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Evolutionary trace for early hydration of cement paste using electrical resistivity method

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HIGHLIGHTS

- Early hydration of cement paste is traced by electrodeless electrical resistivity method.
- Linear relationship explored between setting time with the electrical resistivity parameters.
- Compressive strength of cement pastes is predicted by electrical resistivity results.

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ABSTRACT

Setting time and early strength of cement are two key parameters to the early hydration of cementitious materials. The two indexes are qualified via traditional electrical method in the past, but several defects still remain in traditional electrical methods, electrical resistivity measurement is put forward to study the two key parameters in this paper. A relationship between setting times (including initial and final setting time) and the electrodeless resistivity has been discussed, aiming to establish a rapid testing method which could predict setting time of cementitious materials. Furthermore, electrical resistivity measurement and standard compressive strength test has been studied and the experimental results show that the cement paste matrices with higher water cement ratio present the lower electrical resistivity value. A linear relation is established between the standard compressive strength of cements at 1 d and the resistivity of the pastes at 24 h, which can demonstrate the resistivity and the standard compressive strength have a close corresponding relationship, and the resistivity curve of cement and the strength development curve has the same trend. So the standard compressive strength of cements could be predicted by electrical resistivity curve.

1. Introduction

Cementitious materials is one of the most important building materials, which is widely used in concrete structures, pavements, bridge decks and so on. Concrete structures always accompany with good mechanical performance and excellent durability. However, cementitious materials are greatly influenced by the early performance, especially the early hydration process.

It is well known that setting time and early strength are two key parameters in the early period of cement hydration. Whereas, setting time of cement paste is conventionally determined by means of needle penetration method, but manual operation is prone to lead an artificial error which can't be ignored. Similarly, the measurement of early compressive strength of mortar is subjected to same situation [1–2]. Thus, alternative methods need to be explored. Reinhardt et al. [3] utilized the velocity of ultrasound waves in order to continuously monitor the setting time of cementitious materials, while Pessiki et al. [4] determined setting time of cement by ultrasonic method. However, several defects still remain in traditional electrical methods [5–7], such as the poor contact between cementitious materials, unavoidable electrodes and the indirect relationships between data sets and physical performance.

Electrical resistivity measurement, by contrast, is non-contact technique, which prevents the influence on experimental result from contact resistance and contact capacitance. In addition, application of electrodeless resistivity device (CCR-II) accompanies with some apparent merits like high accuracy, automatic recording and explicit physical meaning of testing curve. Thus, the hydration of cementitious material can be better characterized by electrodeless resistivity device [8–14].

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In this paper, electrical resistivity method is used for tracing the early hydration evolution of cement materials. The development curve of cementitious material resistivity during hydration and mechanical properties have been studied, which is used to establish a relationship between setting time of cement paste and the characteristic points of resistivity curve. In addition, compressive strength of different water cement ratio at different ages is tested and analysed with the development curve of resistivity, the relationship between resistivity and compressive strength can be determined.

2. Experiments

2.1. Experimental materials

The cement used for experiment is Portland cement (P.O 42.5). The composition of cement is shown in Table 1.

2.2. Experimental process

Cement paste matrices were prepared with water cement ratio of 0.25, 0.3, 0.4 and 0.5 respectively. Electrodeless resistivity device is used for electrodeless resistivity measurement, grout the fresh paste into the annular mold of device, and smooth the paste surface by slight vibration to eliminate bubble generated in mixing process. Then, a plastic film covered over the mold to reduce evaporation. The recording system automatically samples with threading interval of 5 s, and resistivity is recorded for 1 day. The ambient temperature is maintained 20 °C during the whole testing process. No-load resistance of more than 50,000 Ω was adjusted to eliminate the influence of air resistance and the interference from electromagnetic field in round space. And then micrometer is employed to measure the average height of samples for data correction. The system for electrodeless resistivity measurement is shown in Fig. 1. Initial and final setting time of cement paste are determined by Vicat apparatus (HG-80S penetration resistance meter) according to GB/T50080-2011. Moreover, the cement cube axial compressive test ($40 \times 40 \times 40$ mm) is performed with the initial value of 2400 N and loading speed of 200 N/s (given by GBT 17671-1999) at the designated curing age (12 h, 18 h, 1 d, 3 d, 7 d, 14 d and 28 d). The specimens are placed in a curing chamber (95 ± 5% RH, 20 ± 2 °C) until they are tested.

3. Result and analysis

As the cement hydration products accumulating, the ion concentration in liquid phase and porosity of cement paste change continuously. Ion concentration in liquid phase affects liquid phase resistivity, the lower the ion concentration, the more liquid phase resistivity is. And porosity has the same effect on matrix resistivity, the smaller the porosity, the more matrix resistivity is. The changing of the two factors influence the resistivity of cement paste system.

By measuring the resistivity of fresh paste, the condensation hardening characteristics of cementitious material can be determined. A large number of researches using contactless resistivity measuring apparatus [15] study the hydration characteristic of cement paste systematically and divide the cement hydration into dissolution period, setting period, acceleration period and deceleration period [16], pointing out that the development curve which electrical resistivity change with time and the strength development curve appears the same trend [17].

Electrodeless resistivity curves of different water cement ratio cement paste are drawn in Fig. 2. And differential results of electrodeless resistivity curves are described in Fig. 3. From the Fig. 2, it is visible that all the resistivity differential curves have a process of first down and then up in the beginning. The reason why the curves go down is that the turbid liquid, a mixture of cement and water, includes K^+, Na^+, Ca^{2+}, SO_4^{2-} and OH^- at early stage. As is known to all, the electrodeless resistivity method which is used to measure the resistivity of cementitious materials along with time actually tests the change of ion. With the accumulation of hydration products after the water added, cement paste ion concentration in liquid phase is continuously changing. Ion concentration in liquid phase affects liquid resistivity, the smaller the ion concentration, the bigger the liquid resistivity [18]. Ion concentration gradually increases, which leads the increase of electric current and the decreases of resistance, until the resistivity curve reaches the lowest point, interior ion concentration get to saturation, hydration products begin to take shape at this time [19]. So

Table 1
Composition of cementitious material.

Composition	Al_2O_3	SiO_2	SO_3	K_2O	CaO	Fe_2O_3
Content (%)	4.62	18.59	5.23	0.92	64.67	4.17

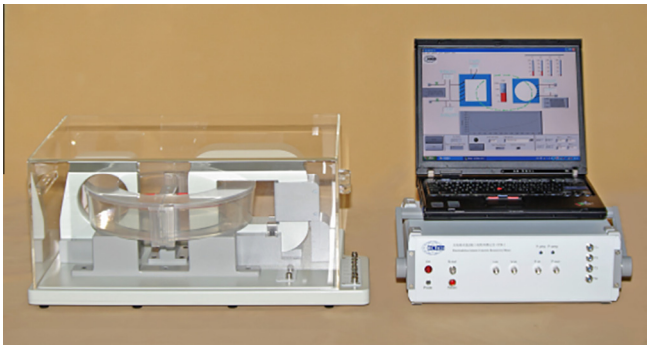

Fig. 1. The system for electrodeless resistivity measurement.

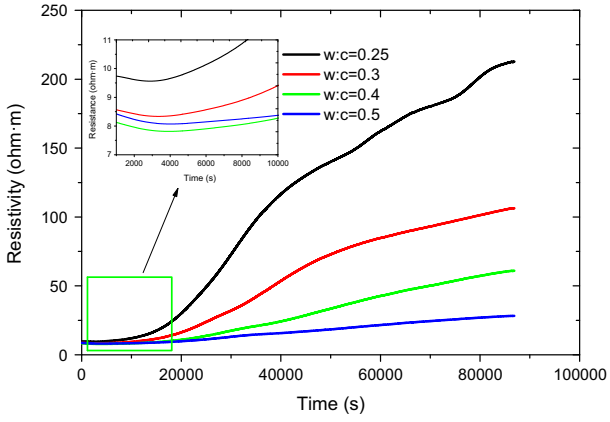

Fig. 2. Electrodeless resistivity curves of different water cement ratio cement paste.

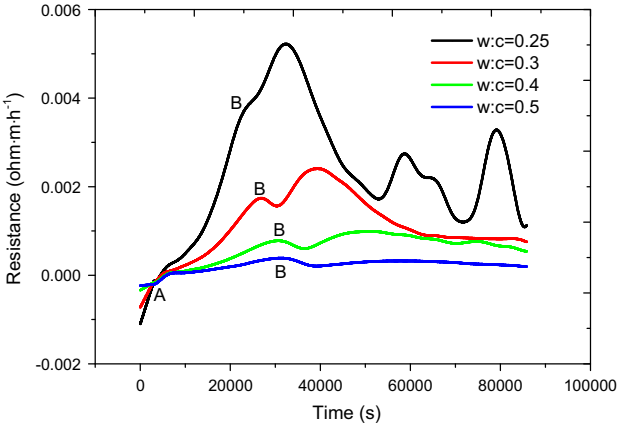

Fig. 3. Differential electrodeless resistivity curves of different water cement ratio cement paste.