Construction and Building Materials 113 (2016) 939–950

Contents lists available at ScienceDirect

Construction and Building Materials

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

Hydration process of fly ash blended cement pastes by impedance measurement

S.W. Tang [a,b], X.H. Cai [a], Z. He [a], H.Y. Shao [b], Z.J. Li [b], E. Chen [b,*]

[a] State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan, China
[b] Department of Civil and Environment Engineering, The Hong Kong University of Science and Technology, Kowloon, Clear Water Bay, Hong Kong

HIGHLIGHTS

- Hydration of high-dosage fly ash blended cement pastes is evaluated.
- Four hydration stages are identified.
- Gismondine is found in the zeolite formation stage.

ARTICLE INFO

Article history:
Received 18 December 2015
Received in revised form 12 March 2016
Accepted 23 March 2016
Available online 29 March 2016

Keywords:
Cement paste
Fly ash
Zeolites
Hydration
Pore
Impedance

ABSTRACT

This study focuses on the early-age hydration development in fly ash blended cement pastes. The characteristic features in different hydration stages and the evolution of zeolites phase, viz., gismondine, are identified in high-dosage fly ash blended cement-based materials using the innovative non-contact impedance measurement (NCIM), X-ray diffraction (XRD), scanning electron microscopy (SEM), thermogravimetric analysis (TGA), heat evolution test and pore solution analysis. It is found that the zeolite formation stage is comparatively distinct at the late hydration period. Besides, the influence of fly ash dosages in cement pastes on setting time and compressive strength are further examined.

1. Introduction

The current global production of fly ash is reported as around 800 million metric tons per year [1]. The amount of fly ash is expected to dramatically increase due to the continuous demand of coal for power production in China and India since 2004. The re-utilization rates of fly ash in United States in 2010 and European Union in 2008 are only 38% and 45% for the concrete production [1]. A good deal of the remaining ash is taken as waste products and dumped into landfill sites or even the ocean [2]. It is also known that fly ash always includes large amount of leachable toxic trace elements. The improper deposition of waste ash may lead to the serious contamination of soil, underground water and ocean, and thus, is a potential threat to the ecological environment and human health [3,4].

It seems that incorporating fly ash in cementitious materials is an effective method to eliminate the replacement burden of fly ash to a great extent [5]. From the view point of chemistry, in fly ash blended cement-based materials, the highly glassy silica and alumina phases in ash can react with the portlandite and/or other hydrated products in the cement matrix in alkaline environment to form additional calcium-silicate-hydrate (C-S-H) and/or cal cium-aluminatesilicate-hydrate (C-A-S-H) phases [1,2,6,7]. Enhanced durability properties of concrete with fly ash by so-called pozzolanic reactions above have been extensively investigated [8–14]. Besides, it was reported that calcium-aluminatesili cate-hydrate (C-A-S-H) phases (also known as zeolites phases) produced in fly ash blended cement-based materials could be employed to remove the ammonium from wastewater [2].

To achieve the goal of sustainable development as possible, the high-dosage fly ash cement-based materials in which more than 50% of cement by mass has been replaced by fly ash is favor for low carbon footprint and cost efficiency [6]. However, studies on the hydration mechanism of fly ash blended cement-based materials, especially high-dosage fly ash ones, based on non-destructive, continuous and in-situ techniques are limited [1]. Meanwhile, the formation process of C-A-S-H in fly ash blended cement-based

* Corresponding author.
E-mail address: victorymother@163.com (E. Chen).

http://dx.doi.org/10.1016/j.conbuildmat.2016.03.141
0950-0618/

Table 1
The chemical composition of cement and fly ash (wt%).

Cement	CaO	SiO$_2$	SO$_3$	Al$_2$O$_3$	Fe$_2$O$_3$	MgO	K$_2$O	TiO$_2$			
wt%	67.27	17.32	5.15	4.92	3.27	1.28	0.62	0.15			
Fly ash	Na$_2$O	MgO	Al$_2$O$_3$	SiO$_2$	P$_2$O$_5$	SO$_3$	K$_2$O	CaO	TiO$_2$	MnO	Fe$_2$O$_3$
wt%	1.14	1.64	31.16	52.14	0.34	1.25	1.19	3.37	2.15	0.05	5.58

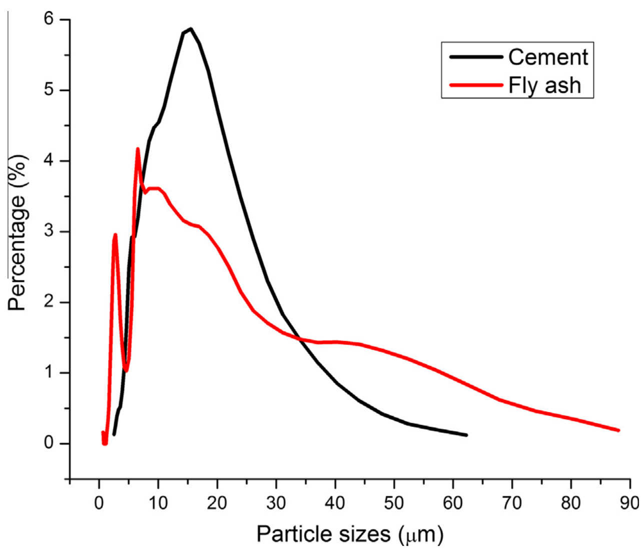

Fig. 1. Particle size distribution of cement and fly ash.

materials has not yet been fully investigated until now, which may restrict the application of fly ash blended cement-based materials.

In this work, the hydration evolution of fly ash blended cement pastes with different fly ash dosages is investigated using innovative non-contact impedance measurement (NCIM) in addition to X-ray diffraction (XRD), scanning electron microscopy (SEM), thermogravimetric analysis test (TGA), heat evolution test, ion chromatograph and inductively coupled plasma tests. In particular, characteristic features in each hydration stage of high-dosage fly ash blended cement pastes are discussed. Moreover, the relations among the dosage of fly ash, setting time and compressive strength of blended cement pastes are analyzed.

2. Materials and analytical methods

2.1. Raw materials

In this study, ordinary Portland cement (ASTM Type I) and de-air water were used. Fly ash blended cement pastes with water to binder (cement + fly ash) ratio 0.4 by mass were prepared in an environmental chamber with temperature (20 ± 5 °C) and humidity (90 ± 5%). These pastes were noted as F0, F10, F20, F30, F40, F50, F60 and F70 in which the number represents the mass percentage of fly ash replacing cement, i.e., 0, 10, 20, 30, 40, 50, 60 and 70%. The chemical compositions of the cement and fly ash are determined from XRF test and given in Table 1. From Table 1, the main component of cement is CaO; while Al$_2$O$_3$ and SiO$_2$ are dominant phases in fly ash. The particle size distribution and morphology of anhydrous cement and fly ash are shown in Figs. 1 and 2, respectively. From Fig. 2, it can be observed that a bulk of cement particles have angular shapes and scattered fly ash particles are spherically shaped.

2.2. Analytical methods

2.2.1. Impedance measurement

The impedance response and temperature development of fly ash blended cement pastes were measured continuously using a non-contact impedance measurement (NCIM) consisting of a transformer and leakage current meter. The details about the working mechanism of this measurement can be found elsewhere [15–18]. The test procedure is illustrated in the following: the raw materials were mixed in a planetary-type mixer at 45 revolutions per minute for 2 min first and then at 90 revolutions per minute for 2 min. The paste with volume of 1.7 L was cast into a ring-shaped mold. The data of impedance and temperature were automatically recorded at 1-minute interval until to three days after casting.

2.2.2. Heat evolution

The heat evolution of all fly ash blended cement pastes (F0, F10, F20, F30, F40, F50, F60 and F70) was measured continuously by isothermal calorimetry for three days. The fresh paste and de-air water with the same weight were injected into the glass ampoules of calorimetry. The heat transfer between the paste and water was measured continuously, from which the releasing heat of cement paste in the whole hydration process was derived.

2.2.3. Setting time and compressive strength tests

The setting time of each fly ash blended cement paste was tested by Vicat apparatus in accordance with ASTM C 191-99. Meanwhile, the fresh cement pastes were cast into cubic moulds with 4 cm × 4 cm × 4 cm for compressive strength tests at 1 and 3 days. Six cubes for each kind of fly ash blended cement paste were tested to get the average value of compressive strength. The tests were undertaken with a loading rate 0.5 kN/s.

2.2.4. Pretreatment for XRD, SEM, and TGA

In order to identify the hydration evolution of fly ash blended cement pastes at early-age hydration, especially the formation of zeolite phases in high-dosage fly ash blended cement paste, various techniques (XRD, SEM and TGA) are utilized for the microstructural investigation of F50, F60 and F70. These blended cement pastes were cast in 300 ml polyethylene bottles, sealed and stored under the condition of temperature 20 ± 1 °C. The hydration of three blended cement pastes (F50, F60 and F70) was stopped after fixed periods of time by successively immersing the crushed pastes into ethyl alcohol for four days and drying them in a vacuum chamber with 20 ± 2% relative humidity at 20 ± 2 °C for four days. These hydration

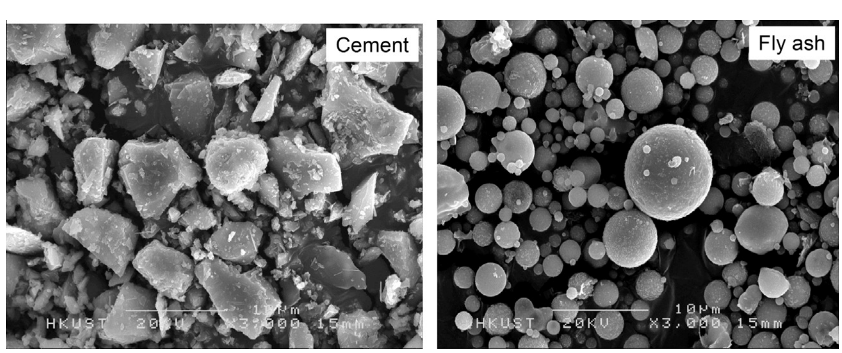

Fig. 2. Morphology of anhydrous cement and fly ash.