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Evaluation of the influence of a superplasticizer on the hydration of varying composition cements by the electrical resistivity measurement method

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HIGHLIGHTS

- Electrical resistivity measurement method is a sensitive monitoring technique for cement paste microstructure development.
- The electrical properties of cement paste are considerably affected by what may affect the chemistry of the pore solution and the microstructure development in cement-water system.
- Electrical resistivity measurement method helps predict the appropriate use of superplasticizer.

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ABSTRACT

Electrical resistivity measurement was employed to study the influence of varying dosages of a superplasticizer on the hydration process of cements with different chemical composition. The electrical resistivity development curves as a function of time for all cement pastes were explained in detail. The electrical resistivity rate curves of the cement pastes were compared, and the results indicate that electrical resistivity measurement by a non-contact method is a sensitive monitoring technique for cement hydration and microstructure development. Much information related to the effect of superplasticizers on the properties of cements differing in composition can be provided by this method, helping mix designers to define more appropriate use of admixtures. Based on the electrical resistivity development behaviour of the samples, and other findings, the superplasticizer used has a more effective dispersive force and more influential retardation effect, in addition to a less bleeding trend in case of the 42.5 class of cement compared to the 32.5 class with the same water-to-cement ratio and curing conditions.

1. Introduction

Investigating the electrical properties of cement pastes by using the non-contact method has recently been proven to be efficient in terms of disclosing reliable information related to the cement hydration process[1] and permeability [2], and the factors affecting this process, i.e. W/C ratio, cement components, curing temperature and admixture incorporation. Electrical resistivity measurement is mainly affected by two parameters: the liquid phase electrical resistivity and the pore development through the system, as clarified by the empirical relationship of Archie's law [3]. Thus, measuring the electrical resistivity of cement paste can be considered as an appropriate method to observe the microstructure development of a cement paste system. It is regarded as a non-destructive testing technique and a helpful indicator of early age properties of cementitious materials. The paste maturity process can be easily monitored by studying the bulk electrical resistivity development with time, since both processes are sensitive to the fundamental changes in the physical and chemical properties of cement paste media. Chemical admixtures are used to change some properties of cementitious materials, and at the same time, they have a direct effect on the hydration process. The complex interaction between the chemical admixture and cement particles creates an obstacle to the appropriate utilisation of admixtures. Thus, admixtures must be evaluated for compatibility with cementitious materials. Determining the optimal dosage of one admixture has a profound impact on enhancing the cement properties in a suitable and economical way. In this regard, measuring the electrical resistivity by a non-contact method has been proven to be efficient and reliable in order to characterise the implications of adding these chemical additives on the hydration process as well

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as its influence on the microstructure development of the cement paste system. A high-range water reducer, a polycarboxylate-type superplasticizer, has been used in this study. It is well-known that the rheological performance of the cement paste is improved remarkably by this kind of admixture [4]. It is extremely important to evaluate the effectiveness of plasticizers when there are specific issues, namely the rapid loss of workability, alteration of setting behaviour, improper strength gain, and bleeding. Common incompatibility issues between cement components and a water-reducing chemical give rise to serious problems that may impair the cement properties [5]. Detecting the influence of the admixture on cement properties by employing the electrical resistivity method can help mix designers in determining the optimum dosage leading to more compatible behaviour between the superplasticizer and cement. Xiao et al. [6] tried to offer a more suitable superplasticizer by employing the non-contact electrical resistivity measurement. The study proposed a methodology for selecting a suitable superplasticizer and the optimum dosage based on the superplasticizer effect in controlling the setting time and maintaining the rate of compressive strength besides the paste fluidity. In this study, we attempt to characterise the electrical resistivity development for cements differing in compositions in the presence of superplasticizers. The aim is to emphasise the ability of the non-contact electrical resistivity measurement method as a selective method and to provide practical information about the compatibility between the cement and superplasticizer.

This study mainly compares the influence of a superplasticizer on the hydration of cement, differing in chemical components, using electrical resistivity measurement. The electrical resistivity development curve as a function of time for all cement pastes is explained in detail. The influence of the superplasticizer on the properties of two kinds of cement is discussed. Furthermore, a non-contact electrical resistivity measurement method is proposed as a suitable monitoring technique for determining the compatible behaviour of the superplasticizer and cement.

2. Experimental materials and methods

2.1. Materials

Ordinary Portland cement of classes (32.5) and (42.5) was used. The chemical composition for both classes of cement is listed in Table 1. The mechanical and physical properties are listed in Table 2. The W/C ratio was fixed for all pastes at 0.3. A polycarboxylate superplasticizer was used in liquid form (40% active solid) with different dosages, as shown in Table 3.

2.2. Methods

2.2.1. Fluidity

The mini-cone test was used to characterise the relative fluidity of cement paste and to determine the saturation dosage of the superplasticizer. A copper truncated cone typically has an internal diameter of 60 mm at the base and 36 mm at the top, with a height of 60 mm. The freshly mixed cement paste was poured into the cone followed by gentle tamping. The cone was quickly removed and the flowing paste spread in a circular pattern. After the paste stopped flowing, the average values of four perpendicularly crossing spread diameters were measured and to determine the cement paste fluidity.

2.2.2. Electrical resistivity measurement

The electrical resistivity for all cement pastes was gauged using the non-contact electrical resistivity measurement. This technique adopts the transformer principle and eliminates electrodes, and thus can overcome the drawbacks that hamper conventional resistivity-measuring methods with electrodes. Each sample was made by mixing the paste for 2 min in a planetary-type mixer at 45 rpm and a further 2 min at 90 rpm. The mixture was then discharged into a plastic mould to act as the secondary coil of the transformer device which consists of two coils and a transformer core. An alternating current (AC) sine wave was applied on the primary coil by a generator at a frequency of 50 Hz, amplified by an amplifier, and then passing through the transformer core, creating a magnetic field. Electromagnetic induction occurs to induce a toroidal voltage (V) in the ring sample as the second coil. Meanwhile, the current passing through the specimen is detected by the leakage current meter, following which the resistivity of the cement paste can be calculated according to Ohm's law [1,7]. The computer records the data for up to 72 h. The test was conducted under a fixed room temperature of 20 ± 2 °C. A schematic diagram of the non-contact electrical resistivity measurement device is presented in Fig. 1.

2.2.3. Setting time

Both the initial and final setting times of the cement pastes were determined by the Vicat apparatus, as described in the Chinese standard GB/T 1346-2001 [8]. The initial setting time is defined as the time period between the time when the cement first comes in contact with the water and the time when the Vicat needle penetration is 36 ± 1 mm, indicating that the paste has started to stiffen considerably. The final setting time is determined as the time period between the time when the cement first comes in contact with the water and the time when the Vicat needle, with an annular attachment visibly stops sinking on the surface of the paste, indicating that the paste has started to harden. The Vicat mould has an internal diameter of 75 ± 0.5 mm at the base and 65 ± 0.5 mm at the top, with a height of 40 ± 0.2 mm. A glass bottom plate was used and glued to avoid leakage of the paste. The specimen was kept in a moist cabinet for 30 min after moulding without being disturbed. The testing temperature was 20 ± 2 °C and the relative humidity was 95 ± 5%.

2.2.4. Compressive strength

After preparing the mixtures, cubic specimens of 40 × 40 × 40 mm were cast for compressive strength. Three specimens were prepared for each cement paste. The specimens were de-moulded 24 h after casting and then dipped into a water tank at 20 ± 2 °C for curing. The compressive strength tests were conducted in a compression testing machine at a loading rate of 2.4 KN/S.

2.2.5. Solution electrical resistivity

The liquid solution was extracted from the pastes through a filter using a vacuum pump at different times after mixing. These fluids were collected in sealed polystyrene containers to minimise contact with CO_2 in the air. The electrical resistivity of the solution was gauged by measuring the electrical conductivity of the solution using digital portable conductivity meter.

3. Results

3.1. Fluidity

Generally, the fluidity of cement pastes is dramatically enhanced when a superplasticizer is incorporated, as shown in Fig. 2. It can be seen that the saturated dosage of the admixture for both classes of cement is 0.15% by cement mass. However, the dosage needed for a given fluidity for the 42.5 class of cement is less than that for the 32.5 class. This may indicates that this kind of superplasticizer is more effective with the 42.5 class of cement samples in disassembling the flocculated structure of the system.

The fluidity loss of the pastes at 30–60 min is determined by decreasing the diameter of the spread. It can be seen that on increasing the superplasticizer dosages, the trend of the fluidity loss is considerably decreased and the loss may be mitigated around the saturated dosage.

Based on the results of the mini-cone test, the saturated dosage, an optimum dosage, and an excessive dosage of the superplasticizer can be determined. The dosage of 0.08% by cement mass of the admixture can be considered as the optimum dosage, while 0.3% by cement mass is the excessive dosage.

Table 1
Chemical composition of ordinary Portland cement by Wt%.

Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MnO	SO_3	K_2O
Cement (32.5)	59.53	24.27	7.55	2.76	0.28	4.66	0.95
Cement (42.5)	62.84	22.76	5.00	3.08	0.28	5.38	0.67