Influence of fly ashes on the drying shrinkage of superplasticized concretes in the presence of SRA

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Synopsis: Concretes with portland cement in the presence of fly ash or beneficiated fly ash (BFA) all at a slump of about 240 mm were made. Fly ash or BFA was used as mineral addition replacing 20% of portland cement in both plain and superplasticized concretes with or without shrinkage-reducing admixtures (SRA).

The 28-day compressive strength of the superplasticized and plain concretes without mineral addition were higher than those of the corresponding concretes with fly ash and lower than that with BFA.

Drying shrinkage of specimens exposed to a dry environment with relative humidity of 50% up to 4 months was measured. In the presence of fly ash the drying shrinkage decreased by about 15% with respect to the corresponding plain concretes without fly ash. In the presence of a superplasticizer and/or a SRA there was further reduction in dry shrinkage of fly ash mixtures.

The drying shrinkage of concretes, where portland cement was replaced by BFA was lower than that of the corresponding concretes with fly ash. Even in the presence of superplasticizer and/or SRA a further reduction of drying shrinkage of BFA concretes was found.

In fly ash or BFA concrete mixtures, and more significantly in the presence of superplasticizer and/or SRA, the cracking in restrained slabs was reduced in terms of both the number and the width of cracks.

Keywords: chemical admixtures, drying shrinkage, fly ash, beneficiated fly ash, shrinkage-reducing admixtures, superplasticizer.

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INTRODUCTION

Restrained drying shrinkage of concrete produces tensile stresses (σ_t) and when σ_t is higher than the tensile strength (**f_t**) of concrete cracks occur and this aggravates the risk of steel corrosion of reinforced concrete structures exposed to air and chloride ions from sea water and de-icing salts. Superplasticizers, used to reduce both water and cement, as well as shrinkage-reducing admixtures can reduce drying shrinkage (1).

As far as mineral additions are concerned, there are numerous papers on the influence of fly ash on the autogenous shrinkage (2-6) as well as on the drying shrinkage (7-9). These papers indicate that in general when portland cement is replaced by fly ash both autogenous and drying shrinkage decrease.

On the other hand, B. Ma and co-workers (10) found that the drying-shrinkage of mortar increases with the addition of fly ash due to the increase in the porosity and the volume of coarser pores in the cementitious paste.

The authors of the present paper did not find published data on the drying shrinkage of concretes with fly ash or beneficiated fly ash (BFA) in the presence of a superplasticizer (SP) and a shrinkage reducing admixture (SRA). The purpose of the present paper is to study the influence of fly ash and BFA in the presence of these chemical admixtures on the drying shrinkage of concrete.

EXPERIMENTAL: MATERIALS AND METHODS

Materials.

Table 1 shows the composition of portland cement, ASTM type F fly ash and BFA. BFA is obtained for reducing the carbon content in coal FA through tribo-electrostatic technique and/or air classification of FA to extract the more reactive fine fraction to improve its performance in terms of higher workability of the fresh concrete and lower porosity in the hardened concrete. In particular, with respect to the corresponding fly ash, the carbon content of the BFA was reduced from 6.6 % to 0.8 % whereas the mean particle size decreased from 20 μm to 5 μm. Details on the characteristic of the BFA used in the present paper can be found in reference [11].

An aqueous solution of 30 % of policarboxylate was used as a superplasticizer (SP) and pure neopentyl glycol was adopted as shrinkage-reducing admixture (SRA) due to its capability of reducing the water surface tension from 72.8 mN/m to 32.4 mN/m when used in a 2 % aqueous solution

Tables 2 and 3 show the composition of the following concretes containing fly ash (FA) and BFA, all at a given slump of 230-240 mm:
CONTROL mix: concrete without mineral and chemical admixtures;
FA mix: concrete with fly ash without chemical admixtures;
FA + SRA mix: concrete with fly ash and SRA;
FA + SP mix: concrete with fly ash and SP;
FA + SRA/ SP mix: concrete with fly ash, SRA and SP chemical admixtures;
BFA mix: concrete with BFA without chemical admixtures;
BFA + SRA mix: concrete with BFA and SRA;
BFA + SP mix: concrete with BFA and SP;
BFA + SRA/ SP mix: concrete with BFA, SRA and SP chemical admixtures.

Methods

Compressive strength of 150-mm cube concrete specimens wet cured at 20 °C was measured.

Prismatic specimens (100 x 100 x 150 mm) demolded at 2 days were exposed to a relative humidity (RH) of 50 % at 20 °C and the unrestrained drying shrinkage was measured from 10 to 120 days.

Restrained shrinkage in 8-m long, 400-mm wide and 60-mm thick slabs (all exposed 4 months to open air at the same conditions of temperature, RH and wind speed) produced cracks on the concrete surface. The number and the width of cracks were determined in order to assess the influence of the mineral additions and chemical admixtures on the behavior of the restrained slabs.

RESULTS

Compressive strength of FA and BFA mixtures

Figure 1shows the compressive strength of the *CONTROL mix* and that of the *FA mix* or *BFA mix*. Due to the replacement of 20 % of cement by BFA there was a strength increase of about 10 % at ages between 28 and 90 days. On the other hand, when portland cement was replaced by 20 % of fly ash the compressive strength decreased at early ages without a significant reduction at later ages. Similar results are obtained at 28 days in the presence of superplasticizers (Tables 2 and 3). In the presence of SRA, the 28-day compressive strength was reduced by about 5 % with respect to the corresponding concretes without SRA.

Fly ash mixtures (FA)

Table 2 indicates that all the concrete mixtures with fly ash were manufactured at the same water-cementitious material (0.62) of the *CONTROL mix*. On the other hand, the water-cement ratio of all the concrete mixtures with fly ash FA) were higher than that of the *CONTROL mix* (0.77 vs 0.62) due to the lower amount of portland.

An adequate superplasticizer dosage (about 1.3 % by weight of the cementitious material) was adopted in the *FA + SP mix* or *FA +SRA/SP mix* to reduce by 30 % both water and cement with respect to the corresponding concretes *CONTROL mix* or *FA + SRA mix* respectively at a given slump of about 235 mm. The reduction of cement and water was compensated by an increase of an equal volume of aggregate, so that the aggregate/cementitious material ratio of 5.2 in the mixtures without SP was increased up to 8.2 in the corresponding concrete mixtures with superplasticizer.

The presence of SRA (1 % by weight of the cementitious material) does not cause any change in the composition of the concretes with respect to that of the corresponding mixtures without SRA.

Unrestrained drying shrinkage of FA mixtures

Figure 2 shows the drying shrinkage of the FA mixtures with respect to the *CONTROL mix* without fly ash. The replacement of portland cement by fly ash in the absence of chemical admixtures decreased by about 15 % the drying shrinkage (RH of 50 %) at 120 days. This result agrees with those reported in references (8-10).

In the presence of SP, due to the increase in the aggregate-cement ratio from 5.2 to 8.2, there is a further decrease of the drying shrinkage: about 25 % at 120 days.

A reduction (22%) in the unrestrained drying shrinkage is found in the presence of SRA with respect to the *CONTROL mix* due to the reduction in the water surface tension which is responsible for the shrinkage.

In the presence of both superplasticizer and shrinkage-reducing admixture there is a further reduction in the unrestrained drying shrinkage with respect to that of the *CONTROL mix*: 37 % after 120 days of exposure to a dry environment with a RH of 50 %.

Restrained drying shrinkage of FA mixtures

Table 4 shows that after 4 months of exposure to open air, due to the reduction of the unrestrained drying shrinkage, the number and the width opening of cracks in the restrained slabs are reduced by fly ash particularly in the presence of SP or

SRA. In the FA concrete mixture containing both SRA and SP no crack was found in the restrained slab.

BFA concrete mixtures

Table 3 indicates that in the *CONTROL mix*, at a slump of 240 mm, the water-cement ratio was 0.62. In all the concrete mixtures with BFA the water-cement ratio was reduced: it was 0.54 in the *BFA mix* and in the *BFA + SRA mix* and 0.52 in the presence of the superplasticizer with or without SRA.

A superplasticizer dosage of about 1.2 % by weight of the cementitious material was adopted in the concretes *BFA + SP mix* or *BFA +SRA/SP mix* to reduce, at a given slump of about 240 mm, by about 30 % both water and cement with respect to the corresponding concretes *BFA mix* or *BFA + SRA mix*. The reduction of both cement and water was compensated by an equal volume of the aggregate, so that the aggregate/cement ratio of about 6.4 in the concrete mixture *BFA + SRA mix* without SP was increased up to about 10.3 in the concrete mixtures *BFA + SP mix* and *BFA + SRA/SP mix* with the superplasticizer.

Even in the BFA concrete mixtures in the presence of SRA (1 % by weight of the cementitious materials) there was not any change in the composition of the concretes with respect to that of the corresponding mixtures without SRA.

Unrestrained drying shrinkage of BFA mixtures

Figure 3 shows the unrestrained drying shrinkage of the BFA mixtures with respect to the *CONTROL mix* without BFA. The replacement of portland cement by 20 % of BFA in the absence of chemical admixtures reduces by 20 % the drying shrinkage at 120 days with a RH of 50 %. Therefore, the reduction of drying shrinkage due to the presence BAF appears to be slightly higher than that (15 %) caused by the presence of fly ash (Fig. 2).

In the presence of SP, due to the increase in the aggregate-cement ratio from 6.5 to 10.4 there is a significant decrease of the drying shrinkage at 120 days: about 30 % with respect to the reference *CONTROL mix*.

A reduction of about 27 % in the unrestrained drying shrinkage is found in the presence of SRA due to the reduction in the water surface tension which is responsible for the shrinkage.

In the presence of both superplasticizer and shrinkage-reducing admixture there is a further reduction in the unrestrained drying shrinkage with respect to that of the *CONTROL mix* : 45 % at 120 days of exposure to a dry environment with a RH of 50 %.

Restrained drying shrinkage of FA mixtures

Table 4 shows that due to the reduction of the unrestrained drying shrinkage the number and the width opening of cracks are reduced by BFA particularly in the presence of SP or SRA. In the BFA concrete containing both SRA and SP no crack was found in the restrained slab after 120 days of exposure to open air.

CONCLUSIONS

There is a significant reduction (20 % at 120 days of exposure to RH of 50 %) in the unrestrained drying shrinkage of concretes when portland cement is replaced by 20 % of fly ash or beneficiated fly ash.

This effect is improved when this replacement is accompanied by either a SRA, due to the reduction in the water surface tension, or a superplasticizer, due to the lower amount of cement paste and the corresponding increase in the volume of aggregate. The reduction in the unrestrained shrinkage was slightly higher when beneficiated fly ash was used instead of fly ash.

The combined presence of superplasticizer and shrinkage-reducing admixture further reduces the unrestrained drying shrinkage with respect to that of the concrete without chemical admixtures: the reduction is about 37 % or 45% when fly ash or beneficiated fly ash is used to replace portland cement.

Due to the decrease in the unrestrained drying shrinkage, both the number and the width of cracks in restrained 8-m long, 600-mm wide and 40-mm thick slabs were reduced when portland cement was replaced by beneficiated fly ash or fly ash. This reduction was higher in the presence of a superplasticizer or a shrinkage-reducing admixture specially when beneficiated fly ash was used. The number and the width of cracks completely disappear when beneficiated fly ash or fly ash was used in the presence of both these chemical admixtures..

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Table 1 - Chemical composition of portland cement, fly ash and BFA.

Chemical Composition	Mass %		
	Portland Cement	Fly Ash	BFA
SiO_2	23.1	54.1	53.7
Al_2O_3	5.1	28.9	34.2
CaO	62.9	2.0	4.1
Fe_2O_3	0.9	3.7	3.8
K_2O	0.3	0.7	0.7
Na_2O	0.4	0.4	0.3
MgO	0.2	0.5	0.9
l.o.i.	2.0	6.6	0.8

Table 2 - Composition and characteristics of concrete mixtures with fly ash (FA) in the absence or in the presence of superplasticizer (SP) and/or shrinkage-reducing admixture (SRA).

Composition (kg/m^3)	CONTROL Mix	FA Mix	FA+SRA Mix	FA+SP Mix	FA+SRA/SP Mix
Cement	357	284	284	198	201
FA	---	71	71	51	51
Water	222	221	220	154	155
Sand (0-4 mm)	933	929	932	993	1004
Gravel (4-25 mm)	926	921	921	1037	1048
SP	---	---	---	3.24	3.28
SRA	---	---	3.55	---	2.52
Slump (mm)	240	240	235	230	230
Water/Cement	0.62	0.78	0.77	0.78	0.77
Water/(Cement+FA)	0.62	0.62	0.62	0.62	0.62
Aggregate/Cement	5.2	6.5	6.5	10.2	10.2
Aggregate/(Cement+FA)	5.2	5.2	5.2	8.2	8.2
28-day compressive strength (MPa)	34.5	29.5	28.0	30.5	28.0

Table 3 – Composition and characteristics of concrete mixtures with beneficiated fly ash (BFA) in the absence or in the presence of superplasticizer (SP) and/or shrinkage-reducing admixture (SRA)

Composition (kg/m^3)	CONTROL Mix	BFA Mix	BFA+SRA Mix	BFA+SP Mix	BFA+SRA/SP Mix
Cement	357	282	281	199	200
BFA	---	71	71	51	52
Water	222	152	146	106	102
Sand (0-4 mm)	933	920	920	991	1002
Gravel (4-25 mm)	926	913	911	1035	1051
SP	---	---	---	3.03	2.98
SRA	---	---	3.52	---	2.52
Slump (mm)	240	230	230	230	235
Water/Cement	0.62	0.54	0.52	0.53	0.51
Water/(Cement + BFA)	0.62	0.43	0.41	0.42	0.40
Aggregate/Cement	5.2	6.5	6.5	10.3	10.3
Aggregate/(Cement+BFA	5.2	5.2	5.2	8.1	8.1
28-day strength (MPa)	34.5	37.5	37.0	39.0	38.5

Table 4 - Crack distribution in concrete slabs due to restrained drying shrinkage.

CONCRETE MIXTURE	NUMBER OF CRACKS	MAXIMUM CRACK WIDTH (mm)
CONTROL mix	7	2.50
FA Mix	6	2.15
FA+SRA mix	3	0.42
FA+SP mix	3	0.35
FA+SRA/SP mix	0	---
BFA Mix	6	2.20
BFA+SRA mix	3	0.31
BFA+SP mix	2	0.20
BFA+SRA/SP mix	0	---

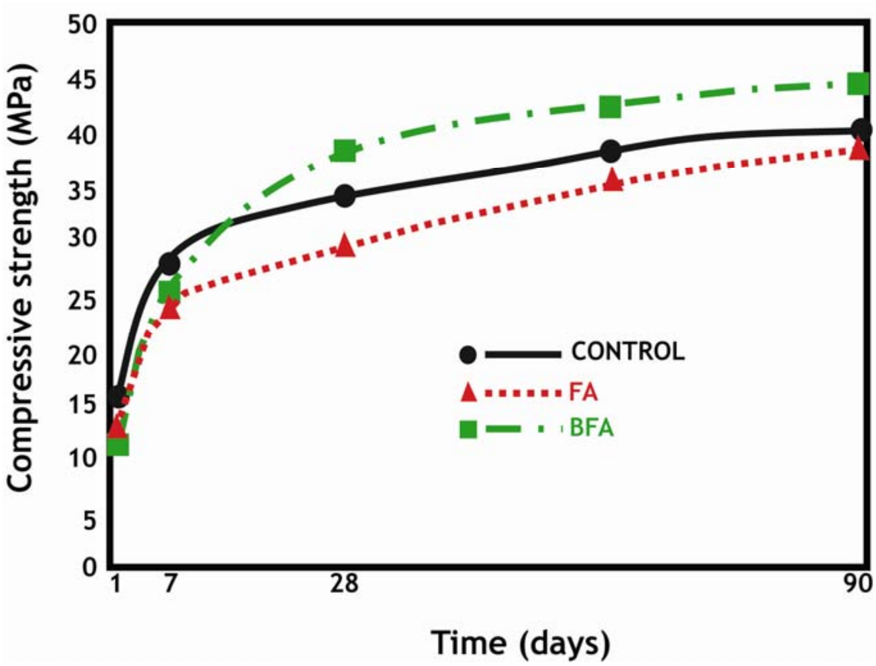

Figure 1 - Influence of FA or BFA mixtures on the compressive strength at 1, 7, 28, and 90 days.

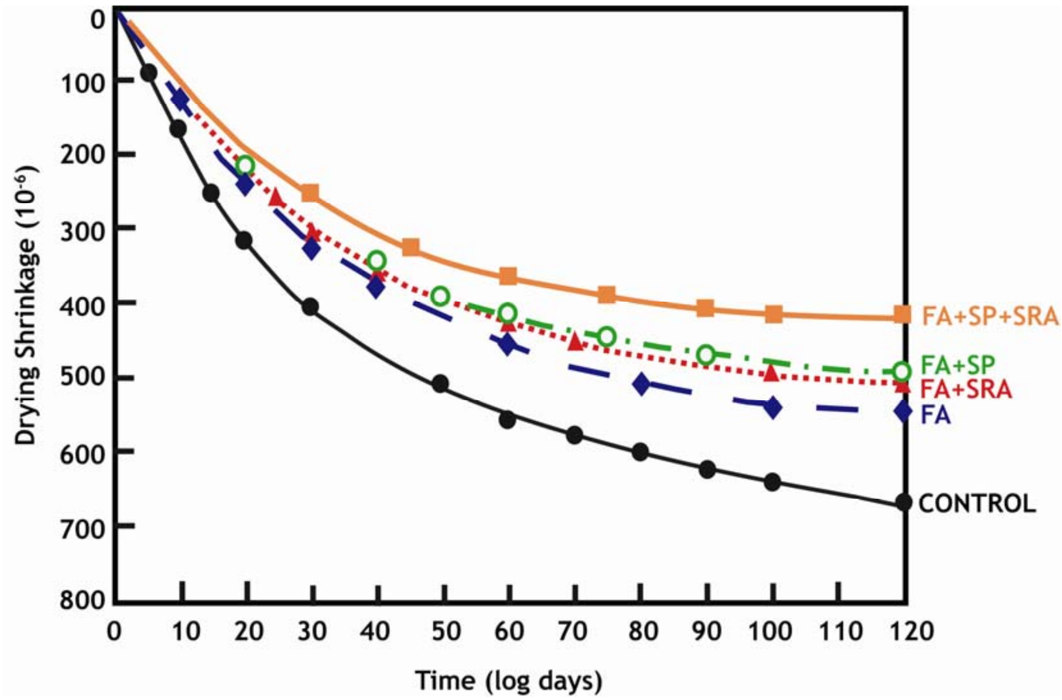

Fig. 2 – Unrestrained drying shrinkage of control and FA mixtures.

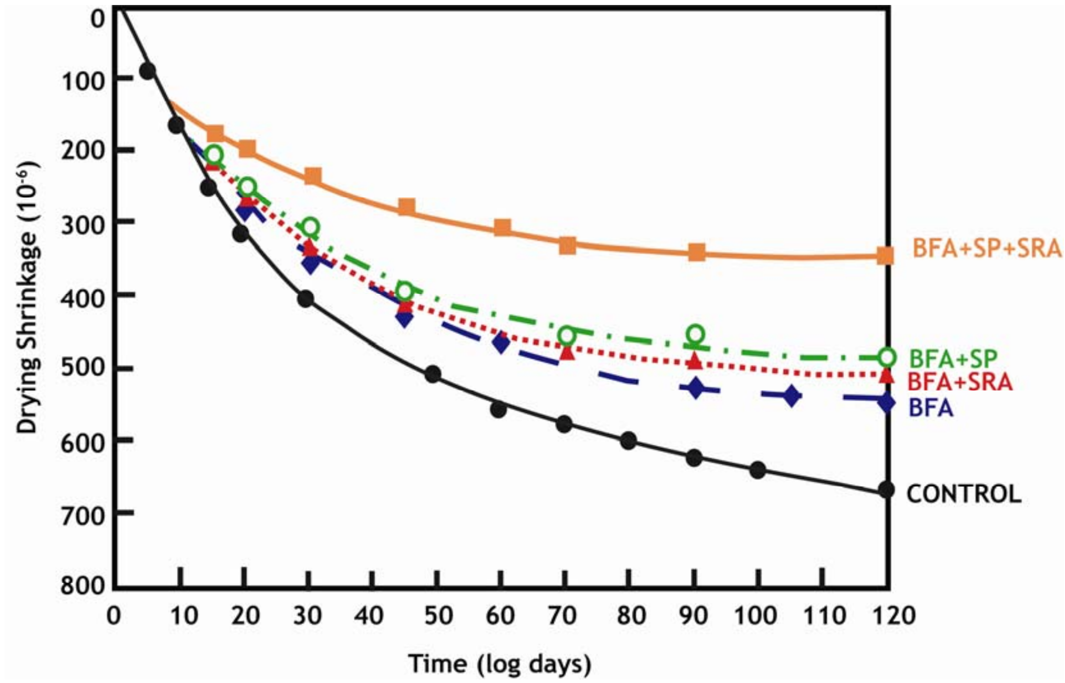

Fig. 3 - Unrestrained drying shrinkage of control and BFA mixtures.