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Investigation of rheological properties of fresh cement paste containing ultrafine circulating fluidized bed fly ash

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HIGHLIGHTS

- Influence of UCFB fly ash on cement rheological properties was assessed.
- Cement paste containing 10 wt% UCFB fly ash has the best rheological properties.
- Particle size distribution is the most important factor affecting rheological properties.

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ABSTRACT

The rheological properties of fresh cement paste with different amount of ultrafine circulating fluidized bed (UCFB) fly ash was fitted through the rheological models. The results show that the fresh cement paste containing different content of UCFB is always Bingham fluid. When the content of UCFB fly ash was lower than 30 wt%, the rheological properties of cement-UCFB fly ash were better than that of pure cement paste. In addition, when the amount of UCFB fly ash was 10 wt%, the fresh cement-UCFB paste has the best rheological properties. The effects of particle size distribution on the rheological properties of cement-UCFB paste were also analyzed through Rosin-Rammler fitting analysis. The packing density and particle size distribution are the main factors affecting rheological properties of the system. When n value is smaller, in other words, the particle size distribution range is wider, the fluidity of cement-UCFB fly ash system is better than that of pure cement. The morphology of the particles also affect the rheological of the fresh cement paste.

1. Introduction

Fresh concrete needs to be mixed and transported, so the workability of concrete is very important. The rheological properties of cement are important factors that affect the workability of concrete [1]. The addition of fly ash to the cement will fill the voids between the cement particles and increase the bulk density of the cement material, thereby improving the rheological properties of the fresh concrete [2]. Studies have shown that cement paste with 10 wt% fly ash has better rheological properties, the cement paste not only has a lower yield stress, but also has a lower viscosity from 120 min after the mixing with water. In addition, FA helps maintain the plasticizing effect and improves the thixotropy of the cement [1]. Three models are commonly used to represent rheological properties of cement paste: Bingham fluid model ($\tau = \tau_0 + \eta\gamma$), Revised-Bingham fluid model ($\tau = \tau_0 + \eta\gamma + c\gamma^2$) and Herschel-Bulkey fluid model ($\tau = \tau_0 + \eta\gamma^n$) [3,4]. In recent years, some studies have focused on improving the rheological properties of cement mixes with different kinds of fly ash [2,5–7].

Circulating fluidized bed (CFB) fly ash is a by-product of the coal combustion process in the circulating fluidized bed boiler [8]. Ultrafine circulating fluidized bed (UCFB) fly ash is obtained by grinding ordinary CFB fly ash with a jet mill. The annual emissions of CFB fly ash in China are about 80–150 million tons every year [9]. Therefore, the demand for CFB fly ash research is increasing from the perspective of environmental protection and resource recovery [10,11]. One of the most effective ways is to use CFB fly ash as a concrete admixture [12]. Because of the lower combustion temperature (850–900 °C), CFB fly ash is usually characterized with a large particle size, loose structure, lower sphericity and high surface roughness [13]. Therefore, cement mixed with CFB fly ash usually result in poor workability. After the ultrafine grinding of CFB fly ash, its particle size becomes smaller, and the loose structure is slightly improved. Ordinary fly ash particles are spherical with bearing effect, which will be conducive to the flow of cement

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slurry after mixed into the cement. However, there was little research on the effect of CFB fly ash on the rheological properties of cement [8]. And the effect of UCFB fly ash on the rheological properties of fresh cement paste has not been studied systematically.

In this research, the rheological properties of fresh cement paste with different content of UCFB fly ash were studied. Moreover, the effect of different factors such as particle size distribution and particle morphology on rheological properties of cement-UCFB fly ash paste was also explored by Rosin-Rammler distribution function and Scanning Electronic Microscope.

2. Materials and methods

2.1. Materials

The cement used in this experiment was P·I 42.5 ordinary Portland cement complying with the requirements of China National Standard GB 8076-2008. The ultrafine circulating fluidized bed fly ash was supplied by a coal-fired power plant in Shanxi province. The physical properties and chemical composition of cement and UCFB fly ash are shown in Tables 1 and 2, respectively.

It can be seen from Table 1, the loss of UCFB is three times higher than that of cement. This may be one of the main reason for the high water demand showed in Table 2. And Table 2 showed that UCFB fly ash had a lower content of sieve residue under 0.08 mm and much higher specific surface area, which is also the main reason leading to its high water demand.

Fig. 1 shows that the mainly mineral composition of UCFB fly ash are quartz, anhydrite, calcium aluminum oxide and calcium oxide, which are corresponded to the chemical composition of UCFB fly ash. The presence of anhydrite was due to the reaction of calcium carbonate with sulfur dioxide during the desulfurization reaction. The calcium sulfate can also delay the hydration reaction of cement and prolong the settling time of cement after UCFB fly ash was added into cement, since the calcium sulfate can react with the calcium aluminate in the cement to form sulphoaluminate coating on the surface of cement particles, delaying the hydration reaction of the cement [14].

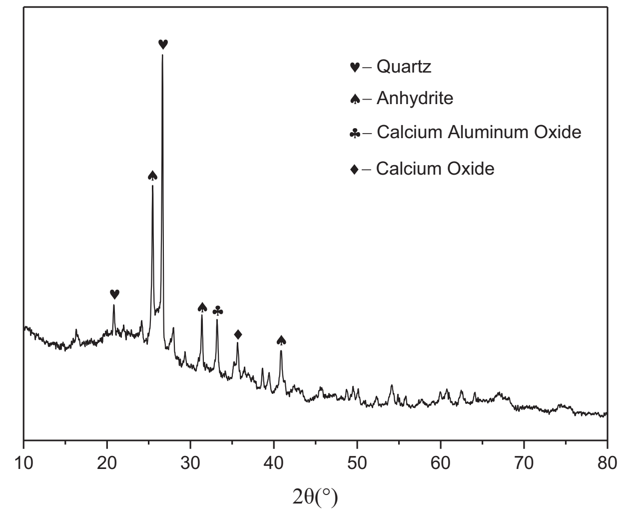

Fig. 1. Result of XRD analysis of UCFB fly ash.

2.2. Mix proportions

The UCFB fly ash were used to replace different content of cement by weight and the mix proportions of the samples are shown in Table 3. And the liquid to solid ratio (L/S) was fixed at 0.35 by weight. The polycarboxylate superplasticizer was supplied by BASF SE which was added to the mixture at 0.2% by weight of cementitious materials. It can be seen from Table 3, the packing density of cement-UCFB fly ash system increased when the content of UCFB fly ash is lower than 30 wt%. When the content of UCFB fly ash is higher than 30 wt%, the packing density of cement-UCFB fly ash is lower than pure cement. The packing density is tested according to Chinese Standard GB/T 16913.3-1997.

Table 3
Mix proportions and packing density.

Number	Cement/%	UCFBFA/%	Superplasticizer/%	Packing density/g cm^{-3}
0#	100	0	0.2	1.49
1#	90	10	0.2	1.68
2#	80	20	0.2	1.59
3#	70	30	0.2	1.50
4#	60	40	0.2	1.37
5#	50	50	0.2	1.15
6#	40	60	0.2	1.01
7#	30	70	0.2	0.92

2.3. Test methods

The fluidity of fresh cement paste with different content of UCFB fly ash were tested in accordance with the Chinese Standard GB/T 8077-2012.

X-ray diffraction (XRD) was used to analysis the polymorph of UCFB fly ash from 10° to 80° with Cu Kα radiation (λ = 1.5405 Å) on a D max/RB diffractometer (D8 Advance, Germany Bruker).

The particle size distribution of cement and UCFB fly ash particles were measured by a laser diffraction-type particle analyzer (OMIC-LS-C(II), China).

The morphology of the cement and UCFB fly ash particles were observed by a tungsten filament Scanning Electronic microscope (SEM, S3400N, Japan Hitachi).

The rheological properties, yield stress and plastic viscosity of cement paste with or without UCFB fly ash were measured by an rheometer (Brookfield DV3T model, United States) and a small sample adapter was selected in this research. According to the obtained results of yield stress and plastic viscosity, the rheological models suitable for each system paste are determined. All the experiments were carried out at 25 °C.

3. Results and discussion

3.1. The fluidity of cement- UCFB fly ash paste

The fluidity of fresh cement paste with different content of UCFB fly ash is shown in Fig. 2. It can be seen from Fig. 2 that the fluidity slightly increased when the UCFB fly ash content was under 30 wt%. When the content of UCFB fly ash was 10 wt%, the

Table 1
Chemical composition of materials.

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	f-CaO	SO_3	Loss
Cement	20.77	4.40	3.15	62.56	2.90	0.70	2.80	1.93
UCFB fly ash	42.65	30.32	5.18	8.57	0.54	3.55	2.13	6.58

Table 2
Physical properties of materials.

Materials	Sieve residue under 0.08 mm/%	Density/(g cm^{-3})	Specific surface area/(m^2 kg^{-1})	Standard consistency/%	D_{50}/μm
Cement	0.50	3.15	386.29	27.20	21.93
UCFB fly ash	0.18	2.35	770.35	44.26	5.30