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Electrical emission in mortar under low compressive loading

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Abstract

Electrical emission in mortar under low compressive loading was investigated in this paper. Electrical emission in mortar is apparent even under the compressive stress less than 30% of compressive strength. Under uniaxial trapezoid load, there are two sinesoids associated with the loading and unloading phases, respectively. With the loading rate increasing, the amplitude of electrical emission increases. The mechanisms of the electrical emission in mortar under low compressive stress include the opening of microcrack, the flow of liquid in mortar, and the charge leakage. The electrical emission under cyclic loading was also studied. An understanding of the electrical emissions may lead to practical applications such as the nondestructive testing of concrete.

Keywords: Concrete; Electrical properties; Mechanical properties

1. Introduction

In order to ensure the safety of concrete structures, the nondestructive testing of concrete is very important. The electrical properties of cement and concrete have been an active field of research for the main part of last century. Valuable information related to the microstructure of the system and the hydration process of cement can be extracted from the electrical resistivity measurement or AC Impendence Spectroscopy measurement. Therefore, measurement of electrical properties is a promising method for nondestructive testing of cement materials [1–3].

However, the electrical emission in mortar means that mortar itself is polarized and electrified under loading, and emits the electrical field or the electromagnetic field. Wittmann [4] observed the reversible electromechanical coupling effect in a bar of hardened cement paste under bending, and a stress-dependent voltage and a voltage-dependent displacement were measured. Moreover, the electrokinetic effects are assumed to be the physical origin of the electromechanical effect [4,5]. Malyshkov et al. reported the electromagnetic emission in concrete during quasistatic and dynamic loadings. Results showed that the amplitude of electromagnetic emission was related to the bondage between the fillers and cement binder, the dimension of fillers, and the compressive strength. And the electromagnetic emission could be used to find defects and regions in concrete structures. Both the opening of cracks in concrete and the interface between stone and mortar influenced the electromagnetic emission [6–8]. Authors have studied the piezoelectric phenomenon in carbon fiber-reinforced cement and plain paste recently [9]. But study of the electric emission in mortar has not been reported. In this paper, the electrical emission in mortar under low compressive loading is studied. The mechanisms of the electrical emission are discussed in the following sections.

2. Experimental

2.1. Materials and specimens

Type 425 Portland cement (made in Huaxin Cement, Hubei Province, China) and quartz sand particles with average radii 0.63 mm were used. The fresh mortar was mixed in the mixer for 2 min at a water/cement ratio = 0.30 and cast to form cube 4 × 4 × 4 cm. A vibrator was used to decrease the amount of air bubbles. The specimens were demolded after 1 day then allowed to cure at room temperature in air for 28 days. Six specimens were made from each mix.

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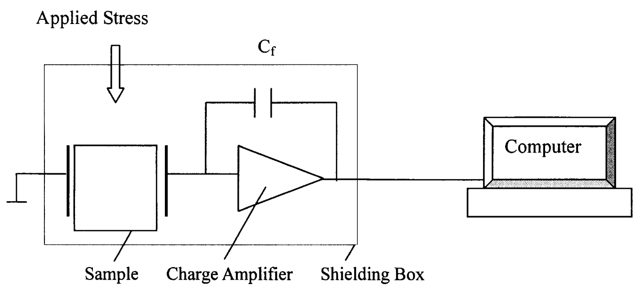

Fig. 1. The experimental set-up.

2.2. Experimental setup

The compressive loading tests were carried out using a INSTRON Testing Machine. The system used to detect electrical signals is shown schematically in Fig. 1. Two copper plates (0.2 mm thin) form a simple flat-plate capacitor, with concrete as a dielectric medium in between. This capacitor responds to changes in the electrical potential within specimens. Copper plates are laid parallel to the specimen surface with a 1- to 2-mm air gap between the plates and sample. So the influence of the interface between electrode and specimen is avoided, while Wittmann et al. attached two electrodes to the compressive surface and the tensile surface under bending. A stainless steel box and the ion net around the sample and the amplifier were required to shield from ambient electromagnetic noise. The charge amplifier has high input resistance ($>10^{12}$ Ω), and the frequency band is 1 Hz–200 kHz. Signals were recorded using a Data Auto Sample and Process System. In our experiments, the amplified coefficient of the charge amplifier is 10 mV/unit.

3. Results and discussion

3.1. The typical pattern of electrical emission in mortar

A typical pattern of electrical emission in mortar is shown in Fig. 2. The loading sequence is: Loading–Sustaining (10 s)–Unloading; the maximum load is 10 kN, loading rate is 2 kN/S. As shown in Fig. 2, there are two sinesoids associated with the loading and unloading phases, respectively.

We can also observe that with the loading rate increasing, the amplitude of electrical emission increases (see Figs. 3 and 4). It is noted that the data written in all figures of this paper are the voltage of the peak.

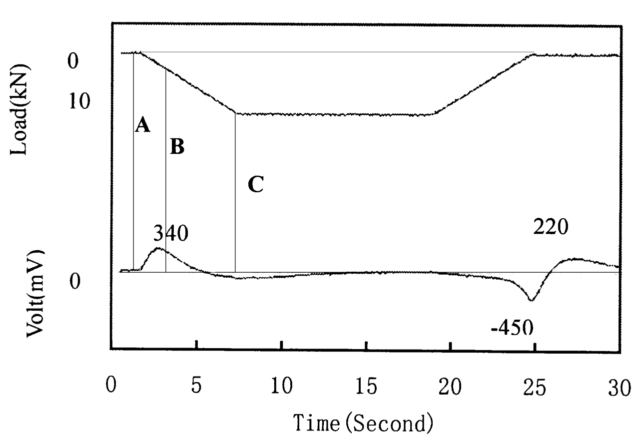

Fig. 2. The electrical emission in mortar (the loading rate is 2 kN/S).

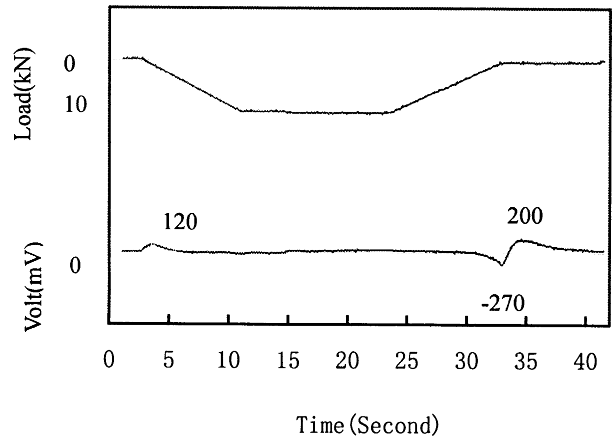

Fig. 3. The electrical emission in mortar (the loading rate is 1 kN/S).

3.2. The mechanisms of electrical emission in mortar

Concrete is an inhomogeneous multiphase material. For example, cement paste is made up of cement gel, $Ca(OH)_2$, unhydrated cement grains, capillary water, etc. The complicated components cause its various microstructures, including solid/solid, solid/liquid, and solid/gas interfaces, where the interface double electrical layer is formed. The interface double layer affects both the mechanical properties and the electrical properties. Many scholars have paid more attention to this special interface region [4,5,10].

As we have known, the fracture of concrete originates from the interface microcracks. When interface microcracks open, the interface is separated, so the surfaces of cracks are electrified [6,11]. The interface double layer between solid/

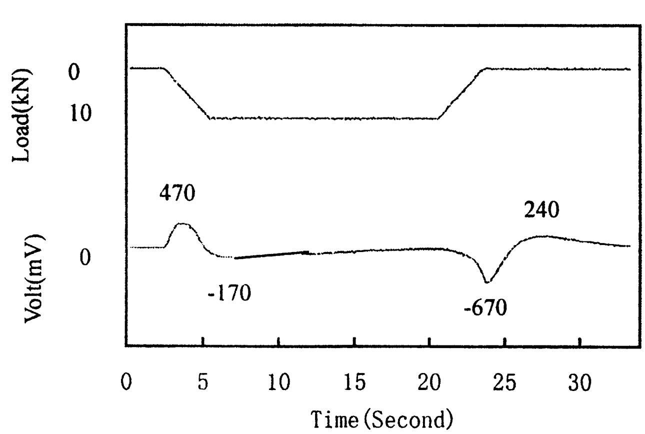

Fig. 4. The electrical emission in mortar (the loading rate is 5 kN/S).

liquid is called the diffuse layer, which can be modeled as Stern model. According to this model, the solid–liquid interfacial zone consists of two parts — the Stern layer and a diffuse layer. The Stern layer is a layer of ions strongly absorbed on the solid surface. The ions in the Stern layer are difficult to move due to the attraction of the solid surface. A diffuse layer exists behind the Stern layer, which contains counter ions. Once compressive force is applied, the flow of liquid makes ions in the diffuse layer separate from ions in the Stern layer. Finally, the streaming current is generated [12].

At the beginning of loading, the specimen becomes densified, and some initial microcracks close while some open. Then with the compressive stress increasing, the flow of liquid begins, and the streaming current is generated. When the load no longer goes up, the charge may leak through the interior bulk and the surface. These three phases form a sinesoid in Fig. 2, and parts A, B, and C in Fig. 2 are mainly due to the opening of microcrack, the streaming current, and charge leakage, respectively. It is implied that the orientation of electrical field produced by microcracks is contrary to that produced by the streaming current. In the sustained loading period, no electrical signal appears, except the charge leakage because the flow of liquid is slow.

During unloading, the streaming current, microcracks opening (referring to cracks which are closed at the beginning of loading), and charge leakage lead to the descending arc, the ascending arc, and the descending one of Fig. 2, respectively, and form another sinesoid.

As the loading rate increases, the speed of crack opening and liquid in mortar both increase, so the amplitude of electrical emission improves with the loading rate.

3.3. The electrical emission in mortar under cyclic loading

Fig. 5 is a typical pattern of the electrical emission in mortar under cyclic loading. The loading sequence is: Loading (0.1 s)–Sustaining (1 s)–Unloading (0.1 s), and the maximum load is 10 kN. Fig. 5 shows that the electrical emission in mortar under cyclic loading exhibits periodicity, and part B described in Section 3.2 has not happened for short loading time.

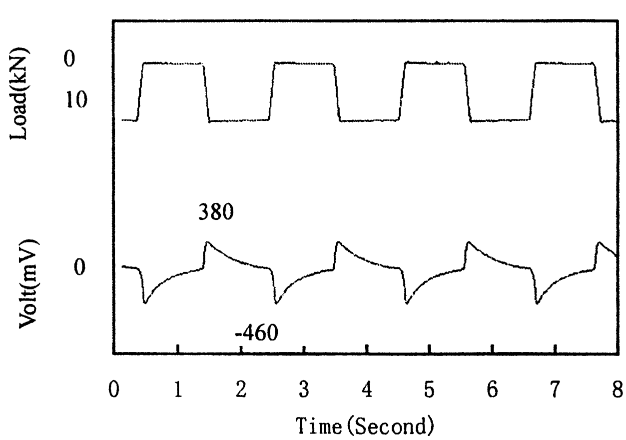

Fig. 5. The electrical emission in mortar under cyclic loading (at the start).

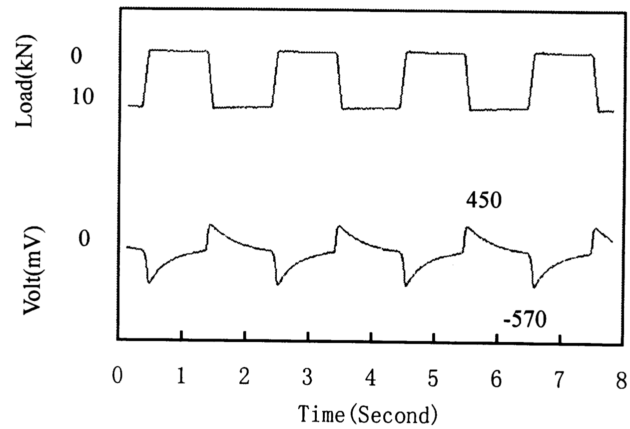

Fig. 6. The electrical emission in mortar under cyclic loading (at the end).

Fig. 6 shows the pattern of the electrical emission in mortar after 1200 cycles. The amplitude of electrical emission increases, indicating that some initial cracks have propagated.

4. Conclusions

1. Electrical emission in mortar is apparent even under the compressive stress less than 30% of compressive strength. Under uniaxial trapezoid load, there are two sinesoids associated with the loading and unloading phases, respectively.
2. With the loading rate increasing, the amplitude of electrical emission increases.
3. The mechanisms of the electrical emission in mortar under low compressive stress include the opening of microcrack, the flow of liquid in mortar, and the charge leakage.
4. The propagation of initial cracks in mortar under cyclic loading leads to the increasing amplitude of electrical emission.

Acknowledgments

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