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Investigating the influence of basalt as mineral admixture on hydration and microstructure formation mechanism of cement

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HIGHLIGHTS

- We found that the basalt has obvious potential pozzolan activities.
- The basalt can be used as a new mineral admixture in concrete.
- Setting and hydration process of cement are retarded by addition of basalt.
- Basalt does not show negative effect on the compressive strength of concrete.

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ABSTRACT

Basalt powder is a by-product of basalt stone crushing plant. It is a big problem to propose utilization of these by-products from the aspects of disposal, environmental pollution and health hazards. In this paper, basalt is attempted to manufacture concrete as a new mineral admixture. Firstly, the chemical compositions and the pozzolan activity of the basalt were measured. Secondly, the cementitious paste with basalt powder was prepared and the normal consistency, setting time and the compressive strength were tested. Finally, the isothermal calorimetric measurement, X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) test were conducted to investigate the hydration process and microstructure formation of the basalt blended paste.

The results show that the basalt has obvious potential pozzolan activities and can be used as a new mineral admixture. The basalt has retardation effect on the setting and hydration heat evolution process of cement. Besides, early age compressive strength development of the basalt blended paste was normally less than the pure cement paste, but the strength are close at later ages.

1. Introduction

Cement is one of the important construction materials, which is widely used in civil engineering across the world. However, the manufacture of cement causes serious environmental pollution. It is well known that 1 ton of cement will approximately produce 1 ton of CO_2 [1,2]. Therefore, the sustainability development has spurred renewed interest in reducing the cement dosage of concrete. Supplementary cementitious materials (SCM), such as fly ash, limestone powder, natural pozzolans [3], slag [3–5], and silica fume are usually used as blender to replace some portion of Portland cement [6–8]. However, the continuous increasing demand in SCM results in great shortage of traditional blenders. So it is necessary to develop new types of SCMs in cement and concrete industry.

In China, a great amount of basalt powder is produced as by-products of stone crusher. At present, large volumes of basalt powders are accumulated like mountains, resulting in serious environmental pollution and health hazards [9]. Considering large specific surface areas and high content of SiO_2, Al_2O_3, basalt powders may be used as SCMs in cement [10]. However, the reference about the basalt used in concrete is limited until now. Binici et al. [11,12] conducted the study to examine possibility of using the industrial wastes of basaltic pumice as fine aggregate in concrete. They found that the basaltic pumice could be conveniently used for low abrasion and higher compressive strength concretes. They also investigated the sulfate resistance [13] and seawater attack resistance [4] of basaltic pumice concrete.

In this paper, the basalt as a new mineral admixture was investigated. The physical properties and chemical compositions were firstly studied. The pozzolanic activity of the basalt was also measured. Then, the normal consistency, setting time and the compressive strength were tested for the cement pastes with basalt and fly

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ash. Finally, the isothermal calorimetric measurement XRD and SEM test were conducted for investigating the hydration process and microstructure of the basalt blended paste.

2. Experimental

2.1. Raw materials

Portland cement with the compressive strength and flexure strength of 60.5 MPa and 8.7 MPa at 28 days respectively was supplied by Huaxin cement plant, Hubei province, PR China. The mineral admixture of grade I type of fly ash (FA), similar to ASTM Class F fly ash, was supplied by Zhenjiang Hebi power plant, Jiangsu province, PR China. The basalt obtained from Sichuan Province of China. The chemical composition of the cement, basalt and fly ash are given in Table 1.

2.1.1. Chemical composition of basalt

By comparing the chemical compositions, it can be seen that the mass fractions of $SiO_2 + Al_2O_3 + Fe_2O_3$ and CaO are 77.8% and 9.64% in basalt powder, similar to Class F fly ash.

X-ray diffraction pattern of basalt powder is presented in Fig. 1. It is observed in Fig. 1 that the basalt is in the form of Albite (A), Anorthite (B), Augite aluminian (C) and Labradorite (D).

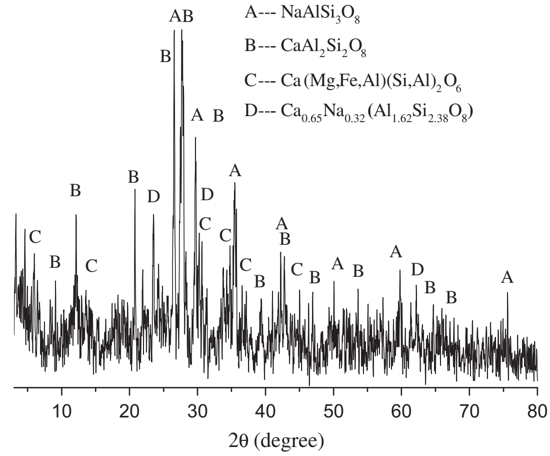

Fig. 1. X-rays diffraction patterns of basalt.

2.1.2. Particle shape

The particle shape analysis is performed on basalt and fly ash using a scanning electron microscope (SEM), shown in Fig. 2. It is clearly seen that the fly ash particles are solid spheres. Comparably, basalt particle is characterized by sharp-edged and split-like grains, originating from relatively hard and brittle-breaking natural stone.

2.1.3. Evaluation of pozzolans of basalt

The chemical compositions and physical properties of basalt powders are measured according to the related specification of natural pozzolans from ASTM C618 [14]. For the purpose of comparison, the corresponding index of fly ash is also tested. The experimental results are listed in Table 2. The important criteria closely related to pozzolanic activity are [15]: (1) the sum of chemical components, that is $SiO_2 + Fe_2O_3 + Al_2O_3$, and (2) the strength activity index, defined as the ration of the compressive strength for a mortar with 20% pozzolan replacement for cement by mass to the compressive strength of a control mortar. According to Table 2, the basalt powder satisfies the requirements of pozzolans ASTM C618, which is close to fly ash. It can be inferred that the basalt has obvious potential pozzolan activities.

2.2. Mixture proportions

In order to investigate the properties of basalt, ten mixture proportions were specially designed, as shown in Table 3. Cement pastes were prepared with constant volume fractions of water and powders, based on a control mixture with a water-to-cement ratio by mass (w/c) of 0.30. The superplasticizer (SP) as much as 1% weight of cementitious material was used to ensure the workability.

"BA-0" to "BA-30" were designed to investigate the effect of basalt as mineral admixture on the fluidity and mechanical properties of cementitious materials. Basalt was added as a partial replacement of cement at levels of 0%, 5%, 10%, 15%, 20%, 25%, 30% by weight of total cementitious materials. Besides, "FA-10" to "FA-30" were used to compare the effect of fly ash and basalt.

2.3. Methods

2.3.1. Normal consistency and setting time

Normal consistency test of the ten mixtures are conducted according to ASTM C187 [16]. To evaluate the setting process of the investigated materials, Vicat needle tests according to ASTM C191 [17] were conducted. After mixing, periodic penetration tests were performed on the sample every 5 min by allowing a penetration needle to settle into the sample until the cementitious paste was completely set.

2.3.2. Mechanical test

The cementitious paste was cast into 40 × 40 × 160 mm prisms steel molds, compacted through external vibration. Then plastic sheets are covered on the molds to prevent moisture evaporation. The specimens were cured at 20 °C and approximately at 100% relative humidity (RH). After 28 days curing, the flexural strength and compressive strength were conducted according to ASTM C348-09 [18] and ASTM C349-08 [19] respectively. Three samples of each batch were tested. The average value was served as the final flexural strength and compressive strength.

2.3.3. Isothermal calorimetric measurement

A TAM Air isothermal calorimeter manufactured by TA Instruments, New Castle DE, USA was used. This instrument has eight calorimeters fitted inside one thermostat so that one can make eight measurements simultaneously. Each calorimeter is twin-instrument with one sample and one reference. The calorimetric measurements of the mixture proportions cured in the same temperature were conducted simultaneously. When performing test, about 5 g paste of each mixture proportion was filled in a plastic ampoule, sealed and loaded into the TAM Air isothermal calorimeter. The test results of heat flow curves related to the hydration process were obtained. Using this procedure, the initial "mixing" peak that occurs when water contacts cement was not examined in this study.

The isothermal calorimetric measurements were conducted on the ten mixtures in Table 3. The rate of heat evolution was also calculated on the basis of a unit weight of Portland cement.

2.3.4. XRD, SEM

When the specified curing ages were reached, the hydration reaction of the cement paste was stopped by crushing the paste specimens into pieces of about 3–5 mm size, and then immersing them in acetone for 24 h. After that the paste sample was dried at 40 °C for 3 h, and next placed in vacuum desiccators for 2 days. The specimens were then grinded into fine powder to be used in powder X-ray diffraction (XRD) and SEM measurements.

The measurement conditions of the XRD were a scanning range of 2θ from 5° to 70° at 40 kV, 20 mA, step width 0.02°, and a scanning range of 2°/min. SEM was carried out on a Jeol 35 type of microscope. Specimens were mounted onto aluminum stubs using double-sided adhesive carbon discs and coated with gold. To ensure that electrical charge surfaces, a line of silver paint was applied connecting the specimen sides to the stub.

Table 1
Chemical composition of the cement and SCM.

Raw materials	Chemical composition (%)									
	Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	SUM
Cement	1.35	23.95	4.77	2.77	58.04	3.11	1.35	0.89	1.12	97.35
Basalt	3.21	47.95	13.24	16.61	9.64	6.32	0.06	1.51	1.12	99.66
Fly ash	1.56	54.51	32.01	5.61	1.72	1.46	0.58	2.47	0.31	99.77