Construction and Building Materials 172 (2018) 499–508

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Study on the effect of chloride ion on the early age hydration process of concrete by a non-contact monitoring method

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HIGHLIGHTS

- Adopt the non-contact resistivity method to study the hydration of concrete.
- Chloride ion influences the hydration rate of concrete after the deceleration stage.
- The free chloride ions left show a linear relationship with its initial proportion.

ARTICLE INFO

Article history:
Received 22 August 2017
Received in revised form 11 March 2018
Accepted 21 March 2018

Keywords:
Strength
Setting time
Chloride ions
Mortar
Concrete
Hydration
Electrical resistivity

ABSTRACT

The quality of the mixing and curing water for the concrete is essentially important since water is definitely a key factor and component which will determine the mechanical properties of the hydrated structures and members. Normally, we make use of fresh water during mixing and curing since it seldom contains excess dissolved ions. And according to the literature review, various kinds of dissolved ions in sea water solution like Cl^-, SO_4^{2-} etc. is about to induce physical and chemical reactions in the fresh cement-based material mixture. The hydration process of it will exhibit apparently different features from the ordinary hydration process of cement-based material with fresh water. However, fresh water is actually quite difficult to obtain sometimes especially in coastal areas and outlying islands. And if we are not able to provide reliable information and solution on the sea water mixed concrete structures and members, the construction effort of infrastructure in coastal areas and outlying islands will be greatly affected. In this study, the early age hydration processes of concrete mixed with sodium chloride solution using various mixture proportions are accurately monitored and recorded by a non-contact resistivity monitoring method to investigate and discuss the similarities and differences of the microstructure development of them compared to that of paste and mortar with sea water and fresh water. The non-contact resistivity monitoring method is found good at revealing the liquid phase conductive path development during hydration. Many research works have proved that non-contact resistivity monitoring method is quite sensitive to the changes of microstructure of cement-based materials. Thus, it is capable of reflecting the subtle changes and the features of the microstructure percolation and the degree of hydration reaction throughout the early age hydration process. Based on the monitoring results, the active hydration reaction of concrete with sea water in the early age are found prolonged and the percolation time point of it is postponed obviously compared to that of concrete with fresh water. It is similar to the effect of superplasticizer. And the dissolving period is observed completely disappeared when chloride ions are used for mixing. However, when compared to the sea water mixed paste and mortar, it is found that coarse aggregate in concrete will obviously weaken the superplasticizer effect from sea water. All of these phenomena provide new information on the early age hydration behavior of concrete with chloride ions and sodium ions. And it is widely accepted that the early age hydration behavior determines the long term durability and reliability of hydrated cement-based structures. Therefore, the durability and reliability of the concrete infrastructure using sea water in coastal areas and outlying islands is found possible to be studied and controlled by the non-contact resistivity monitoring method.

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https://doi.org/10.1016/j.conbuildmat.2018.03.206

1. Introduction

Concrete is a kind of extremely important construction material which are widely applied in the construction of building and infrastructure projects since it is easy to obtain in place and to shape for structures with complex design. Moreover, the cost of concrete materials themselves and maintenance when in service are relatively cheap compared to that of steel. In the year of 2014, over 4.18 billion tons of concrete are consumed for construction purpose of buildings and infrastructures in the world. However, the construction of concrete structure is not as that relaxed as steel building since the cement-based materials require a certain period of hydration. And the quality and degree of the hydration process of the early age cement-based materials will determine and influence the corresponding later stage porosity, micro scale pore structure and compressive strength of the structures and members. Furthermore, when fresh water is totally replaced by sea water in mixing and curing of concrete, the situation of hydration will be much more complicated. Unfortunately in the coastal areas and outlying islands, fresh water is rarely available in most cases. And sea water is the only option for construction. Thus, the investigation and study on the hydration process of the cement mortar, paste and concrete with seawater is definitely necessary.

Historically, a great amount of research effort has been made on how to obtain and explain the hydration behavior of cement-based material timely and precisely. Various kinds of methods have been utilized to investigate the microstructure development of early age concrete. Sayers and Dahlin discussed the possibility of continuous measurement of velocity and amplitude of ultrasonic compressional wave to reflect the evolution of cement paste microstructure development. Based on their results, the microstructure development of cement paste was thought to be a process from a viscous suspension of irregularly shaped cement particles into a porous elastic solid with non-vanishing bulk and shear moduli [1]. Inspired by this idea, Grosse et al. made and improved a series of ultrasound testing devices aiming to characterize the hydration process of cement-based materials [2]. Traditional tests like the Vicat-needle test, penetrometer test and flow test are not fashionable any more since it need skilled operative experience and assessable information is very limited. Lately, Ye et al. study the development of microstructure in cement-based materials by means of HYMOSTRUC model and ultrasonic pulse velocity [3]. Assisted by the model, the microstructure development was vividly explained and divided. A percolation time point was clearly identified.

In this research, we attempt to make use of a non-contact NDE monitoring technology to acquire the variation of specific property parameter during the early age hydration process of concrete with sodium chloride solution. We also studied the hydration process of paste and mortar mixed with fresh water and sodium chloride solution for the purpose of comparison using this equipment. The fundamental principle of this non-contact NDE monitoring technology is to monitor and record the data of resistivity of the fresh concrete continuously in real time throughout the hydration process [4]. It is well known that resistivity is a quantitative representation of the ability of the free movement of electron in the conductive material [5–8]. And the electron is prone to move towards the area of low resistivity i.e. liquid phase solution in concrete [12]. Thereafter, this monitoring method is quite sensitive to the micro scale development of liquid phase structure of cement-based material during its hydration process [10]. According to the previous study on the hydration behavior and process of concrete, micro scale development of cement-based material is the complementary process of relative rise and decline of the solid phase and liquid phase respectively [15]. Thus, it is possible to precisely locate and distinguish the percolation and the active hydration reaction period of the mixture based on the characteristic point of the resistivity curve. Based on the comparison results from concrete with fresh water and sodium chloride solution respectively, it could be clearly figured out that the influence of chloride ion on the hydration behavior and process of cement-based materials is highly similar to that of superplasticizer. And according to the comparison results from paste and mortar with the same kind of mixing water, the coarse aggregate in the concrete could effectively weaken the effect of superplasticizer.

2. Experiments

2.1. Experimental materials

The experimental materials contain water, cement, aggregates and sodium chloride. All tests were used the ordinary Portland cement P.O42.5, which satisfied the Chinese standard GB175-2007. Its chemical composition is shown in Table 1. The aggregates include standard sand with size of 0.1 mm–1 mm and gravel made of basalt with size of 5 mm–20 mm. Moreover, experimental samples were divided to paste, mortar and concrete. The cement paste was used in the tests with mix proportions by weigh as follows: (cement: water; 1: 0.4) and the mix proportions of cement mortar as follows: (cement: sand: water; 1:1.5:0.4) and the mix proportions of concrete as follows: (cement: sand: gravel: water; 1: 1.5: 2.5: 0.4). No matter whether they are paste, mortar or concrete samples, each group of samples would add five different concentration levels of sodium chloride solution. The special mixture proportions of samples for the electrical resistivity tests are given in Table 2.

2.2. Experimental method and principle

In this study, a third-generation non-contact electrode resistivity monitoring instrument was used to monitor the change in resistivity of fresh cementitious materials. The test equipment consists of five parts as shown in Fig. 1: data acquisition system, sample mould, signal generator and amplifier, transformer and small current sensor. The instrument overcomes the shortcomings of the contact electrode tester. For example, avoiding the effect of the capacitance and polarization effects and improving the accuracy of the test. The non-contact electrode resistivity monitoring instrument was invented which was based on the principle of the transformer, as the Fig. 2 showed. The resistivity formula was derived from Ohm's law and the sample rule, as shown in Eq. (1):

$$\rho = \frac{h}{2\pi}\left[-\frac{h}{r_2 - r_1}\ln\frac{r_2}{r_1} + \ln\frac{r_3}{r_2} + \frac{r_4}{r_4 - r_3}\ln\frac{r_4}{r_3}\right]\frac{U}{I} \tag{1}$$

In this formula, U is a constant annular voltage of 1.53 V, I is the annular current measured by a small current sensor at each fixed time, r1, r2, r3 and r4 are the size of the annular mould, h is the height of the sample to be measured.

2.3. Experimental process

Around 1.5 litters fresh cementitious materials was cast into the annular mould (1.672 L in volume), as shown in Fig. 2, the interface of the mould pointed Vaseline and clamped by clips for preventing

Table 1
Chemical composition (%) of cement.

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