The acoustic emission characterization of mechanical damage of geopolymer recycled concrete

Abstract: As a non-destructive testing method, acoustic emission technology can be used to detect the internal damage of concrete specimens in the process of stress. Geopolymer concrete is expected to replace cement as a new generation of green building material because of its outstanding features of low carbon emission and low energy consumption while utilizing industrial solid waste. And with the increasing amount of concrete, due to the mining of sand and gravel aggregate caused by environmental damage and resource depletion has become increasingly serious. In this paper, acoustic emission technology is used to detect the damage of geopolymer recycled concrete during bending and pull-out tests. The results show that the acoustic emission energy distribution map can well reflect the characteristics of load rising and falling stages,it can provide a reference for related research.

1. Introduction

The cement industry is the industry with the largest carbon emission in the building materials industry, and controlling the carbon emission of thecement industry has become the key work to achieving the goal of "double carbon". At the same time, with the increasing amount of concrete, the environmental damage and resource depletion caused by the exploitation of sand and gravel aggregate are becoming more and more serious. From the perspective of sustainable development and resource development and utilization, it is urgent to find substitutes for natural sand aggregate and low-carbon emission cementitious materials. It is found that reusing waste concrete as aggregate can not only turn waste into treasure and realize the resource utilization of waste concrete, but also effectively alleviate the shortage of concrete raw materials and reduce the exploitation of natural aggregate. Industrial wastes such as fly ash and slag have the characteristics of cementitious materials and are characterized by low carbon emissions and low energy consumption. [1,2], and promising to replace cement as a new generation of green building materials [3].

As a non-destructive method, acoustic emission (AE) technology is used to detect the real failure state of structures and the damage behavior of materials, which has the characteristics of high sensitivity, accurate location of damage sources, and real-time monitoring [4]. This technology is based on parameter analysis, which can only reflect its change characteristics from the overall situation in the early stage. However, AE techniques have shown great potential for quantitative analysis and acoustic source mechanism studies in recent years.As a mature nondestructive testing method thathas been widely used in aerospace, petrochemical, materials testing, and other fields, it is a new method with considerable vitality and development prospects, which has a great role in promoting the research of materials and their structural properties.

Concrete is a multiphase inhomogeneous composite material, and the cement mortar-aggregate interface is the weak link within the structure, where defects such as microcracks exist. When the specimen begins to bear load, the original defects generate high stress concentrations and lead to the emergence and expansion of microcracks. When damage occurs within the concrete, elastic waves of a certain intensity are released and propagate to the surface of the concrete. These elastic waves are collected by AE sensors and processed into electrical signals, which can be used for damage analysis of concrete. [5]。

Due to the wide range of sources of geopolymer materials and the differences in mineral components in different regions, it is still necessary to carry out a lot of research work if we want to implement large-scale popularization and application in the whole country. The study of the mechanical properties of concrete is essential if it is to be used in building structures. Moreover, due to the diverse forms of concrete structures, a wide range of materials, complex and variable loading conditions, and harsh and unpredictable service environment, it is necessary to develop non-destructive damage detection technology and intelligent health monitoring technology to achieve the goal of long-term stable service of composite engineering structures, avoid sudden structural damage, and reduce the cost of operation and maintenance, so as to realize the defect detection, defect localization, defect identification, performance evaluation and failure warning, and thus ensure the reliability of composite structures in the long term. Therefore, in order to popularize the use of geopolymer recycled concrete in structural engineering and fully understand the mechanical properties of geopolymer recycled concrete, this paper uses AE technology to detect the concrete structure and analyze the damage evolution and failure mechanism of the structure.

2. Experimental design

In this experiment, S95 grade blast furnace granulated slag and class II fly ash of class F were used as cementitious materials, and the material properties are shown in Table 1. A mixed solution of water glass with a modulus of 3.09 and NaOH flake crystals with a purity greater than 99% was used as the exciter. As well as the use of recycled stone with a particle size of 5-20 mm as coarse aggregate and natural river sand as fine aggregate to prepare geopolymer recycled concrete.

Table 1 Chemical composition of slag and fly ash (mass fraction/%)

	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	TiO_2	Na_2O	K_2O	MnO	P_2O_5
slag	32.71	15.3	39.43	1.43	7.29	1.42	0.36	0.39	0.24	0.07
fly ash	64.08	19.94	4.98	4.66	1.65	1.39	0.44	0.86	0.11	0.54

In accordance with the "Standard for Test Methods of Physical and Mechanical Properties of Concrete" (GB/T50081-2019), the mechanical properties were tested, and the flexural strength as well as the bond strength were tested using the universal testing machine WDW-100V. The size of the flexural specimen is 100mm×100mm×100mm, and the flexural strength test adopts displacement loading with a loading speed of 0.2mm/min, and the loading device is shown in Fig. 1. The device shown in Fig. 2 was used for the center pullout test, and the bond specimens were all 150 mm×150 mm×150 mm in size, using ribbed steel bars with a diameter of 16 mm, and the bond length was 5d.

The AE test was carried out using a full information AE signal analyzer (DS2-8B series, Beijing Soft Island Times Technology Co., Ltd.), with a signal sampling frequency of 3 HZ and an amplifier gain of 40 dB.

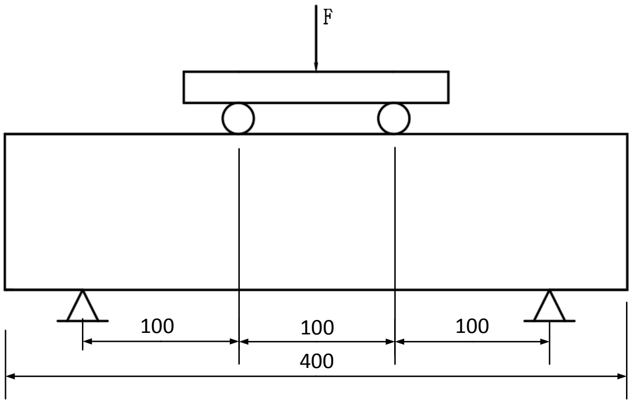

Fig. 1. Flexural specimen loading device.

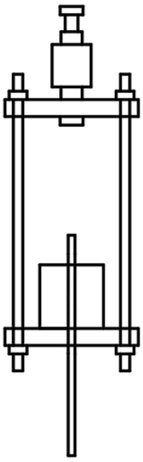

Fig. 2.Pull-out specimen loading device.

3. Results and discussion

3.1 Analysis of flexural properties

Since the changes of different specimens in the loading process are different, directly taking the average of the test results of each group will have a large error, this paper takes the specimen with intermediate peak stress as the representative of each group, to obtain the energy of flexural specimen and the bending load change curve with loading time. As can be seen in Fig. 3, the variation pattern of the acoustic emission energy with time of the specimens has a strong correlation with the variation curve of the bending load[5]. At the early stage of loading until 70% of the peak load, it can be seen that the value of AE energy also tends to be close to zero due to the absence of cracks within the concrete. As the load increases, the energy of AE inside the concrete grows rapidly due to the generation of microcracks. When the load is increased to close to the peak load, the energy reaches the maximum, which indicates that high-strength ordinary concrete in the bending and fracture process shows a significant increase in the possibility of brittle fracture, cracks, once formed, it is rapidly along a major path of expansion, to reach the peak load will be instantaneous destruction, the extensibility of the small, the AE energy is therefore not a continuous increase in the energy to reach the peak, the energy is also gradually reduced. This suggests that microcracks within the concrete near the peak converge to form macroscopic cracks, with the source of damage concentrated in a localized area only[6].

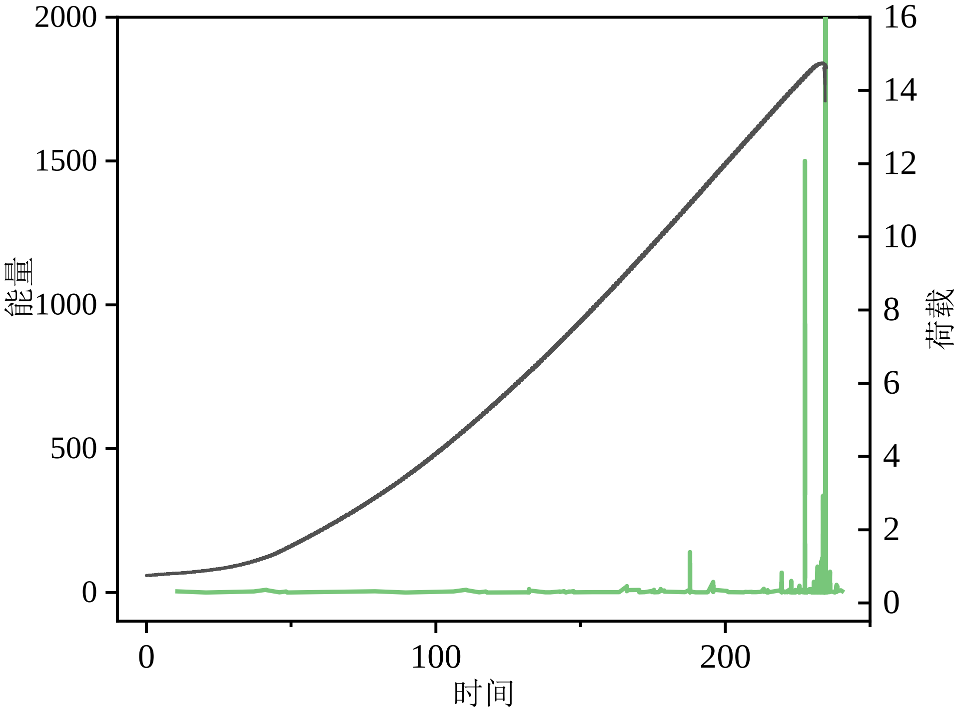

Fig. 3. Acoustic emission energy, load versus arrival time for flexural specimens.

3.2 Analysis of bond properties

The correspondence between the load-slip curve and the AE energy is shown in Fig. 4. The process of rebar being pulled out is roughly divided into three stages, which are the ascending stage, the local debonding stage, the crack expansion stage, and the descending stage [7].

Among them, in the rising section, the linear relationship between load and slip shows that the pullout force immediately after loading is transferred to the whole bonded section, which makes it subject to shear and the shear force is transferred from the stressed end to the free end from large to small[8]. At this time, the slip between the reinforcement and concrete has not yet occurred, but the concrete may produce micro-damage internally, and the macroscopic modulus of elasticity of the specimen is obviously smaller than that of the reinforcement. The acoustic emission signal in this stage is very small, mainly from the concrete micro-damage and the interference signal generated by the contact parts at the beginning of loading. The second stage is the local debonding stage, in which the reinforcement bar also enters the yielding stage, and when the pullout force increases to a critical value (about 70% of the peak pullout force), the bond interface starts to slip from the stressed end. However, because the distal interface has not yet reached the critical bond, the tensile capacity continues to rise, and the concrete also begins to gradually produce micro-cracks. This stage produces obvious acoustic emission signals, especially at the turning point, the acoustic emission signal is relatively concentrated and haslarge energy. The third stage is the crack expansion stage. In this stage, the reinforcement bar enters the yielding stage, which is manifested in the fluctuation of the pullout force at the peak value and the increasing slip, and the acoustic emission signals generated in this stage mainly come from the slip of the reinforcement bar and the continuous expansion of the cracks, and the friction coefficient between the interfaces changes continuously due to the grinding of the reinforcement bar to the concrete interfaces in the process of pulling out, so that the load fluctuates into a jagged shape and slowly decreases. The fourth stage is the descending section, when the whole bond section is slipping, the pullout force starts to decline from the maximum value. The acoustic emission energy increases significantly in this stage and a maximum energy event occurs. The pullout force decreases sharply and the AE energy release is concentrated at the time of specimen splitting. After the continuous decrease of the pullout force, the friction between the reinforcement and the concrete reaches a constant state and the pullout force stabilizes. The change of AE signal at this stage is also very complicated, but the general trend is that the energy is gradually weakened, due to the congestion effect in the interior, the load is slightly raised and lowered and then there is a large energy AE signal, while in the later stage the signal becomes very weak[9].

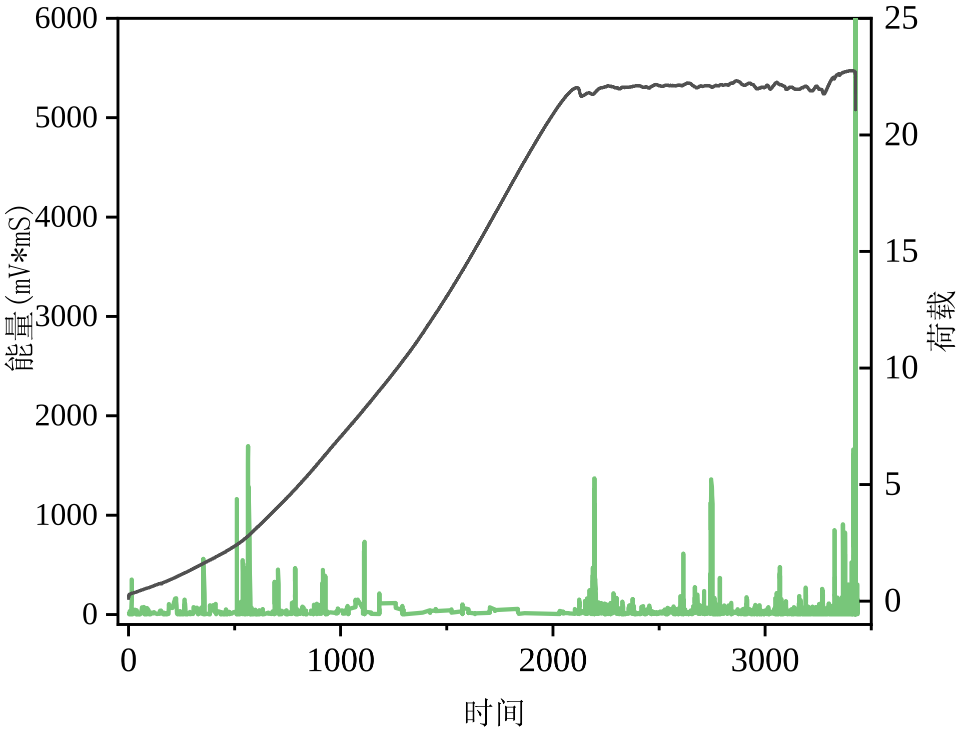

Fig. 4. Acoustic emission energy, load versus time for extracted specimens.

4. Conclusion

The AE energy distribution graph better reflects the change rule of load and acoustic emission energy with time.Two early warning signal characteristics of the specimen in bending and drawing tests are obtained: one is the acoustic emission characteristics of initial damage, and the other is the acoustic emission characteristics of failure.According to the change of AE signal, flexural and bonded specimens can be roughly divided into ascending section, local debonding stage and descending section during loading.

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