Goumans/Senden/van der Sloot, Editors
Waste Materials in Construction: Putting Theory into Practice
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UPGRADING AND QUALITY IMPROVEMENT OF PFA

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ABSTRACT

An example of upgrading and quality improvement is micronization of fly ash (PFA). The usual fly ash particle size range is up to 200 micrometer. For the improvement of concrete properties, however, fine fly ash particles in the range up to 10 micrometer are preferable. Micronized fly ash is produced with a mean diameter of less than 5 micron. This very fine powder is an excellent high performance type II filler for concrete.

1 INTRODUCTION

In the Netherlands about 30% of the production of electricity is realised by coal-firing, which results in a collection of about 900.000 tons/year fly ash in the electrostatic precipitators. Nowadays, fly ash is fully accepted as a raw material. It is used for the production of cement (62%), light weight aggregate (20%), concrete, asphalt and other applications (18%).

With respect to by-products management the approach is more and more focused on the reduction of costs and further economical optimization.

The value of a product like fly ash is mainly determined by the value of the products that will be partly substituted, or by new attractive possibilities of the end products. If for instance cheap regular sand is replaced by fly ash, its value is relatively low. If fly ash can be used as cement, the value is higher. If, moreover, the resulting concrete properties are improved, its value will raise further. In general, quality control measures and upgrading will turn by-products into valuable resources as schematically indicated in figure 1. To improve the quality of fly ash, methods for benification are being introduced. The methods are focussed on various fly ash parameters like grain size and carbon-content (1).

A main reason for upgrading fly ash is to enhance its added value, which makes it more profitable. For the use in concrete, the particle size of the fly ash is very important. Especially fine particles are needed because they improve the packing of the combination of gravel, sand and cement particles. This results in a denser concrete, which is consequently stronger and more durable.

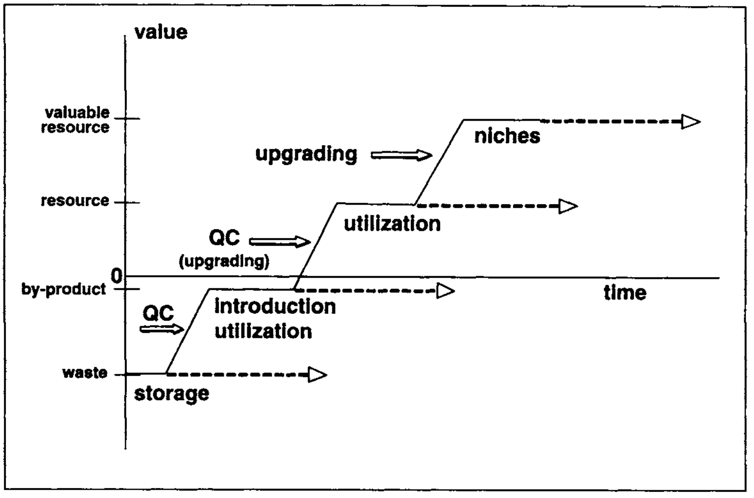

Figure 1 Trends in by-products marketing

2 HIGH PERFORMANCE CONCRETE

The use of high performance concretes (high strength and high durability) is becoming more and more common. At the same time there is a tendency towards concrete mixtures which need only minor compaction energy for optimal filling of the formwork. These concretes have a high slump and must therefore be very stable in order to assure homogeneity (see figure 2).

For the proportioning of these concrete mixtures, special additives and ultra fine fillers like silica fume (particle size 0.1-1.0 microns), are needed. However, the availability of these ultra fine fillers is very limited and as a consequence the price is high. Because of the developments indicated, it is expected that the need for ultra fine fillers will strongly increase.

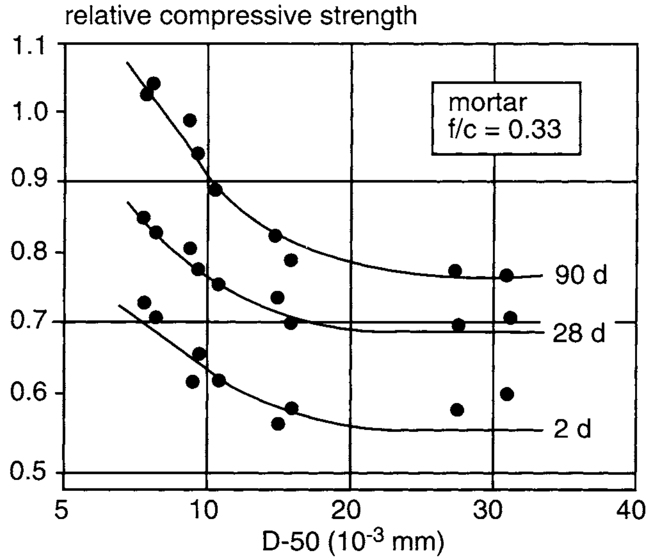

Figure 2 Concrete strength versus fly ash fineness (D-50) (6)

3 FLY ASH FINENESS

It is well known that fly ash fineness is a major parameter for its effect in concrete. The fine particles in the grain size distribution have a relatively high contribution to the strength development of concrete. This was shown in various research projects (2, 3, 4). Also by KEMA this effect was demonstrated (5). A typical result is shown in figure 3. Fly ashes were classified and mixed to given D-50 values (being the mean particle size of the size distribution). It can be seen that both mortal and concrete strengths increase, if finer fly ashes are added. The effect is stronger for concrete and is more pronounced for the finer particle size range.

The usual fly ash particle size range is up to 200 micrometer. For the improvement of concrete properties, however, fine fly ash particles are preferable in the range up to 10 micrometer. These fine fraction can be separated from the bulk amount fly ash, or the coarser fly ash can be processed to finer particle sizes. Separation is cheaper but less effective because the amount of fine particles in the original fly ash is very limited.

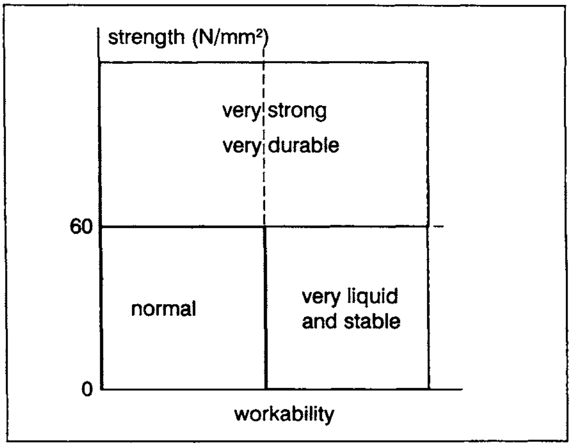

Figure 3 Trends in concrete properties

4 CLASSIFICATION OF FLY ASH

Two low-NO_x fly ashes with lower and higher carbon content (indicated as B and M) produced by Dutch power stations were selected for the tests. The ashes were processed in an air classifier and, if necessary, mixed to obtain certain gradings. The particle size distribution was measured by Malvern 2600 C analyzer and the gradings were qualified in terms of characteristics of the size distribution, i.e. D10, D50 and D90, but also by the grading modulus G (4).

G = (6/((1/d1) - (1/d2))/ln(d2/d1)

In the formula d1 and d2 represent the diameters of the smallest and the largest size particles of a group between two successive sieves. Between these sieves the size distribution is assumed to vary linearly to a log scale. Table 1 gives the corresponing values.

Concrete cubes (150x150x150 mm) were cast and stored in the fog room (20 °C and RH > 95%). The cement content of the reference mixes was 320 kg/m^3, which was substituted with 20% (by weight) fly ash in the case of the fly ash mixtures.

For all mixtures normal hardening Portland cement was used. The maximum aggregate size was 31.5 mm, while the slump of the fresh concretes was adjusted at 70 mm (plus or minus 10 mm).

The amount of water needed for a given workability (the slump of the concrete cone = 70 mm) was measured for all concrete mixtures. Then cube compressive strength was determined at ages of 7 and 28 days. The results are presented in table 2. The results prove that fly ash fineness is a major factor for concrete properties.

5 MICRONIZATION OF FLY ASH

5.1 Processing

It was decided to process fly ash to particles in the one micrometer range, because this will result in an important market for fly ash as a high valuable resource.

Besides by air classification fly ash fineness was increased by grinding to particle sizes down to between about 5 and 10 micron (6). The ultra-fine range was also reached in Japan, by vaporization at about 2400 °C and condensation of fly ash (7). The present project, investigates whether fly ash can be micronized economically to less than 5 μm and to see if the performance of this product in mortar and concrete is satisfactory.

5.2 Materials

The effects of the various types of fillers were tested with normal hardening Portland cement (PC-A). A typical fly ash was used (57.0% SiO_2, 26.4% Al_2O_3, 4.4% Fe_2O_3, 4.2% C and 1.8% CaO). The fine fraction was collected in the bag-filter of an air classifier, whereas the ultra-fine fraction was obtained by grinding. It was found that the mean particle size being 21.6 μm for the input fly ash was reduced to 9.9 μm for the air classified fly ash and to 1.6 μm for the ground one. A picture of micronized fly ash is given in figure 4. Particle size distribution curves are given in figure 5.

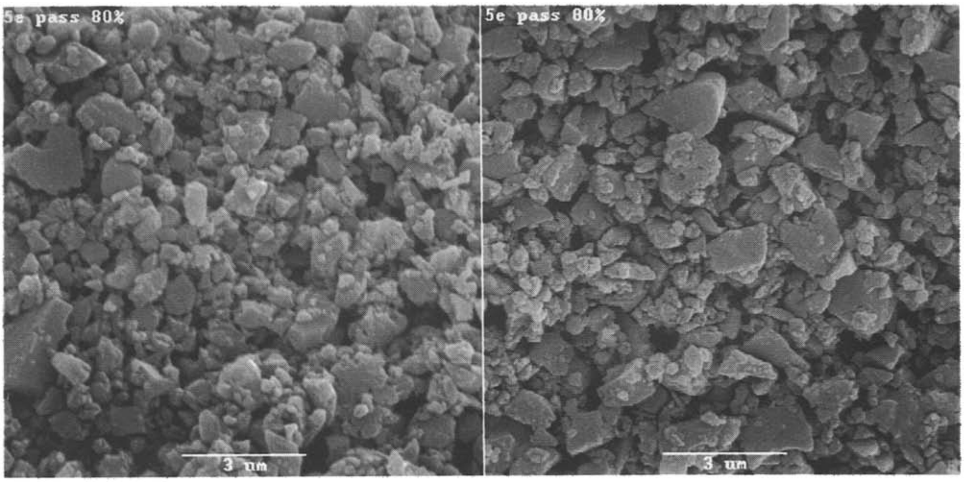

Figure 4 SEM-picture of micronized fly ash

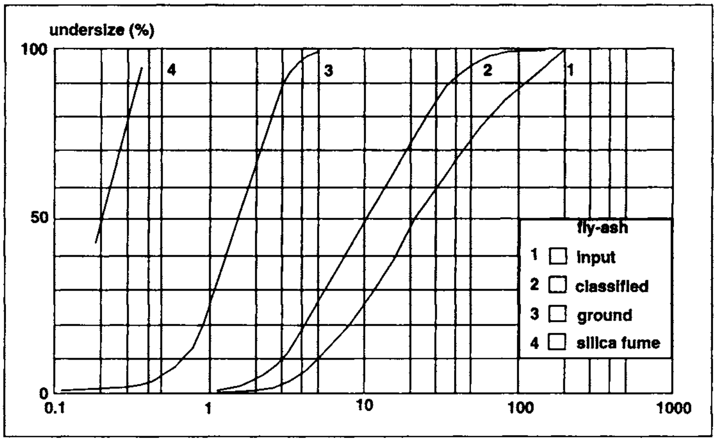

Figure 5 Particle size distributions of the classified and ground fly ashes in comparison with the input fly ash (percentage passing versus sieve opening in micrometers)

The silica fume involved, had an SiO_2 content of 92% (m/m) and a mean particle size of 0.12 μm. In the tests, a 50% to 50% (m/m) combination of silica fume and micronized fly ash was also applied.

5.3 Laboratory scale tests

In the concrete compositions, 360 kg/m^3 PC-A cement was used; the maximum grain size of the river gravel was 31.5 mm. Because a major objective was to realise highly fluid mixtures, the fresh concrete slumps were 230 plus-minus 40 mm. This resulted in a water to cement ratio of 0.32 for the mixtures containing fillers and 0.35 for the reference mixture (no filler added). An overview is given in table 3.

If needed, chemicals called super plasticizers were added to improve the workability of the fresh concrete. The amounts of filler added were 5%, 10% and 15% (m/m cement).

After 3, 7, 28 and 91 days curing, the compressive strength was determined (see table 4). The results indicate that the strength values are significantly higher for the mixtures with higher filler content, especially in the case of filler types micronized fly ash and silica fume.

Note: In table 3 and 4 the reference mixtures are indicated as CREF 1, 2 and 3. The various types of fillers are AC (= air classified PFA), AG (= ground PFA), SF (= silica fume) and SA (= 50% AG plus 50% SF). The numbers 5, 10 and 15 indicate the amount of addition of filler (m/m cement).

5.4 Full-scale test

Based on the results of the laboratory tests two mixes were designed for the full-scale tests, being precast L-shaped elements (100 x 150 x 300 cm^3). Special attention was given to the workability in order to realise a mixture which can be placed with minor compaction energy. So the PC-A cement content was raised to 410 kg/m^3 and about 2% (m/m cement) melamine-sulphonate super plasticizer was added. The maximum grain size in the mixes was 16 mm. In mixture 1 the water to cement ratio was 0.36 and in mixture 2, 0.38. The addition of micronized fly ash was 12% (m/m cement) in both cases (see figure 6).

The moulds were filled in one batch of 1.2 m^3 fresh concrete. After that compaction was needed for 2 minutes. One day later the elements were demoulded. Mixture 1 showed air-encapsulations at the surface, while the element made from mixture 2 showed an excellent surface texture.

At an age of 28 days, concrete compressive strength was determined from drilled cores. It was found that after one day hardening the cube strength was already about 55 N/mm^2. The 91 days strength values proved to be about 95 N/mm^2 for both mixes.

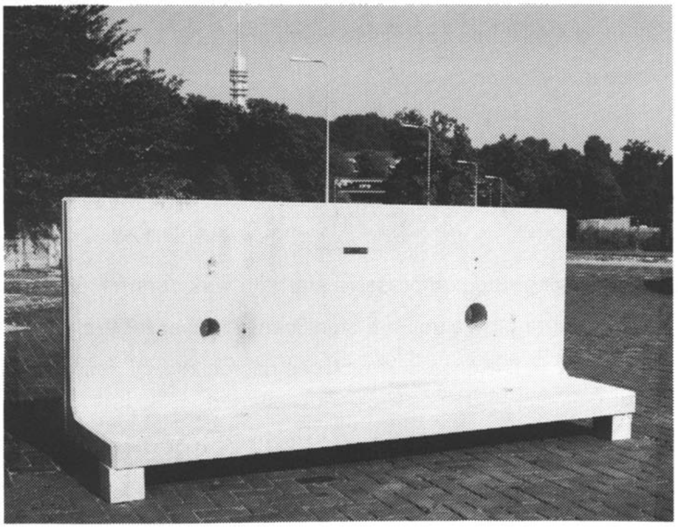

Figure 6 High performance concrete element with micronized fly ash

6 CONCLUSIONS

It is a challenge to use the potentials of the by-products of coal combustion. Because of environmental, economical and technical reasons the present worldwide utilization rate of 35% will strongly be stimulated. In many countries like the Netherlands these by-products are fully accepted, which results in a 100% utilization, mainly in the building materials industry.

By adequate measures like quality control and up-grading, fly ashes prove to be excellent raw materials for the building industry. Fly ash fineness proves to be an important parameter for the quality of the products.

By appropriate grinding it is possible to micronize fly ash to sizes under 5 μm. By micronizing all fly ash can be processed, while in the case of air-classification the output of fine material is very limited (< 10%). The effect of addition of these ground fly ashes on properties of concrete was determined and compared to the effects of air classified fly ash, silica fume and combinations of these two types of fillers. It was found that in concrete, the fluidity was positively effected by these types of fillers. So, the irregular shape has no significant effect. Also high strength values were reached.

Mixes with micronized fly ash behaved well during full-scale tests. It can be concluded that micronized fly ashes are excellent high performance fillers for concretes.

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Table 1 Size distribution characteristics and LOI

sample code	D10 (μm)	D50 (μm)	D80 (μm)	G (1/mm)	LOI* (%)
B0	7.4	39.2	133.5	225	4.56
B1	4.5	23.0	75.3	456	4.50
B2	6.6	17.4	46.1	462	4.14
B3	3.2	9.5	32.2	850	5.70
M0	6.5	24.2	96.8	299	8.31
M1	4.4	17.7	53.5	563	8.04
M2	4.2	15.7	45.3	600	7.46
M3	2.9	8.7	36.3	919	7.94

* loss on ignition at 815 °C for 10 minutes

Table 2 Concrete test results

sample code	water content (dm^3/m^3)	compressive strength (N/mm^2)	
		7 days	28 days
reference	163	30.3	38.3
B0	163	23.0	31.4
B1	160	25.2	33.3
B2	161	23.9	32.9
B3	156	28.2	38.7
M0	162	24.5	33.3
M1	160	27.0	36.8
M2	158	27.3	36.0
M3	157	27.9	38.7

Table 3 Concrete compositions and workability data

Sample code*	fly ash (kg/m^3)	SF (kg/m^3)	w/c	SP (%)**	Slump (mm)	Spread (static) (mm)	Spread (jolting) (mm)
CREF1	0	0	0.32	2.75	170	320	420
CREF2	0	0	0.35	2.5	220	470	540
CAC05	18	0	0.32	2.5	190	330	420
CAC10	36	0	0.32	2.5	230	430	520
CAC15	54	0	0.32	2.5	250	500	570
CAG05	18	0	0.32	2.5	230	420	520
CAG10	36	0	0.32	2.5	240	540	600
CAG15	54	0	0.32	2.5	270	610	>700
CSF05	0	18	0.32	2.5	220	400	500
CSF10	0	36	0.32	2.5	220	350	470
CSF15	0	54	0.32	2.5	190	320	440

* C = concrete; AC = type of filler; 0.5 = % filler (m/m cement)

** superplasticizer as weight percentage of cement plus 0.2 filler

Table 4 Properties of hardened concrete containing the indicated types and amounts of fillers

Sample code	filler type	filler (%)	Compressive strength (MPa)			
			3 days	7 days	28 days	91 days
CREF1	no	0	56.0	68.7	81.8	90.6
CREF2	no	0	38.8	49.8	64.2	69.3
CAC05	AC	5	56.3	68.2	83.6	92.3
CAC10	AC	10	52.3	64.9	81.6	93.7
CAC15	AC	15	49.7	62.3	79.8	92.4
CAG05	AG	5	53.0	65.3	80.0	85.9
CAG10	AG	10	52.6	66.2	86.2	96.0
CAG15	AG	15	55.0	69.6	95.8	105.9
CSF05	SF	5	55.1	69.4	94.0	95.3
CSF10	SF	10	58.3	70.6	96.6	103.9
CSF15	SF	15	57.9	74.3	99.3	104.8