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Influence of Paper Mill Ash Addition on the Performance of Self-Compacting Concrete

Valeria Corinaldesi, and Saveria Monosi

Department of Materials and Environment Engineering and Physics – Università Politecnica delle Marche, Via Brecce Bianche, 60131 Ancona - Italy. E-mail: <v.corinaldesi@univpm.it>, <s.monosi@univpm.it>.

ABSTRACT

Self compacting concrete (SCC) is characterized by high workability and stability during the placement and before setting. For this reason high volume of very fine materials should be present and excessive amount of cement, dangerous for hydration heat and shrinkage, can be avoided by using mineral additions. In this paper, SCCs containing ashes coming from the combustion of paper mill sludge as fine mineral addition were studied. In particular, flowability of fresh mixtures, as well as compressive strength and drying shrinkage at different curing times of the hardened concrete, were examined. The paper mill ash (PMA) was used with two different rates and finenesses. When used without any preliminary grinding, no improvement in the concrete performance was observed while, if previously ground, seems to be effective for obtaining better mechanical performance and stable mixtures by avoiding VMA addition, due to a significant increase of its fineness.

INTRODUCTION

Self compacting concrete is characterized by high workability that does not require any vibration to place it. Moreover, SCC must be stable during the placement and before setting in order to guarantee homogeneity and durability. The above performances can be obtained: by decreasing the amount and size of the coarse aggregate; by using high volume of fines; by combined use of superplasticizer and viscosity modifying agent (VMA) in order to obtain high fluidity as well as high stability of the cement paste [Khayat and Guizani 1997; Borsoi et al, 2006]. Therefore, one of the key points is the increased volume of the fine powders, cement and mineral addition, to improve both mobility and segregation-resistance of the fresh mixture [Okamura and Ozawa 2003]. On the other hand, an excessive cement content would cause cracks promoted by thermal and drying shrinkage which would severely penalize the durability of the concrete structure. Therefore, some fine mineral filler such as fly ash, limestone filler, ground blast furnace slag (GBFS), to replace a significant volume of Portland cement is certainly needed to manufacture SCC [Borsoi et al, 2006; Troli et al, 2003]. Since 1996, with the new cement norms [EN 197-1], blended cements rather than pure Portland cement are often manufactured, so that in the market there is a shortage of fine mineral fillers.

The aim of the present work is to assess whether the ash from incineration of paper mill sludge can be proposed as fine mineral addition in manufacturing SCC, therefore attention is focused on its fresh and hardened properties [Collepardi et al, 2005; Bonen and Shah 2005].

Paper mill sludge is a by-product of paper production. About 6 kg of sludge are produced per ton of paper. In the year 2004, the production of paper mill sludge in Italy was around $6 \cdot 10^5$ tons [Asquini et al, 2008]. Paper mill sludge is composed of mineral fillers, inorganic salts, small cellulose fibres, water and organic compounds. The composition of mineral fillers depends on the type of paper produced. Paper mill sludge is often burnt in order to reduce the waste disposal and sometimes to recover heat. This process is achieved first by de-watering (i.e. evaporation) at low temperature (< 200 °C), followed by incineration at high temperature (> 800 °C). During incineration, paper and organic compounds are burned out at temperatures of around 350-500 °C, whereas mineral fillers and inorganic salts are transformed into the corresponding oxides at higher temperatures (> 800 °C). CaO, Al_2O_3, MgO and SiO_2 are the most abundant oxides in incinerated paper mill sludge [Liaw et al, 1998]. The obtained paper mill sludge ash is classified as waste, and at present it is mainly conferred to landfill at high costs. Recycling it would have beneficial effects for paper producers, and the environment as well. A possible reuse of paper mill sludge is its blending with natural raw materials extracted from the ores in the production of bricks or cements [Marcis et al, 2005; Ernstbrunner 2007; Liaw et al, 1998], since the main constituent elements of paper mill sludge are Al, Mg, Si and Ca, whose oxides are largely used in the ceramic industry. Paper mill sludge can be recycled in the paper industry itself where it is co-burnt with wood residue, to produce energy for internal use. The combustion fumes carry fly ashes which are collected and available as a new by-product that can be recycled.

EXPERIMENTAL INVESTIGATION

Materials

A commercial portland-limestone blended cement type CEM II/A-L 42.5 R according to European Standards EN-197/1, quartz sand (4 mm maximum size), crushed limestone (15 mm maximum size) and fine limestone filler (Blaine fineness 0.52 m^2/g) were used in the reference mixture as solid constituents.

Furthermore, in order to manufacture the concrete mixtures of this experimental study, ashes from paper mill sludge combustion (PMA) were alternatively used either just as received (see Figure 1) or after grinding (Blaine fineness 0.55 m^2/g), instead of limestone powder. For the PMA as received, the percentage of material passing through the sieve of 150 micrometers is about 80% (see Figure 1). This information was taken into account during SCC mixture proportions, in order to correctly control the amount of filler introduced. Two images of PMA as received obtained by means of scanning electron microscopy are reported in Figure 2. Its typical chemical composition is roughly 40% CaO, 30% SiO_2, 15% Al_2O_3, 5% MgO and other minor constituents (10% as a whole).

A polyacrylic based superplasticizer was added to each mixture whereas a viscosity modifying agent (VMA) was used if necessary.

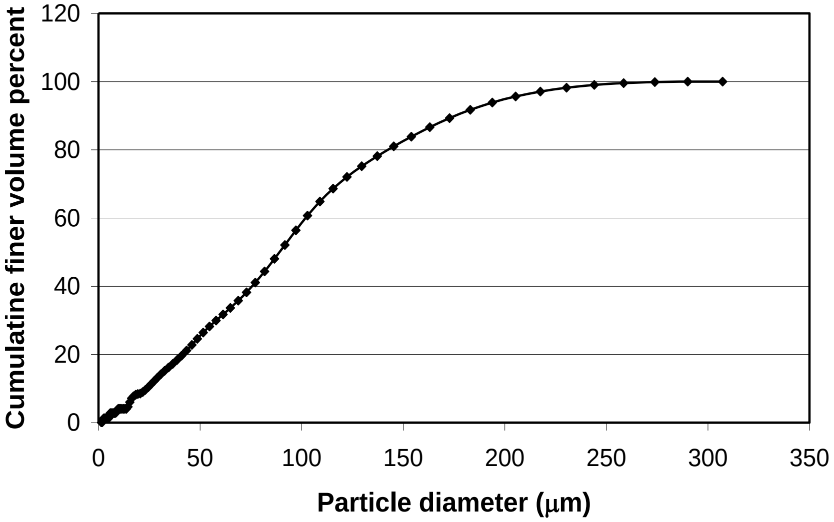

Fig. 1. Particles Size Distribution of PMA as Received

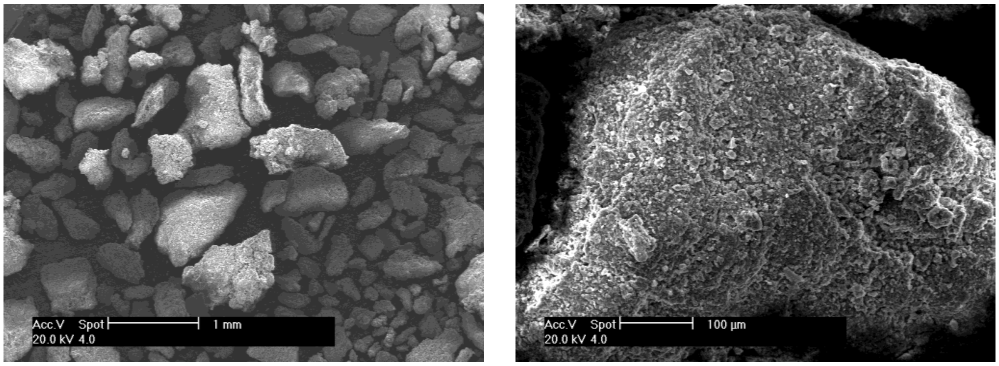

Fig. 2. SEM Observations of PMA as Received

Mixture proportions

The manufactured concretes differ for amount of PMA and for its particle size distribution. PMA partially or totally replaced limestone powder. The concrete mixture proportions are reported in Table 1.

When PMA was used as received, the correct dosage was hardly taken under control, because its right apparent volume cannot accurately known. It was adopted a relative specific gravity value of about 1.2 while for the ash after grinding the relative specific gravity value, easier to determine, was equal to 2.1.

The cement dosage was kept equal to 370 kg, while the water to cement ratio was kept equal to 0.54. Two kinds of chemical admixtures were used: a superplasticizer with a dosage of 1.1-1.4% by weight of cement and, in some cases, a water reducing admixture at a dosage of either 0.05% or 0.1% by weight of cement. In the presence of PMA, the requested dosage of superplasticizer increases, while that of VMA decreases until to zero, when ground paper mill ash is added (mixtures 'L+GPMA' and 'GPMA').

Mineral additions were added at a suitable dosage in order to achieve an overall volume of very fine particles included in the range 180-190 litres per cubic meter of concrete. In this way, the ratio between water and very fine particles volumes was in the range 1.0-1.05.

Table 1. SCC Mixture Proportions

MIXTURE	Lref	L+PMAar	L+GPMA	GPMA
Water/Cement	0.54	0.54	0.54	0.54
Water	200	200	200	200
Cement	370	370	370	370
Quartz sand (0-4)	810	810	810	810
Crushed limestone (5-15)	690	690	690	690
Limestone powder	160	100	85	-
PMA as received	-	50	-	-
Ground PMA	-	-	60	130
Superplasticizer	5.6 (1.1%)	5.5 (1.0%)	6.5 (1.25%)	7.0 (1.4%)
Viscosity Modifying Agent (VMA)	0.56 (0.1%)	0.40 (0.05%)	-	-

Quartz sand and crushed limestone were proportioned at 54% and 46% respectively. In this way, the ratio between sand and mortar volumes was equal to 0.45 and the volume of coarse particles was quite low, equal to 265 litres per cubic meter of concrete.

RESULTS AND DISCUSSIONS

Fresh property tests

Fresh concrete workability was evaluated through slump flow test. The consistency requirements for a good SCC must include high mobility and high stability in order to facilitate the placement and to avoid segregation. Results obtained are reported in Table 2.

Table 2. Results of Slump Flow Test

MIXTURE	Lref	L+PMAar	L+GPMA	GPMA
Slump flow (mm)	650	580	630	620
Time (s)	15	9	12	13

All concretes had enough deformability under their own weight (strictly related to the value of the mean diameter), and adequate viscosity (related to the value of the elapsed time to stop), except for the reference mixture characterized by too much viscosity. The reason probably is the high dosage (0.1% by weight of cement) of VMA employed. However, neither the presence of a halo of cement paste around the slumped concrete nor the ‘sombrero effect’ were observed.

Compressive strength development

Compressive strength was measured on cubic (100x100x100 mm) specimens at different curing times: 1, 3, 7, 14 and 28 days. All cubic specimens, after demolding (1 day) were covered by plastic shift to prevent water evaporation, and cured at constant temperature of 20°C.

Results obtained are reported in Table 3 and shown in Figure 3. It can be noticed that paper mill ash (PMA) used as received slightly penalizes the strength (-4%). An explanation can be found on its high porosity that weakens the concrete matrix.

Table 3. SCC Compressive Strengths (MPa) at Different Curing Times

Curing time (days)	Lref	L+PMAar	L+GPMA	GPMA
1	21	18	9	20
3	36	33	21	35
7	40	37	29	50
14	45	42	33	54
28	50	48	35	56

On the other hand, the addition of ground PMA with high fineness allows to reach good results in particular at later curing time (+30% when limestone powder was completely replaced). The reason can be a better filler effect of ground PMA with respect to limestone powder.

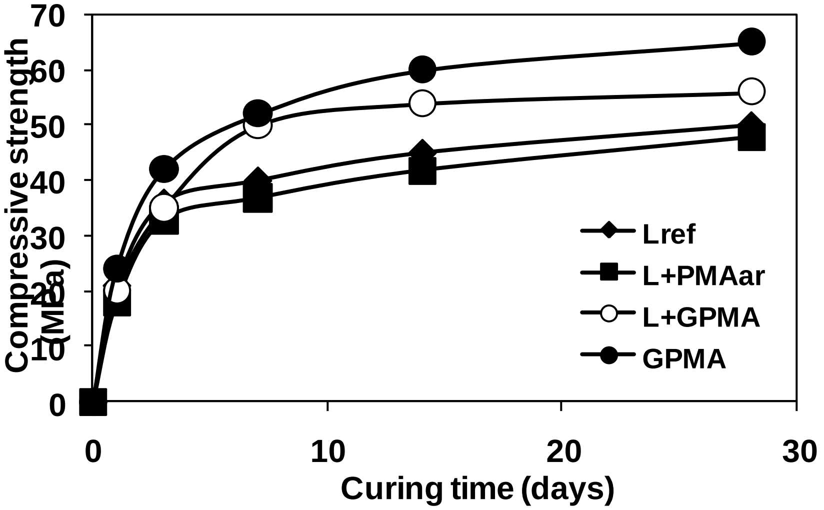

Fig. 3. SCC Compressive Strength vs. Curing Time

Drying shrinkage measurements

Drying shrinkage was monitored on prismatic (100x100x500 mm) specimens from 1 day to six months. Prismatic specimens after demolding were exposed to an environment at 60% R.H. and 20°C temperature. Results obtained are reported in Figure 4.

With respect to the reference mixture (Lref) the use of both PMA as received and ground PMA produces slightly higher shrinkage. In particular, in the case of PMA as received, 12% higher shrinkage with respect to the reference mixture was detected, due to the higher volume of very fine materials added to the mixture. On the other hand, when ground PMA was used either 16% or 30% higher shrinkage with respect to the reference mixture was detected, depending on the rate of substitution. In this case the reason lies on the higher fineness, and consequently water absorption, of ground PMA with respect to limestone powder.

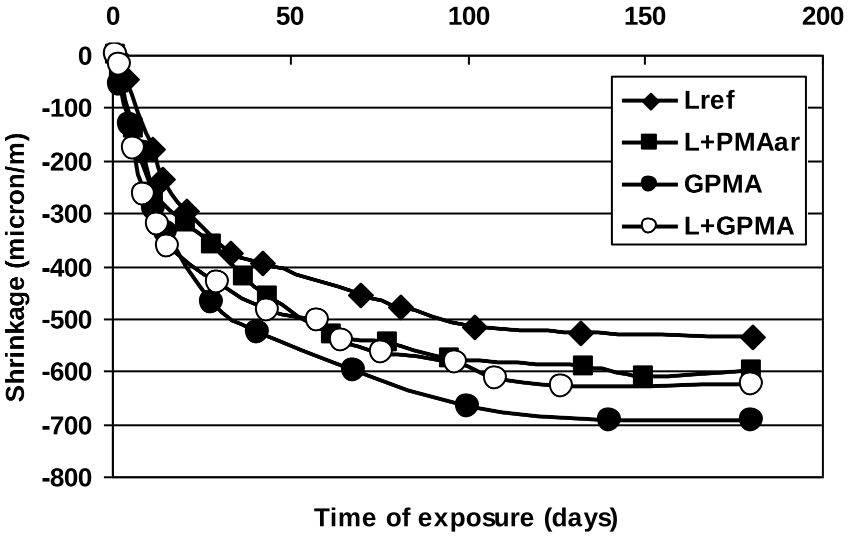

Fig. 4. Drying Shrinkage Measurements up to 180 Days of Exposure

CONCLUSIONS

The following general conclusions can be drawn from the study provided in the paper:

- if a viscosity modifying admixture is added to the mixture, the use of PMA as received proves promising to preserve fresh concrete workability;
- when PMA as received was used, the mechanical performance is 4% lower with respect to the reference mixture, while drying shrinkage was 12% higher, likely due to the higher volume of very fine materials added to the mixture;
- the use of ground PMA proves to be effective to produce SCC, even without viscosity modifying admixture;

- when ground PMA was used at a rate of 100%, significant improvement of mechanical strength (plus 30%) with respect to the reference mixture was detected, mainly due to a more effective filler effect of ground PMA with respect to the limestone powder used for the reference mixture;
- on the other hand, for the mixture prepared by fully replacing limestone powder with ground PMA, 30% higher drying shrinkage was measured, due to the higher fineness of ground PMA with respect to limestone powder.

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