

THE EFFECT OF FLY ASH ON THE FLUIDITY OF CEMENT PASTE, MORTAR, AND CONCRETE

Li Yijin, Zhou Shiqiong, Yin Jian, and Gao Yingli
Central South University, PRC

Abstract

The addition of ultra-fine fly ash (UFA) to cement paste, mortar and concrete can improve their fluidity, but some coarse fly ash can't reduce water. This paper investigates the effect of fineness and replacement levels of fly ash on the fluidity of cement paste, mortar, and concrete. The fly ash is collected by electro-static precipitators and airflow classing technology. Three different finenesses were chosen, and their replacement levels were 20%, 30%, and 40%, respectively. The experiment results show that particle size distribution, Zeta potential, density and particle morphologies of fly ash are the major factors affecting their fluidity.

1. Introduction

Currently, high-performance concrete (HPC) is widely used due to their technical and economical advantages. Such materials, so called the 21st century concrete, are characterized by improved mechanical and durability properties resulting from use of chemical and mineral admixtures as well as specialized production processes [1-4]. In the modern concrete, active mineral additives, such as fly ash, silica fume and slag, etc., have been the essential component that provides concrete with higher compressive strength, great fluidity, and higher durability. The use of fly ash is accepted in recent years primarily due to saving cement, consuming industrial waste and making durable materials, especially due to the improvement in the quality stabilization of fly ash. Because of these, more and more investigations have been made about their effects on concrete. A popular hypothesis put forward to explain the workability enhancement due to the use of certain fine mineral admixtures, especially fly ash or SF, is that the spherical particles easily roll over one another, reducing interparticle friction [5]. Sakai et al. [6] reported that a higher packing density was obtained with spherical particles as compared to crushed particles in a wet state. This resulted in lower water retention in the spherical case and subsequently lower water demand for a specific workability. A strong dependence of fluidity (defined as the inverse value of the viscosity) on the average particle size was reported with a pessimism value [6]. It was explained that, at an optimal particle

size, the packing density was maximum, which helped to achieve maximum fluidity. Previous studies concentrated on the effect of fly ash on the fluidity of concrete [7-8]. In this study, the fly ash is collected by electro-static precipitators and airflow classing technology. The mechanisms are analyzed based on their characteristics such as particle morphology, particle size distribution, specific surface area and density.

2. Materials and Methods

2.1. Materials

The materials used in the presented research are described as the following:

- Cement: Shaofeng 42.5 grade ordinary portland cement made in Xiangxiang
- Fine aggregate: Xiangjiang river sand, fineness modulus 2.88
- Coarse aggregate: Qualified 5-20-mm broken gravel rushed from Xiangjiang river gravel, broken stone being 51%-53%, broken index being 7.7%-8.0%
- Superplasticizer: Naphthalene sulfonic acid-based superplasticizer.
- Ultra-fine fly ash: Collected by electro-static precipitators and airflow classing technology in Xiangtang power plant; Their chemical compositions and properties parameters are given in Tables 1 and 2, respectively. Particle morphologies of the fly ashes are given in Fig. 1.

Table 1: Chemical composition of fly ashes used (wt %)

Sample ash	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	Cl ⁻
A	51.7	26.8	4.39	3.4	0.95	1.28	0.65	0.31	0.009
B	49.5	28.6	4.98	3.6	1.02	1.26	0.7	0.27	0.008
C	48.2	30.31	5.57	3.85	1.05	1.34	0.60	0.30	0.009

2.2. Experiments methods

The tests of fluidity of cement paste fluidity of mortar and workability of concrete generally conform to Chinese National Standard GB/T 8077-1987, GB/T 2419-1994, and GBJ80-85 test methods, respectively. In this study, the mortars were prepared at a water-to-binder ratio of 0.30 and sand-to-binder ratio of 1.5, with 20%, 30%, and 40% equivalent replacement of cement by low-calcium fly ash A, B, and C, respectively. The concretes are prepared with three different finenesses fly ash A, B, and C and the equivalent replacement level is 20%, 30%, and 40%. The effect of the addition of FA is expressed by the changes in concrete slump, water demand, or water reducing rate in the concrete.

Table 2: Properties of fly ashes used

Properties		A fly ash	B fly ash	C fly ash
Specific gravity (g/cm ³)		2.111	2.256	2.258
Specific surface area (m ² /kg)	Blaine fineness	370	761	819
	BET	–	1560	2220
	Laser diffraction	1514	2819	3185
Mean particle size (μm)		27.16	9.31	6.05
Water demand ratio (%)		96	93	89
Zeta potential in de-ionized water (mV)		-27.35	-35.57	-80.67
Water reducing rate in concrete (%)		2.1	7.9	9.7

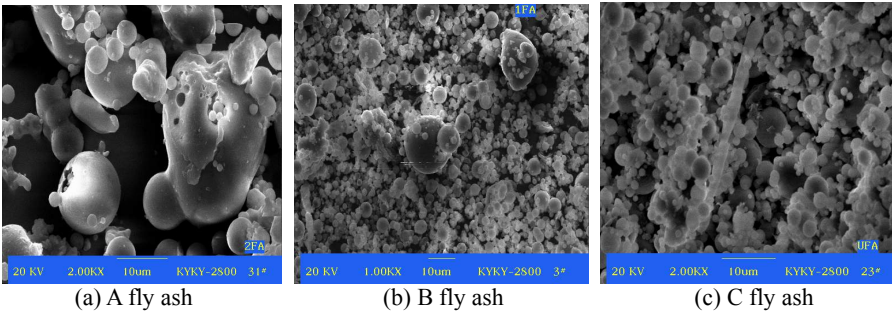


Fig. 1: SEM of different fineness fly ash

3. Results and Discussion

3.1. Effect of UFA on cement setting time

The initial and final setting time of cement paste containing C fly ash is shown in Fig. 2. When the UFA replacement level is 20%, the initial and final set time of UFA-cement paste was about 9.56 and 11.25 hours, respectively. When the UFA replacement level increased to 40%, the initial and final setting times of UFA-cement paste are prolonged to about 11.85 and 13.58 hours, respectively. In general, the set time of UFA-cement paste is prolonged with the increase of UFA. The outer surface of UFA particle increase with the increase of UFA, the amount of absorbed calcium ions increased. That inhibits calcium ions concentration build-up in fresh paste during early hydration, resulting in the setting time is prolonged, thus, the heat of hydration decreases.

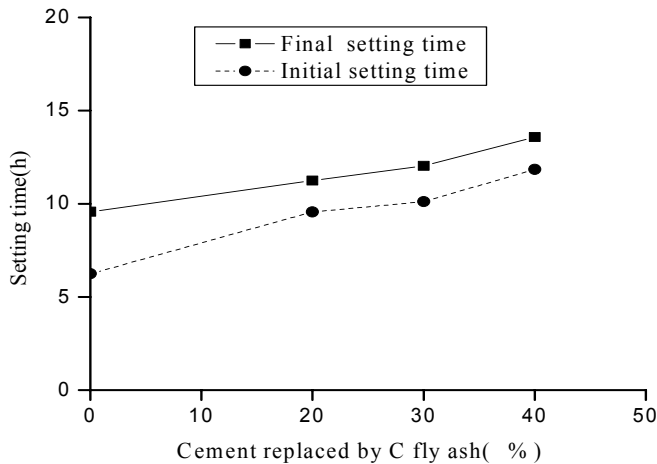


Fig. 2: Relation between the setting time and cement replacement

3.2. Effect of UFA on mortar fluidity

Fig. 3 shows the water demand of mortar containing different finenesses and replacement levels of FA for a given flow, where flow table tests were used. All water demand ratios of FA mortar are lower than 100%, that is, A, B, and C fly ashes all have water reducing function. When the replacement is equal, the water demand ratio of C fly ash is the lowest, B fly ash is the second, and A fly ash is the highest. In general, the finer the cementitious material, the larger surface area the material.

Thus, the more water will be absorbed by the material, that is the negative effect of UFA water reducing. At the same time, the finer fly ash, the more spherical-like fly ash particles morphology, the internal friction in fresh mortar reduce, the better “lubricant effect” fly ash has, on the other hand, the finer fly ash, the better close packing effect fly ash has when it partially replace cement, those are positive effect of UFA water reducing. The increase of positive effect is bigger than that of negative effect when the fineness of fly ash is increased in this study, Consequently the water demand ratio decrease with the increase of fly ash fineness. A fly ash is more porous than B and C fly ash, more water is adsorbed into FA pores. With the replacement level of A fly ash increasing, the water demand ratio decreases a little. When the replacement levels of B and C fly ash are increased from 0% to 30%, the water demand ratio reduce, but when the replacement is increased to 40%, the increase of negative effect of UFA water reducing surpass that of positive effect, the water demand ratio increase slightly. In order to obtain better fluidity, B and C fly ash cannot replace cement too much.

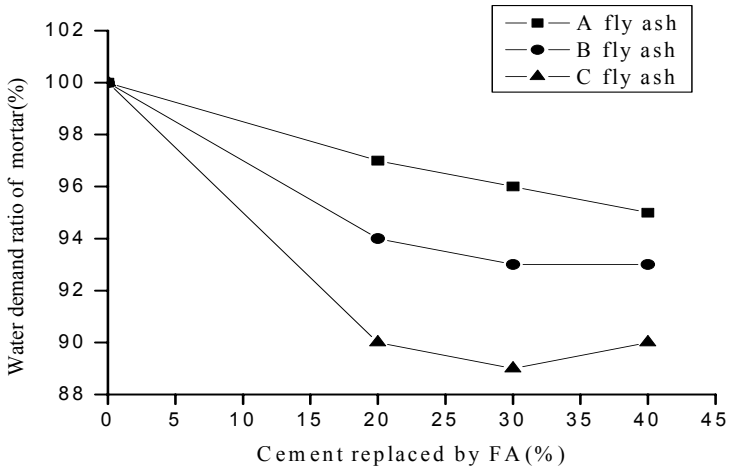


Fig. 3: Effect of FA replacement levels and fineness on water demand ratio of mortar

3.3. Effect of FA on concrete workability

High slump and low slump loss of fresh concrete were considered as an assurance for good concrete casting, vibrating and finishing. Generally, superplasticizer increases concrete slump, but causes high slump loss when compared with the plain concrete having the same initial slump. Because of a low water-to-binder ratio in HPC, when the same amount of water is lost through evaporation or by cement hydration, the slump loss was more significant.

Fig. 4 shows the water reducing rate of concrete containing different finenesses and replacement levels FA when the slump is equal. All fly ash have water reducing effects. When the replacement is 30%, the water rate of A, B, and C fly ash are 2.1%, 7.9%, and 9.7%, respectively. The water reducing rate increases with the level of fly ash replacement. The fly ashes actually function as a kind of mineral water reducers.

The test results of HPC containing C fly ash were presented in Table 3. As to plain concrete, the slump loss after 1 hour is 8.5%, 2 hours is 19.1%, and 3 hours is 36.2%, but the slump loss of concrete containing 30% UFA after 1 hour is 2%, 2 hours is 8.2%, and 3 hours is 10.2%. UFA could not only increase slump and spread, but also reduce the slump loss. First, because UFA can prolong the setting time, which result in decreasing slump loss of concrete, secondly UFA have huge specific surface area which can adsorb some superplasticizer, thirdly the Zeta potential of UFA is negative in de-ionized water.

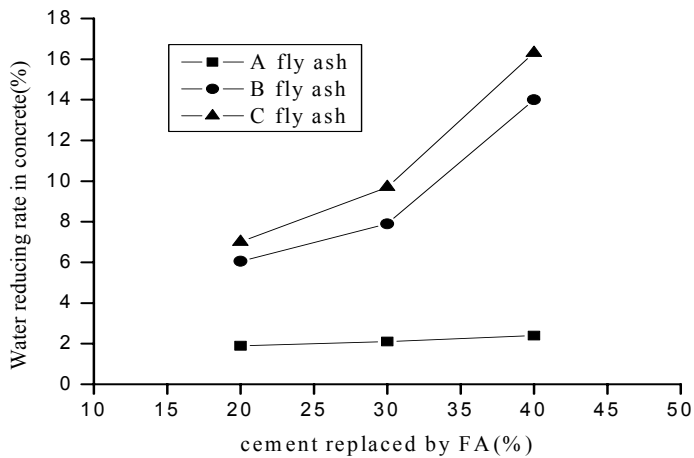


Fig. 4: Effect of FA replacement levels and fineness on water reducing rate

Table 3: Slump loss of concrete containing UFA

Specimen	Mix proportions (kg/m ³)			Slump (mm)			
	UFA	C	W	0h	1h	2h	3h
1	0	540	153	235	215	190	150
2	162	378	151	245	240	225	220
3	216	324	150	250	255	250	245

4. Conclusions

The fly ashes studied were collected by electro-static precipitators and airflow classing technology. Due to their spherical shape and smooth surface features, the fly ashes demonstrated improved water reduction effect with increased fineness. Based on the test results, the following conclusions can be drawn:

- The incorporation of ultra-fine C fly ash may increase the setting time of cement paste.
- The water demand ratio of UFA decrease with the increasing of fineness.
- The water reducing rate of 30% ultra-fine C fly ash reach 10%, ultra-fine C fly ash is a kind of good mineral water reducer.
- Ultra-fine C fly ash has significantly increased the slump and reduced the slump loss of concrete.

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