected by the sensors, is generated when part of the strain energy stored in the samples is rapidly released. In order to analyze the results of experiments better, the acoustic emission event rate and the strain curve are applied. The results show that the concrete strength has an important impact on acoustic emission signals: for low-strength concrete, the acoustic emission event rate columns of fracture process are divided into six stages, and display a clear "bimodal" distribution, but such phenomenon does not appear in high-strength concrete.*

Streszczenie. *W artykule zaprezentowano testy określające korelację między sygnałem emisji akustycznej a parametrami betonu. Badano sygnał emisji akustycznej towarzyszący pękaniu betonu. (**Eksperymentalna analiza procesu pękania betonu z wykorzystaniem sygnału emisji akustycznej**)*

Keywords: acoustic emission (AE), concrete, event rate, uniaxial compression.
Słowa kluczowe: metoda emisji akustycznej, beton

1. Introduction

Acoustic emission (AE) technique is one of the non-destructive testing methods that can be used to detect damage in material or structure through the detection of stress waves generated by sudden energy release.

Kaiser (1950) started the research work on metals by AE technique [1]. The application of AE to concrete started in the late 1970s, when the original technology developed for metals was modified to suit heterogeneous materials [2].

Because concrete is one of the most important materials in construction, the fracture and failure of concrete has been a widespread subject. At present, the AE technique is frequently applied to monitor the response of concrete and concrete structures under mechanical loading. Hongguang Ji (2004) made a detailed study on AE characteristics of concrete materials, and he summarized the relationship between many aspects of concrete material properties and AE characteristics [3].

The sensors which are used to transform the energy of the transient elastic wave to an electric waveform are typically piezoelectric. The information of these waveforms includes the location of the crack source, the density of cracks, as well as the severity of the material condition [4]. The technique can be used to the specifically defining AE parameters events which were generated in the whole fracture process of a material using sensors that act like the doctor's stethoscope. The cumulative AE activity, as recorded by the sensors, is indicative of the severity of cracking, since crack propagation is a prerequisite for AE [5].

The AE data can be analyzed in two ways: AE parameter-based analysis and AE signal-based analysis. The former is qualitative while the latter is quantitative [6]. The AE event rate is an important parameter of signal analysis, and the strength is an important indicator of concrete materials. This paper adopts parameter-based analysis to evaluate the correlations between event rate characteristics of AE signals and that of strength parameters. The results show that the concrete strength has an important impact on AE signals.

2. Experimental setup

2.1 The digital servo hydraulic testing system

The compressive strength tests were performed by using the WAW-2000DL digital servo hydraulic testing system in Mechanics Laboratory of China University of Geosciences (Beijing). The test system was configured with visualization software, and the digital type electronic control unit of the press is driven by management software: Test Expert (Version 3.6). This machine makes it possible to carry out tests in either load control or displacement control. At the same time, it can record and generate the stress-strain curve, load-displacement curve and other relevant data during the test.

2.2 Acoustic emission testing equipment

SAEU2S acoustic emission instrument produced by Beijing Shenghua Corporation is used for AE data acquisition during the experiment, as shown in Fig. 1. The AE monitoring system has four channels at present, one for each of the four resonant type sensors. The device was connected to a computer for collecting and showing the waveforms of AE signals and other related parameters. At the same time, it can record all the original parameters of AE data. According to the needs of users, various signal analysis and processing tools can be used for subsequent in-depth signal analysis, including defining AE parameters of specific definition, etc. Also the system has advantages of low noise, anti-interference ability and so on.

Fig.1. SAEU2S acoustic emission instrument

3. Production of the concrete samples

In order to research the AE parameters variation in the process of uniaxial compression on concrete specimens of different strength, the mixing proportion was calculated respectively according to the common concrete by the design compressive strength of C10, C20, C30, C40 and C50. The details of the specimens tested in this experiment are demonstrated in Table 1. The coarse aggregate used crushed granite aggregates of maximum size 25 mm, and the fine aggregate was natural sand, of which fineness modulus is 2.6. The samples were 150 mm×150 mm×150mm in size. For this test, six specimens of various strengths were fabricated. After molding for 24 hours, strip the samples, and then put them into the curing box, and keep them under the curing conditions (environmental humidity>90%, temperature 20℃±2℃) for 28 days. The specimens are shown in Fig. 2.


Fig.2. The concrete specimens

Table 1. Concrete mix proportion

Specimens	Cement [kg/m^3]	Sand [kg/m^3]	Aggregate [kg/m^3]	Fly ash [kg/m^3]	Mineral powder [kg/m^3]	Admixture [kg/m^3]	Water [kg/m^3]
C10	136	951	951	54	82	4.4	181
C20	180	842	1030	65	82	5.9	175
C30	219	804	1024	78	94	7	174
C40	283	750	1035	67	99	9	167
C50	335	715	1029	75	90	11	165

Table 2. Lead break test data

Specimen number	1	2	3	4	5	6	7	8	9	10	average
Rise time [μs]	197	198	198	195	201	198	197	200	196	199	197.9
Duration time [μs]	530	540	525	530	550	530	545	535	535	540	536

4. Test

4.1 Pencil-lead break test

Wave amplitudes exceeding a defined threshold value are referred to as AE events, and signals below the threshold value are considered as noise. In practical applications, the detection threshold was often set to 35 ~55dB. Because this experiment was performed in the laboratory, the noise was slight. The threshold value of 40dB was selected to ensure a high signal to noise ratio. The emitted AE signals during testing were detected by the sensors with the resonant frequency of 150 kHz. The AE signals were amplified by 40dB in a preamplifier.

Before the uniaxial compression, the pencil-lead break experiment for the C30 concrete should be done at first. Keep the pencil-lead about 10cm far from the sensor, and then break it. The device was shown in Fig.3. The angle between the pencil-lead and the specimen surface is 30 degrees, and the length of lead is about 2mm. Repeat the test for 10 times and get the average value. The results are shown in the Table 2.

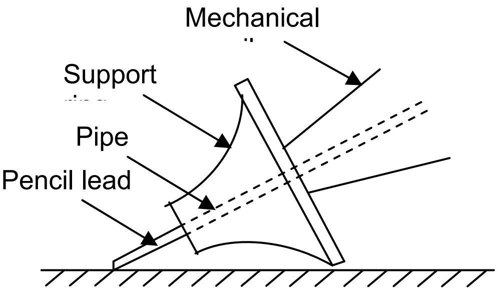


Fig. 3. The schematic diagram of pencil lead break

Owing to the limited space, there is only two waveforms listed here, as shown in Fig. 4 and Fig. 5. The average rise time is 197.9μs, and the average duration time is 536μs. Therefore, the peak definition time (PDT) is set at 300μs which is about 1.5 times of the rise time, while the hit definition time (HDT) is set at 800μs roughly 1.5 times of the duration time, and the hit lockout time (HLT) is set to 1000μs which is slightly higher than HDT.

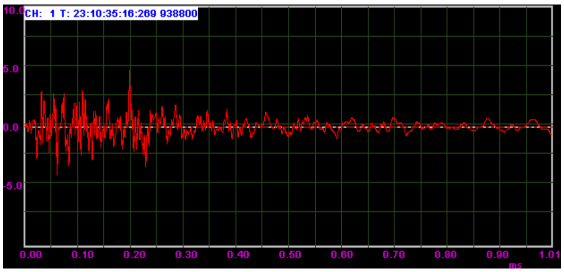


Fig.4. The first pencil-lead break waveform

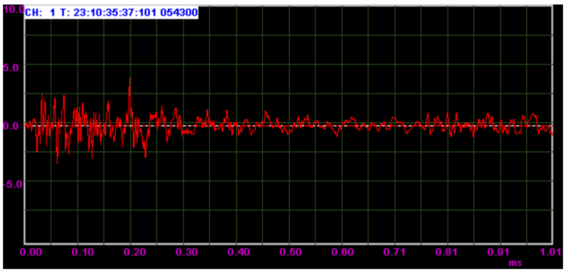


Fig. 5. The second pencil-lead break waveform

4.2 Uniaxial compression test

In order to receive the AE signal more efficiently, the sensors were arranged in the middle of the specimen surface. Three AE broadband sensors were attached to the surface of the specimen (Fig. 6). First, use abrasive paper to polish the surface, then clean it with cotton cloth dipped in acetone. The sensors were coupled with the specimen with high temperature vacuum grease, and finally were fixed with an elastic band.

Set up the parameters of AE instrument software, and place the specimens on the digital servo hydraulic testing machine (Fig. 7). The test was performed in piston travel stress controlled by setting a velocity of 0.5MPa/s. The AE signals, load, deformation, time and other parameters, which have occurred in the whole process were recorded. The complete experimental system is shown in Fig. 8.

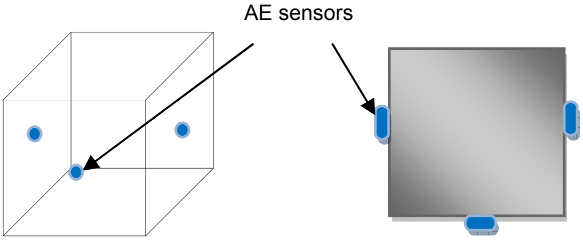


Fig. 6. The sensor arrangement diagram

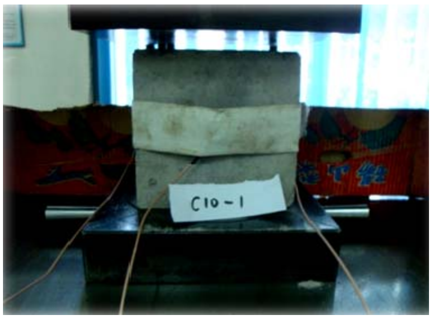
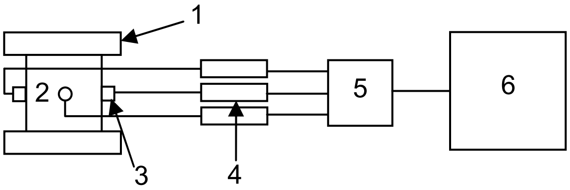


Fig. 7 The concrete sample of this uniaxial compression test



1-Digital Servo hydraulic testing machine；2-Concrete specimen；3-AE sensor；4-Preamplifier；5-AE instrument；6-PC

Fig. 8 The experimental system

5. Results and discussion

It is understandable that the rate of incoming AE activity is of primary importance since the high rate of AE recording is connected to the high rate of crack propagation incidences, while no AE activity implies no serious crack propagation. In order to reflect the frequency of internal rupture events of concrete, the AE event rate was selected to describe the AE characteristics of the concrete specimen under uniaxial compression. According to the results of this test, the strain curve and AE event rate column of different concrete strength can be drawn respectively, as shown in Fig. 9-13. The strain curve and AE event rate column of different strength corresponded with the test data very well. The peak of AE event always occurs at the turning point of the strain curve, which illustrates the mutation of the energy. This is consistent with the view that the AE event is the sudden release of energy in the concrete.

AE characteristics of Granite under uniaxial compression have been studied by Zhizhen Zhang (2010) [7]. Through those test results, for low-strength concrete specimens (C10, C20, C30), the similar phenomenon was detected and the process of acoustic emission can be divided into six stages, the forming reasons are shown in the Table 3 corresponding with the stages of concrete damage.

As the strength of concrete is relatively low, the smaller the concrete strength is, the more obvious the deformation is after being compacted. The specimen deformation continues with the load increasing in the compression process, which causes AE event rate displaying a "bimodal" distribution from elastic to plastic in both transitional stage and destruction stage.

To the relatively high strength concrete specimens (C40, C50), there is no "bimodal" phenomenon. Analyzing the distribution of event rate during the loading, one will find that the fatigue process of concrete can be separated into four stages, namely, initial stage, rising stage, stable stage and declining stage. It corresponds to the initiation, the steady propagation and the coalescence of micro-cracks to macro-cracks respectively. With the increase of concrete strength, the deformability is descended. Thus the brittleness of concrete is more obvious. After the rising stage, the AE event rate has been maintained at a high level, with the duration of the entire process is growing, result in the internal of the specimen accumulate more energy, the micro-cracks turn to the macro-cracks required the shorter time.

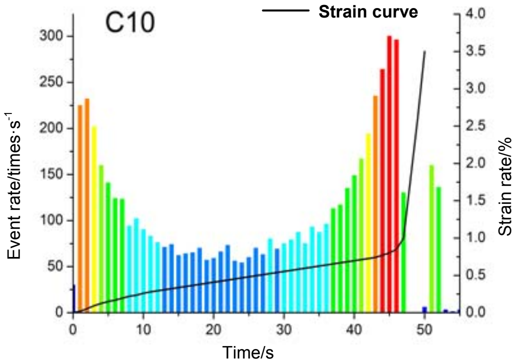


Fig.9 The AE event rate and strain curve of C10 concrete

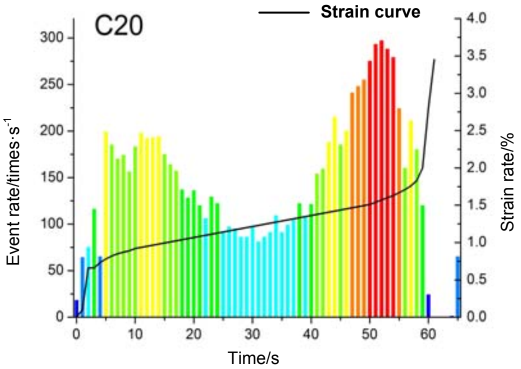


Fig.10 The AE event rate and strain curve of C20 concrete

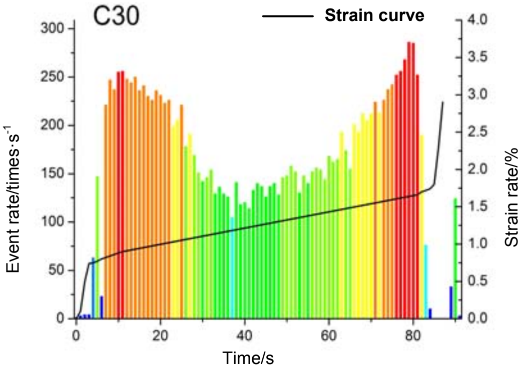


Fig.11 The AE event rate and strain curve of C30 concrete

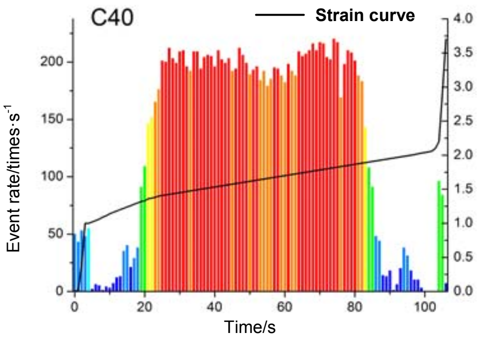


Fig.12 The AE event rate and strain curve of C40 concrete

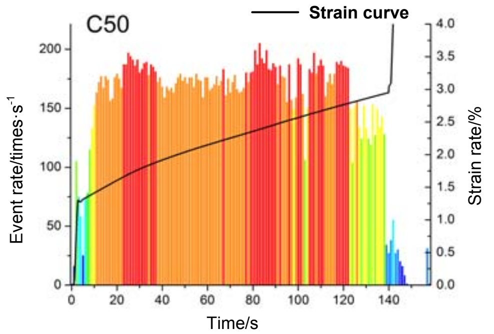


Fig.13 The AE event rate and strain curve of C50 concrete

Table 3. The six stages of AE signal for low concrete strength by this test

Characteristics of AE parameters	Stage of concrete damage	Reasons
Initial stage	Compaction stage	The AE events were mainly caused by compaction of the primary micro-cracks in the concrete
Rising stage	Elastic deformation stage	The stress increased linearly with the strain, and the AE event rate appeared linear growth
First peak stage	Transitional stage from the elastic to plastic	Micro-cracks within the concrete were at the critical state, and they began to produce more micro-cracks, which made the energy accumulate at the first two stages release in a twinkling and lead the AE signals to the peak
Stable stage	Plastic deformation stage	Micro-cracks began to expand with the energy released constantly, and the AE signal has stayed at a high level
Second peak stage	Destruction stage	Micro-cracks in concrete continued expanding, and macro-cracks appeared through the specimens. The stress reached ultimate strength and the maximum AE event rate occurs during the test
Declining stage	Post-destruction stage	The specimens had been damaged, but they still maintained a certain carrying capacity with continuing loading. The AE signal level gradually decreased and eventually disappeared

6. Conclusions

The compressive failure process of concrete specimens is monitored by AE measurement. The conclusions are summarized as follows.

1. The AE signals obtained during the experiment are closely linked to the physical and mechanical properties of concrete specimens. The peak of AE event rate always occurs at the turning point in the strain curve. The results presented show that the AE event rate and the strain curve of different concrete strength have good correlation.

2. For different strength concrete specimens, the AE event rate changes in the process of uniaxial compression. For the lower strength concrete test blocks, the column charts of the AE event rate showing "bimodal" phenomenon were summarized in six stages. As for the relatively high strength concrete, there is no "bimodal" phenomenon. This is mainly due to the difference of the concrete strength. The higher the strength is, the greater the brittleness is, it leads to the decrease of plastic deformation. The AE event rate has been remained at a stable level during the failure process of plastic deformation.

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