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Communication

Influence of ultrafine fly ash composite on the fluidity and compressive strength of concrete

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Abstract

This paper presents the fluidity and compressive strength of concrete containing ultrafine fly ash composite (UFAC). The experimental results indicate that UFAC can improve the fluidity and compressive strength of concrete at 30–70% replacement of cement. UFAC concrete had been prepared with a larger slump, higher compressive strength, lower slump loss and lower drying shrinkage ratio. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Fly ash; High-performance concrete; Slump loss; Compressive strength

1. Introduction

In modern cement and concrete technology, addition of active mineral additives, such as fly ash, silica fume, slag, natural pozzolan, etc., is a measure of great technological and economical significance. The ultrafine powders have been the sixth component in HPC, which can prepare the concrete having higher compressive strength, great fluidity and higher durability.

The use of fly ash is accepted in recent years primarily because of resulting economy from saving cement, secondly because of consuming industrial wastes and thirdly because of making durable materials. Fly ash has larger output and critical contamination in China, the development of ultrafine fly ash used in HPC is first priority. The replacement of cement by ultrafine fly ash cannot only improve the properties of concrete, but also increase the green degree of concrete [1].

Several studies were published in the last decade on the reactivity of fly ash by various chemical activators ($CaSO_4$, Na_2SO_4, $CaCl_2$, alkali, waterglass, etc.) [2–4]. The use of fly ash together with Portland cement causes a reaction between glassy phase of fly ash and calcium hydroxide generated from the hydration of Portland cement, which leads to the formation of additional C–S–H gel and results in higher density and strength.

In this paper, the concrete containing ultrafine fly ash composite (UFAC) was studied, and the fluidity, slump loss and compressive strength of this concrete were presented.

2. Experimental procedure

The cement used is 525 ordinary Portland cement made in Xiangxiang and complies with Chinese National Standard GB175-92. The fine aggregates came from the Xiangjiang River, and its fineness modulus is 2.88. The

Table 1
Chemical composition and properties of UFAC

Item	Index							
Chemical	SO_3	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Composition (%)	0.30	51.2	5.80	28.1	3.70	1.20	1.64	0.71
Ratio of water demand (%)	89.2							
Ignition loss (%)	6.49							
Water content (%)	1.0							

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Table 2
The test results of cement paste containing UFAC

C (%)	UFAC (%)	SP (%)	NC (%)	Setting time (h) Initial	Setting time (h) Final
100	0	0	26.0	2.48	6.07
100	0	1.5	19.6	6.25	9.58
65	35	1.5	18.4	10.38	12.22
55	45	1.5	18.6	11.35	13.77
45	55	1.5	18.8	13.42	16.25
40	60	1.5	18.0	13.87	15.45

coarse aggregates are crushed stone or broken gravel with nominal maximum size of 25 mm. The crushed index of crushed stone is 10.2%, and that of broken gravel is 8.0%. A superplasticizer (SP) of sulfonated naphthalene formaldehyde base is used in the mix, which complies with Chinese National Standard specified by GB8077-87. The ultrafine powders are UFAC based on ultrafine fly ash improved by some mineral powders, its chemical composition and properties are given in Table 1, and its Blaine surface area is about 740 m^2/kg.

The specimen used for cubic compressive strength in this paper has a measurement of 100×100×100 mm.

3. Results and discussion

3.1. Properties of cement paste containing UFAC

The existence of UFAC in cement paste can influence the normal consistency and setting time; the experimental results are given in Table 2.

It can be seen from Table 2 that UFAC has significant effect on the setting time, and superplasticizer has marked effect of water reducing. The results show that the superplasticizer content of 1.5% can reduce the NC of 6.4%, and UFAC content of 35% can reduce the NC of 1.2%. Along with the increment of UFAC, the effect of water reducing is not significant. UFAC can significantly influence the setting time; the setting time was lengthened along with the increment of UFAC, thus, the heat of hydration decreases.

3.2. Retention of slump of concrete by UFAC

HPC requires the mix not only having higher fluidity, but also having lower slump loss, and the latter is more important. When a concrete mix must be transported for a long period, particularly in hot weather, it should be kept as moist as possible in the initial slump to avoid redosing the concrete with water above what is required in the mix design. In general, slump loss higher in superplasticized concrete with respect to the corresponding plain mix at a given initial slump, especially when traditional sulfonated naphthalene formaldehyde base admixtures are used [5]. It seems that the lower water/cement ratio in superplasticized concrete and the consequently lower distance among cement particles cause a more significant slump loss when the same amount of water is lost through evaporation or by reaction with cement during the transportation time.

The test results of HPC containing UFAC were presented in Table 3. As to ordinary concrete, the slump loss after 1 h is 9%, 2 h is 19%, 3 h is 39%, but the slump loss of concrete containing UFAC after 1 h is not more than 5%, 2 h is not more than 10%, 3 h is not more than 20%. Compared with the results shown in Table 2, the effect of restraining slump loss is lower, first, because UFAC has lengthened setting time, which resulted in decreasing slump loss of concrete, secondly,

Table 3
Slump loss of concrete containing UFAC

Specimen	UFAC (kg/m^3)	C (kg/m^3)	W (kg/m^3)	Slump/mm 0 h	Slump/mm 1 h	Slump/mm 2 h	Slump/mm 3 h	Remark
1	0	540	153	235	215	190	150	Broken gravel concrete
2	270	270	153	250	240	225	220	
3	189	351	150	240	230	225	195	Crushed stone concrete
4	385	165	137.5	240	245	220	210	
5	275	275	137.5	225	230	225	195	

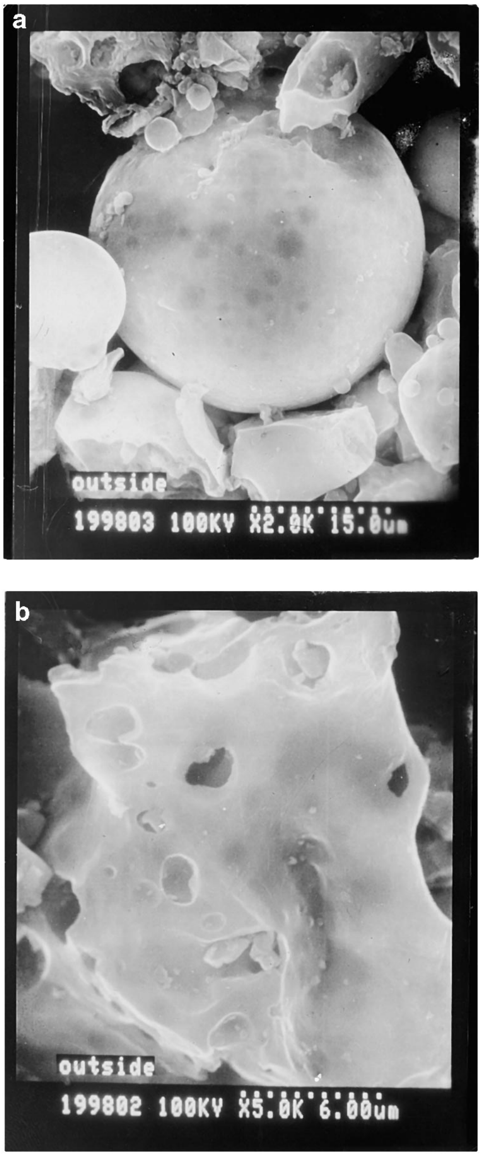

Fig. 1. SEM micrograph of UFAC.

because ultrafine powder have huge specific surface area and the surface of grains has some pore, which takes action by carrying the superplasticizer (Fig. 1).

The cement content, as well as the chemical and mineralogical composition of cement, plays an important role in determining slump loss, although the detailed mechanism is not clear [5]. It seems that the content of C_3A, gypsum and alkali can affect the rate of slump loss. There is a compatible issue between cement and superplasticizer. Then, is the slump loss of concrete used different superplasticizer the same? The tests adopt three types of superplasticizer, which are all sulphonated naphthalene formaldehyde base. The results were shown in Table 4.

The slump loss of the mix containing superplasticizer A is lower. It can be seen that the difference among slump loss after 3 h is great, therefore, the compatibility issue between cement and superplasticizer must be noted.

The addition of superplasticizer can increase the slump of concrete, however, the method of superplasticizer addition affects the slump-increase and the slump-loss effect. The method of superplasticizer addition has early addition, immediate addition (IA) and delayed addition (DA, after an initial period of 1 min). The aforementioned tests all adopt IA. The method of IA and DA were tested. The results were shown in Table 5.

The results show that the method of superplasticizer addition has some effect on restraining slump loss. Generally, the slump loss of adopting DA way after 1h is lower than initial slump, and slump loss after 3 h is lower. Therefore, the method of superplasticizer addition must be selected according to the practical engineering.

3.3. Influence of UFAC content on compressive strength

When UFAC takes the place of the same quality of cement, the reducing degree of the early strength is great, along with the increment of UFAC content (Table 6). It can be seen that the use of UFAC has obviously increased compressive strength of 28 days and that of 56 days. When UFAC substitutes for 50–71% cement, the compressive strength of 28 days is closed to or even higher than that of control concrete, the compressive strength of 56 days is higher than 90 MPa.

3.4. Drying shrinkage of concrete containing UFAC

The mix proportions are provided in Table 7, and the results are shown in Fig. 2. The results show that the UFAC content of specimen no. 2 is 51%, the early strength of this concrete is lower, and the early drying shrinkage is higher than that of standard concrete, and the long-term drying

Table 4
Slump loss of concrete containing UFAC and different superplasticizers

	Mix proportions (kg/m^3)				Slump (mm)				Compressive strength (MPa)		
Specimen	C	UFAC	W	SP (%)	0 h	1 h	2 h	3 h	3 Days	28 Days	56 Days
1	351	189	150	1.3 (A)	240	230	210	180	44.3	93.6	96.1
2	351	189	150	1.3 (B)	250	205	180	65	45.5	78.8	93.8
3	351	189	150	1.3 (C)	240	205	160	75	50.3	91.2	91.5

Table 5
Influence of addition method on slump loss

Mix proportions (kg/m^3)					Slump (mm)/spread (cm)				
C	UFAC	W	SP	Mode of addition	0 h	1 h	2 h	3 h	$f_{cu.28}$ (MPa)
324	216	150	7.6	1A	250/68	245/54	225/48	195/38	72.0
324	216	150	7.6	DA	230/70	255/64	230/49	220/44	72.4
162	378	150	8.1	1A	230/51	210/38	180/30	150/22	77.5
162	378	150	8.1	DA	240/65	240/61	230/55	200/41	77.1

Table 6
Results of compressive strength

					Compressive strength (MPa)			
Specimen	UFAC (kg/m^3)	C (kg/m^3)	W (kg/m^3)	Slump (mm)	3 Days	28 Days	56 Days	Remark
1	0	540	150	230	57.7	79.2	–	Broken gravel concrete
2	167	378	151	225	46.6	74.7	84.8	
3	189	351	150	240	53.8	91.1	–	
4	226	324	150	240	49.1	83.7	–	
5	227	324	151	230	39.8	75.9	87.2	
6	270	270	153	250	36.1	86.1	–	Crushed stone concrete
7	0	550	160	195	55.5	73.7	–	
8	189	351	150	240	44.3	93.6	–	
9	199	378	145	235	53.2	90.5	101	
10	216	324	147	235	37.8	89.5	96.0	
11	275	275	138	225	37.3	86.3	95.2	
12	396	165	137	240	27.1	80.3	95.1	

shrinkage of two kinds of concrete is approached. Since it is low after 14 days, the curing of HPC having a great quantity of PFAC must be strengthened for the first 14 days. At the same time, the results indicate that UFAC has significant water-reducing effect, the specimens were molded at the same condition, and the UFAC can reduce

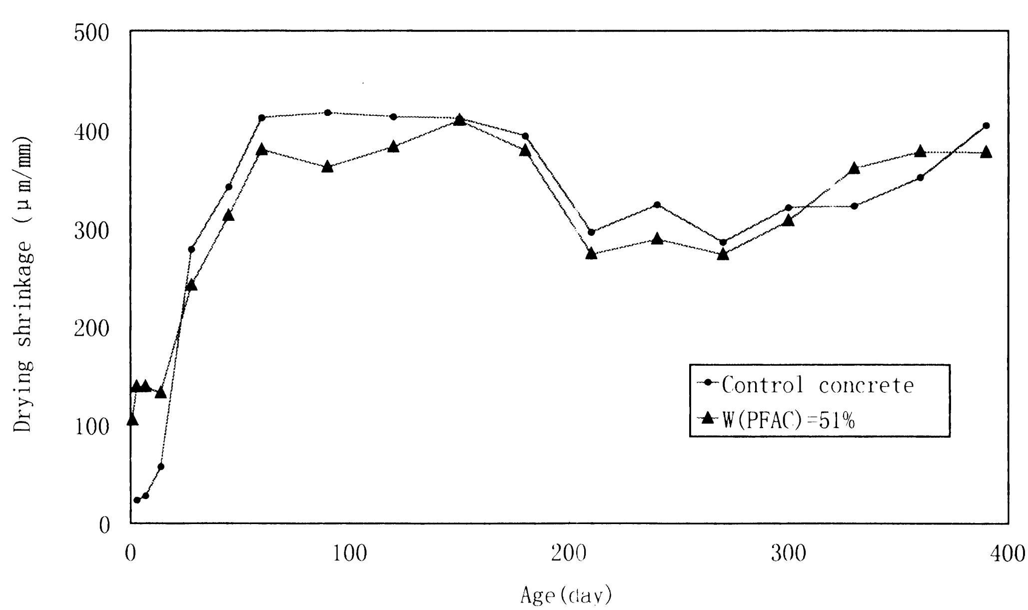

Fig. 2. The results of drying shrinkage.

Table 7
Mix proportions of concrete for drying shrinkage test

Specimen	PFAC (%)	W (kg/m^3)	W/B	Slump (mm)	$f_{cu.3}$ (MPa)	$f_{cu.28}$ (MPa)
1	0	160	0.296	195	55.5	73.7
2	51	137.5	0.243	195	40.7	90.0

water of 14%. This result is in contrast to the one shown in Table 2. Further study is still needed.

4. Conclusion

1. The content of UFAC can lengthen the setting time of cement paste.
2. UFAC has significantly reduced the slump loss of concrete, which has something to do with superplasticizer type and addition method.
3. The compressive strength of concrete containing great quantity UFAC is lower, and the drying shrinkage is great, but drying shrinkage after 14 days is lower than that of standard concrete. Therefore, the concrete must be cured before the first 14 days.

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