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Beneficiated Fly Ash Versus Normal Fly Ash or Silica Fume

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Synopsis: The performance of a beneficiated fly ash (BFA), with very low carbon and very fine particle size ($5\ \mu\text{m}$ as mean size) was compared with silica fume in superplasticized high strength concretes. The silica fume content of concrete was $40\ \text{kg}/\text{m}^3$ and the amount of BFA was $80\ \text{kg}/\text{m}^3$ to obtain approximately the same cost as that of silica fume (SF). When the two concrete mixtures are compared at the same water-binder ratio (0.39) and at a given slump (about 165 mm), the dosage of superplasticizer was much higher for the SF concrete ($2.6\ \text{kg}/\text{m}^3$) than for the concrete with BFA ($1.2\ \text{kg}/\text{m}^3$). The compressive strength of the SF-concrete was higher than that of the BFA-concrete, particularly at early ages, and this effect could be related to the better space filling capability of SF, as compared to BFA. However, when the same dosage of superplasticizer was used, the water-binder ratio of the BFA-concrete turned out to be lower (0.31) than with SF concrete (0.39). The strength increase in the BFA-concrete with respect to the SF-concrete has been recorded in specimens cured at room temperature as well as with steam-cured.

In a second set of tests, BFA was used to manufacture high strength self-compacting concrete (SCC) in comparison with a corresponding SCC where untreated fly ash (FA) was used. In such a case the most important advantage in using BFA rather than FA was the self-leveling properties needed particularly in placing slabs or ground-floors. Due to the higher cost of BFA with respect to FA, there is no significant advantage in using the former in manufacturing SCC when the above mentioned self-leveling properties are not needed.

Keywords: beneficiated fly ash; fly ash; self-compacting concrete; self-leveling concrete; silica fume; superplasticizer

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INTRODUCTION

Coal fly ash is a supplementary cementitious material widely used to replace part of portland cement by improving some properties of concrete such as reduction in heat of hydration and related risk of thermal cracking, durability and impermeability of the concrete in service. However, there is a strength loss at early ages with respect to the control concrete without fly ash.

Silica fume performs much better than fly ash in manufacturing high performance concrete without any strength loss at early ages. However, due to its low availability, silica fume is very expensive and used only for special concretes.

In the present paper a beneficiated fly ash (BFA) has been studied in comparison with untreated fly ash (FA) and silica fume (SF). BFA can be based on the separation technology for reducing the carbon content in coal FA through tribo-electrostatic technique [1] and/or air classification of FA to extract the more reactive fine fraction [2] to improve its performance in terms of higher workability of the fresh concrete and lower porosity in the hardened concrete.

EXPERIMENTAL: MATERIALS AND METHODS

BFA, FA and SF have been used in two sets of concrete mixtures:

- a first set of concretes has been devoted to the manufacturing of fluid ordinary mixtures at a slump level of about 170 mm, by using BAF (80 kg/m^3) versus SF (40 kg/m^3) in order to keep the same cost incidence of these cementitious materials;
- a second set of concretes was based on the comparative use of BFA versus FA in manufacturing self-compacting concrete (SCC) with 50% of replacement of ordinary concrete by BFA or FA.

Chemical composition of BFA, FA, SF are shown in Table 1; in particular the loss on ignition (LOI) of the BFA is only 0.8% and than much lower than that of SF (2%) and FA (6.6%).

Figure 1 shows the micro-structural morphology of BFA, by scanning electronic microscopy and indicates that BFA particles are perfectly round grains. Figure 2 shows the particle size distribution results which indicate that BFA, with a mean particle of size of about $5 \mu\text{m}$, is an intermediate material between SF (about $0.2 \mu\text{m}$) and FA (about $25 \mu\text{m}$).

Tables 2 and 3 show the composition of ordinary concrete (with SF or BFA) and SCC (with FA or BFA), respectively. High-strength portland cement (CEM I 52.5 R according to the European standard EN 197-1) has been adopted. The total amount of portland cement and SF or BFA or FA is indicated as "binder", so that in Tables 2 and 3 are also shown the water-cement ratio (w/c) as well as the water-binder ratio (w/b).

Natural aggregates have been used with maximum size of 30 mm for the ordinary concretes and 16 mm for SCC mixtures.

A polycarboxylate-based superplasticizer (SP) has been used at an adequate dosage to manufacture ordinary concretes at a given slump (165 mm in Table 2) or at a given SP dosage (2.6 kg/m^3). Moreover, SCC mixtures with BFA or FA at a given slump-flow (about 740 mm in Table 3) were also studied through the rheological measurements [3] based on V-funnel, U-box and L-box (Table 4).

All concrete specimens were cured at room temperature (20°C). Moreover, the ordinary concrete has been also steam-cured at 55°C after a preliminary curing at room temperature of 3 hours and heated in 4 hours from 20°C to 55°C .

RESULTS

Ordinary concretes. Table 2 shows that the dosage of SP needed to produce fluid concretes at a given water-binder ratio of 0.39 with BFA is 1.2 kg/m^3 , 50% less with respect to the concrete with SF (2.6 kg/m^3). Moreover, when the same dosage of SP (2.6 kg/m^3) is used in the SF-mixture and in the BFA-concrete the water-binder ratio for the latter is much lower than in the former (0.31 vs. 0.39). These results are related to the larger size of BFA particles with respect to that of the SF particles (Fig.2), at the same spherical morphology as shown in Fig.1.

Figure 3 shows the compressive strength development of concretes cured at 20°C . When concretes are compared at the same water-binder ratio of 0.39, the compressive strength of the SF-mixture is significantly higher than that of the BFA-mixture, particularly at early ages (about 50% more at 1 day), whereas the difference decreases at longer ages (about 20% at 90 days). On the other hand, when the concretes are compared at the given slump of 165 mm and at the same superplasticizer dosage of 2.6 kg/m^3 , then the compressive strength of the BFA-mixture is higher than that of the SF-mixture: about 10% more at early and later ages.

Figure 4 shows the compressive strength values in the steam-cured concretes as a function of the time and confirms those obtained at room temperature (Fig.3).

All these results indicate that –at a given cost of the concrete mixtures– BFA (80 kg/m^3) performs better than SF (40 kg/m^3) in terms of compressive strength only if

the concrete mixtures are compared at a given slump and at the same dosage of superplasticizer (Table 2): due to the much lower mean size of SF with respect of BFA (0.2 μm vs. 5 μm), the water-cement ratio as well as the water-binder ratio is much higher in the SF-concrete than in the BFA-concrete.

Self-compacted concretes. Table 3 shows the composition of two SCCs, both with a portland cement content of about 245 kg/m^3 , for which the same amount of FA or BFA (245 kg/m^3) was adopted. At given w/c and slump-flow, the SCC mixture needs a significantly lower dosage of superplasticizer in the presence of BFA with respect to the corresponding concrete with FA (3 vs. 9 kg/m^3). This behavior is due to the most favorable spherical shape of BFA (Fig.1) with respect to that of the FA which includes some irregular particles specially in the range of the larger ones. Consequently, the BFA-SCC appears to be much more mobile than the corresponding FA-SCC (Table 4) in terms of much lower times needed in the V-funnel test (7 vs. 50 sec.) or in the U-box test (2 vs. 40 sec.) or in the L-box test (6 vs. 57 sec.). This property makes the BFA-SCC much more suitable, than the corresponding FA-SCC, to place self-leveling concretes for slabs and ground-floors or to fill more quickly the formworks specially if congested by steel reinforcements.

There is no significant differences in the compressive strength (Fig.5) at early ages, whereas at longer ages (≥ 14 days) the BFA-SCC performs slightly better than the corresponding FA-SCC probably for a more reactive behavior of the smaller particles of BFA.

All these results indicate that, except for some special applications where SCCs with particular flow-properties are needed for placing self-leveling mixtures, there is not a significant technical advantage in using BFA rather than FA. Moreover, the lower dosage of superplasticizer (3 vs. 9 kg/m^3) does not compensate for the higher cost of BFA with respect to FA.

CONCLUSIONS

The results of the present paper indicate that a beneficiated fly ash (BFA) with a low carbon content, very fine particle size (mean size of 5 μm), and a more favorable shape of the small spherical particles, could be used instead of silica fume (SF) for high performance concretes. In particular, the BFA-concrete mixture derives more advantage from the use of polycarboxylate-based superplasticizer (SP), when compared to the SF-concrete. Therefore, when the same SP dosage is adopted, the water-cement ratio as well as the water-binder ratio were lower. The compressive strength tends to be higher when BFA (80 kg/m^3) is used instead of SF (40 kg/m^3) for the same cost.

On the other hand, when BFA is used instead of ordinary fly ash in the manufacture of self-compacting concrete (SCC), there is a significant technical advantage only where a self-leveling concrete is needed.

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Table 1 – Chemical Analysis of Fly Ash (FA), Beneficiated Fly Ash (BFA), Silica Fume (SF) and Portland Cement (PC)

Chemical Analysis	Mass %			
	FA	BFA	SF	PC
SiO ₂	54.1	53.7	94.4	23.1
Al ₂ O ₃	28.9	34.2	0.2	5.1
CaO	2.0	4.1	0.8	62.9
Fe ₂ O ₃	3.7	3.8	0.7	0.9
K ₂ O	0.7	0.7	0.3	0.3
Na ₂ O	0.4	0.3	0.2	0.4
MgO	0.5	0.9	0.6	0.2
l.o.i.	6.6	0.8	2.0	2.0

Table 2 – Composition of concrete mixtures with SF or BFA at a given slump

Mix	Binder			Aggregate		Water kg/m ³	SP kg/m ³	w/b	w/c	Slump (mm)
	Portland cement kg/m ³	SF kg/m ³	BFA kg/m ³	Gravel 4-30 mm kg/m ³	Sand 0-4 mm kg/m ³					
SF	360	40	0	1074	795	157	2.6	0.39	0.43	160
BFA	320	0	80	1074	796	157	1.2	0.39	0.48	170
BFA*	325	0	81	1090	810	127	2.6	0.31	0.39	170

w/b = water/binder

Table 3 – Self-compacting concretes with FA or BFA

SCC mixture	Cement kg/m ³	Sand 0-4 mm kg/m ³	Gravel 4-30 mm kg/m ³	Water kg/m ³	SP kg/m ³	w/c	w/b	Slump flow mm	FA kg/m ³	BFA kg/m ³
FA-SCC	244	858	925	166	9.0	0.68	0.34	750	244	—
BFA-SCC	246	869	938	163	3.0	0.66	0.33	750	—	244

Table 4 – Rheological properties of FA-SCC and BFA-SCC at the same slump-flow of 750 mm

SCC type	Times (sec) for the following test:			
	V-tunnel	U-box	L-box	Slump flow
FA-mix	50	40	57	50
BFA-mix	7	2	6	7

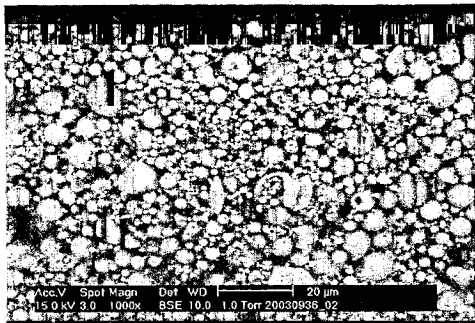


Fig. 1—SEM microscopy of BFA.

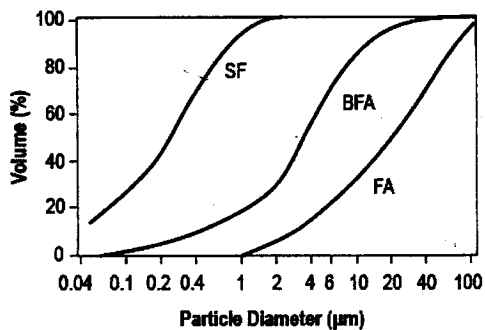


Fig. 2—Particle size distribution of SF, FA, and BFA.

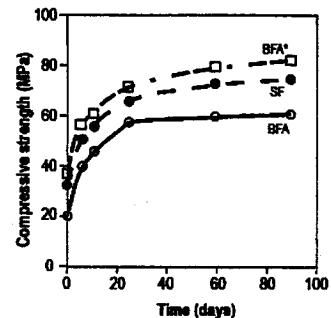


Fig. 3—Compressive strength versus time at 20 °C for concretes with silica fume (SF) and beneficiated fly ash at the same w/c (BFA) or at the same dosage of superplasticizer (BFA*).

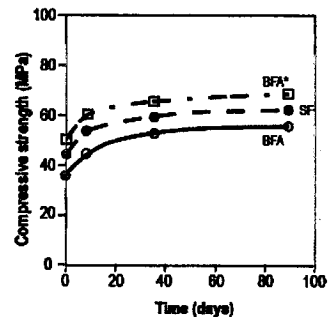


Fig. 4—Compressive strength versus time for steam-cured concretes with silica fume (SF) and beneficiated fly ash at the same w/c (BFA) or at the same dosage of superplasticizer (BFA*).

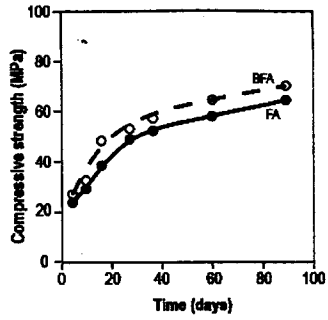


Fig. 5—Compressive strength versus time for SCC with fly ash (FA) or beneficiated fly ash (BFA).