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USE OF SEWAGE SLUDGE ASH(SSA)-CEMENT ADMIXTURES IN MORTARS

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ABSTRACT

The chemical composition of sewage sludge ash (SSA) and their sized fractions are studied, some differences in chemical composition are observed. SEM studies show irregular shape of SSA particles and sized fractions, this shape has a decisive influence on workability of mortars. The effect of replacing 15% of portland cement by SSA and their sized fractions: coarse (SSAC) and medium (SSAM) obtained by sieving on compressive (R_c) and flexural (R_f) strength of mortars was investigated. The study reveals an enhancement of strength when ashes are used, due to probably, pozzolanic properties of SSA.

Introduction

Although the use of waste materials and industrial by-products in construction is well known since a long time ago, in recent years has been specially studied. Scientist, engineers and technologists are continuously on the lookout for materials such as fly ashe and silica fume which can be used as substitutes for conventional cement and aggregates in concrete. The main reasons of this rising interest in using waste materials in construction are ecological, economical and technological reasons. The use of waste materials permits firstly, to remove them, to reduce costs and, in most cases, to improve the quality of conventional construction materials.

As a consequence of water treatment processes, a large amount of sewage sludge is produced, a part of it is used in agriculture as organic fertilizer and soil amendment. But continuous application of sewage sludge to land without appropriate management might have adverse impacts on human health and the environment (1). An alternative for sewage sludge disposal is to consider the use of this by-product in building materials. Dried wastewater sludge was mixed with clay to produce bricks (2) and "biobricks" (3), or pulverized and blended with Potland cement to produce mortars (4).

The most common sewage sludge disposal alternative is to incinerate and to deposit it in controlled landfills. However, space limitations on existing landfill sites, and increasing environmental concerns have prompted the investigation of alternative ash disposal routes. Sewage sludge ash (SSA) has been used to manufacture bricks (3), to incorporate into concrete mixtures (5,6), and as a fine aggregate in mortar (7). Moreover, Al Sayed et al (8) have studied the utilization of SSA in asphaltic paving mixes. The objective of the present research was to study Spanish SSA and their influence on strength and workability of cement-based mortars. SSA were obtained from sewage treatment plant of Pinedo (Valencia, Spain) that produces about 2,000 tons/year. Respecting periodic chemical composition values no information is available but is proper to think that homogeneus chemical composition is obtained because of sewage water for purifying has same chemical parameters.

Experimental

Materials. Portland cement used for mortar preparation was conforming to the specifications of ASTM type I. Fine aggregate was natural sand with 2,94 fineness modulus. SSA was collected from the sewage treatment plant of Pinedo (Valencia, Spain). Original SSA was separated in several sized fractions using sieves of 80, 40 and 20 µm. In order to obtain optimum conditions for sieving process (power level and sieving time) 250 g. of SSA was put into 80 µm sieve and measured the percentage of ash retained on 40 µm sieve varying sieving level power and sieving time. The results obtained are presented in figure 1. In this figure can be noticed a continuous increase of retained ash percentage for sieving level powers 5 and 6 when sieving time is modified between 0-60 minutes. A different behaviour is observed for sieving level power 7, that no significative differences in retained ash percentage are observed for sieving times higher than 20 minutes. This experience makes clear that optimum conditions for obtained sized fractions were sieving level power 7 and 20 minutes of sieving time. No significative differences were observed when experience was repeated using SSA oven-dried at 105°C to uniform dryness.

Using optimum conditions, SSA was separated obtaining three sized fractions: the coarsest fraction, SSAC (retained on 80 µm sieve, 26% in weight), the medium-sized fraction, SSAM (retained on 40 µm sieve, 72%) and the finest one, SSAF (retained on 20 µm sieve,

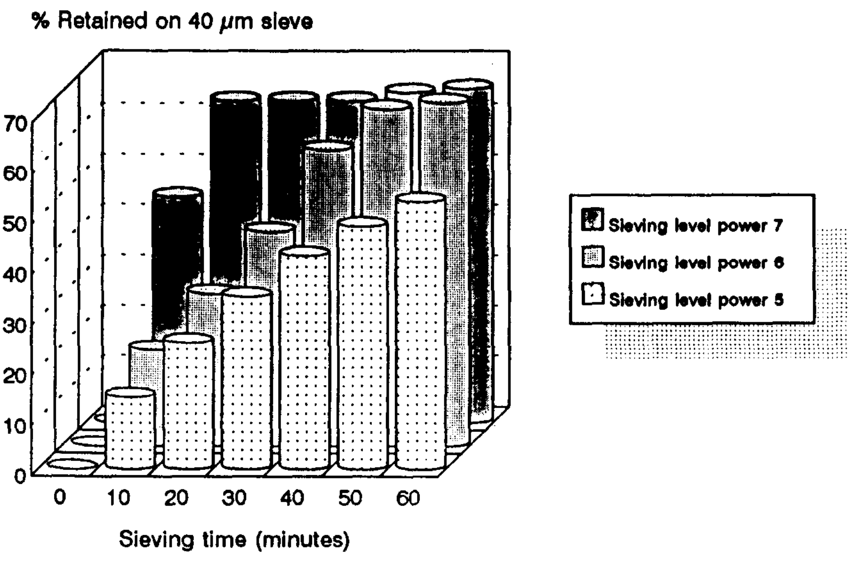

FIG. 1.
Retaining on 40 µm sieve development with level power and sieving time.

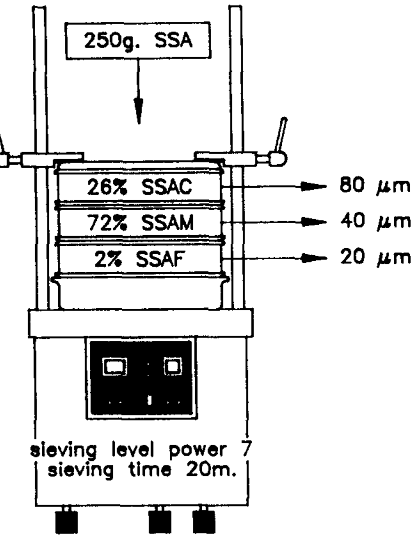

FIG. 2.
Scheme of sieving process.

2%). No significant amount of ash passed through 20 μm sieves. Figure 2 show, sieving optimum conditions, sieves used and sized fractions obtained.

In order to verify SSA size separation process granulometric distribution were registered (Figure 3). Significative differences among sized fractions and low differences between SSA and SSAM can be established. Table 1 shows SSA and sized fractions chemical data, from among these data can be emphasized the high concentration of sulfate in SSA (12.4% expressed in SO_3 content) and the increase of SO_3 content when fineness do. An irregular SiO_2 content in sized fractions can be observed, coarse fraction SSAC has double SiO_2 content that medium and finest fractions (SSAM and SSAF). Figure 4 shows SEM micrographs of SSA, these micrographs makes clear the irregular morphology of particles and the presence of crystalline aggregates (a, c, d). Micrograph b shows a wide range of diameters of particles. Shape of particles and granulometric distribution will have a decisive influence in workability of mortars.

Apparatus and Procedures: A digital electromagnetic sifter CISA with variable sieving level powers (1 to 10) was used for obtaining sized fractions. Particle size distributions were recorded using Malvern Mastersizer X Analyzer. Micrographs were obtaining in a Scanning Electronic Microscope (SEM), JEOL JSM-6300.

Mortar specimens cast in square prismatic mortar molds with internal dimensions of (40 x 40 x 160) mm were used. Preparation of mortars was carried out according to ASTM C-305 test (9), mixing 450 g. of portland cement, 1350 g. of natural sand, 4.5 g. of superplasticizer (commercial sulphonated condensate melamine formaldehyde) and 200 mL of water for control mortar and the rest of mortars replacing by mass a 15% of portland cement by SSA or sized fractions (SSAC and SSAM). SSAF fraction was not tested because of the low amount obtained (only 2% in weight). Mortars were put in a mold for obtaining specimens, which were stored in a moisture room (20 ± 1°C) for 24 hours. Afterwards, the specimens were demoulded and cured by inmersion in 40 ± 1°C water in order to activate the hydrata-

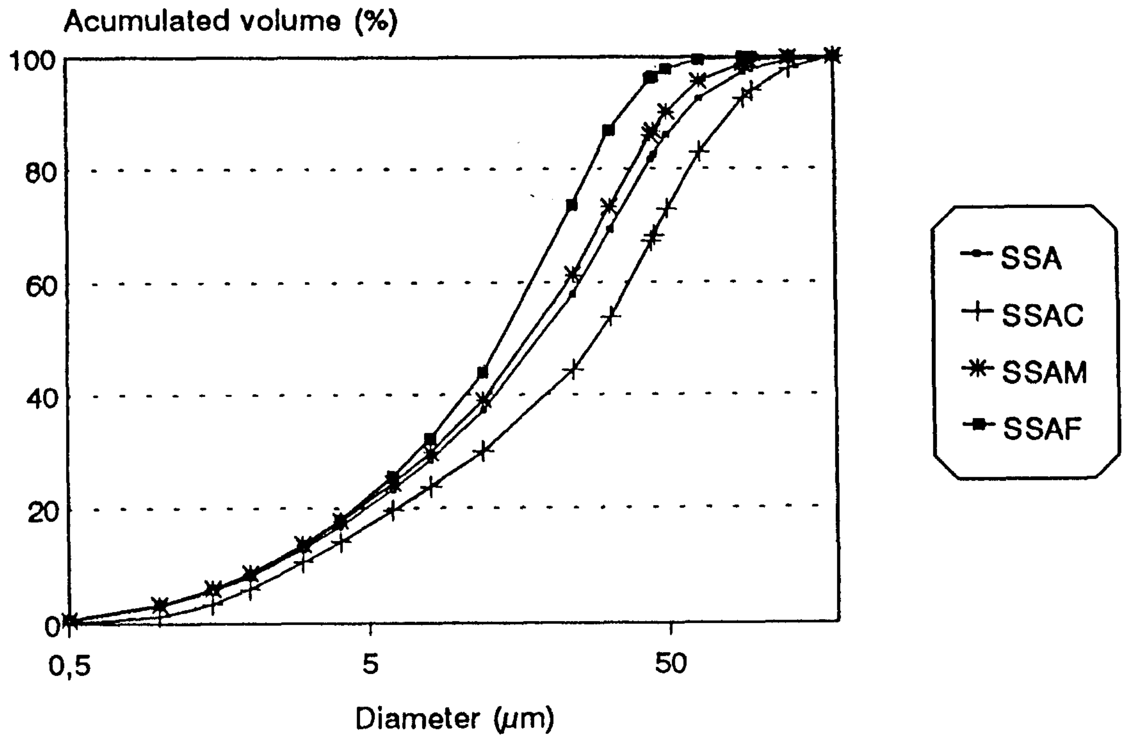

FIG. 3.
Granulometric distributions of SSA and sized fractions obtained by sieving (SSAC, SSAM and SSAF).

tion process until testing at 3, 7, 14 and 28 days. Table 2 shows weight composition of mortars for strength test.

Mortars for workability studies were prepared according to ASTM C-305 (9) test, mixing 450 g. of portland cement, 1350 g. of sand and varying water volumes between 200-225 mL for control mortar. The rest of mortars were prepared replacing 15% (in weight) of portland

TABLE 1
Chemical Composition of Original Sewage Sludge Ash (SSA), Their Sized Fractions (SSAC, SSAM and SSAF) and Portland Cement

%	Sewage Sludge Ashes				Cement
	SSA	SSAC	SSAM	SSAF	
Moisture	0.5	0.5	0.4	0.4	------
Loss on ignition	5.1	3.6	5.2	5.2	------
Insoluble Residue	16.1	28.0	11.7	11.3	------
SO_3	12.4	10.7	13.1	13.7	3.7
Fe_2O_3	7.4	7.1	8.2	8.3	2.2
SiO_2	20.8	30.1	16.2	15.5	20.4
CaO	31.3	25.9	32.9	32.1	64.9
MgO	2.6	2.2	2.4	2.6	1.8
Al_2O_3	14.9	11.9	14.7	14.0	5.8
P_2O_5	6..7	6.3	7.6	6.9	------

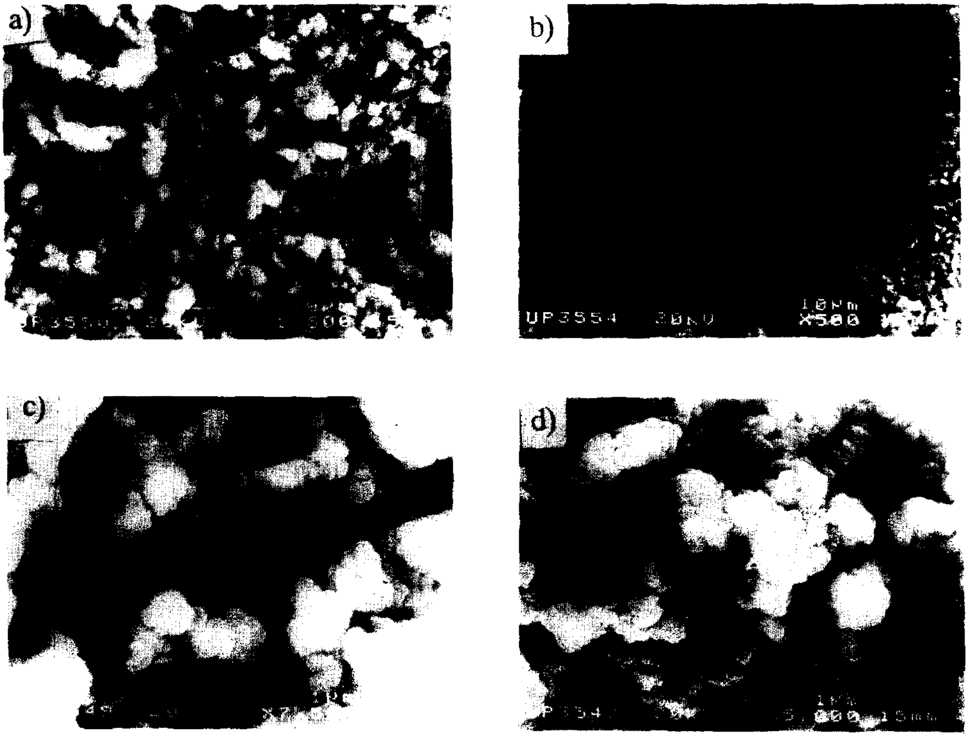

FIG. 4.
SEM Micrographs of SSA particles.

cement by SSA or sized fractions (SSAC and SSAM) and workability test were developed following ASTM C-109 (10) test. Table 3 shows weight composition of mortars for workability test.

Freshly prepared mortars were placed into a conic mold which is centered on the flow table. Mortar was put on two layers and compacted with a wooden tamper (10 times). Afterwards, the mold was removed and the table was dropped 15 times (one per second). Flow table spread (FTS) was given as a mean of maximum and minimum diameters of the spread cone.

Results and Discussion

Workability (FTS). The influence of SSA and sized fractions (SSAC and SSAM) on mortars workability has been studied. The results obtained are showed in figure 5. In this figure

TABLE 2
Weight Composition of Mortars for Strength Test

Cement (g)	SSA (g)	SSAC (g)	SSAM (g)
450	-	-	-
382.5	67.5	-	-
382.5	-	67.5	-
382.5	-		67.5

All mortars contain 200 mL of water, 1350 g of natural sand and 4.5 g of superplaticizer

TABLE 3
Weight Composition of Mortars for Workability Test

Cement (g)	SSA (g)	SSAC (g)	SSAM (g)	Water (mL)
450	-	-	-	200
450	-	-	-	208
450	-	-	-	216
450	-	-	-	225
382.5	67.5	-	-	200
382.5	67.5	-	-	208
382.5	67.5	-	-	216
382.5	67.5	-	-	225
382.5	-	67.5	-	200
382.5	-	67.5	-	208
382.5	-	67.5	-	216
382.5	-	67.5	-	225
382.5	-	-	67.5	200
382.5	-	-	67.5	208
382.5	-	-	67.5	216
382.5	-	-	67.5	225

All mortars contain 1350g of natural sand

can be observed a decrease of FTS when SSA or sized fractions are a part of mortar. This behaviour can be explained taking into account the irregular morphology of SSA particles (see figure 4), that do not permit the "lubricant effect" as occurs in fly ash-cement mixtures produced by spherical particles. On the other hand, adsorption of water molecules on surface of SSA particles could influence on free water content. Other experiences developed with coal fly ashes showed an increase of workability when portland cement was replaced by fly

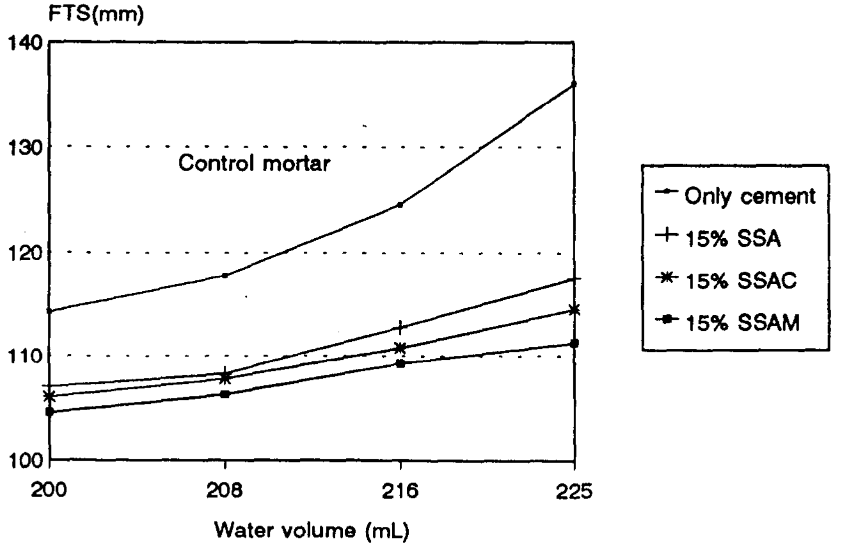

FIG. 5.
Correlations between flow table spread (FTS) values and water volumes for mortars containing 15% replacing percentage of ash.

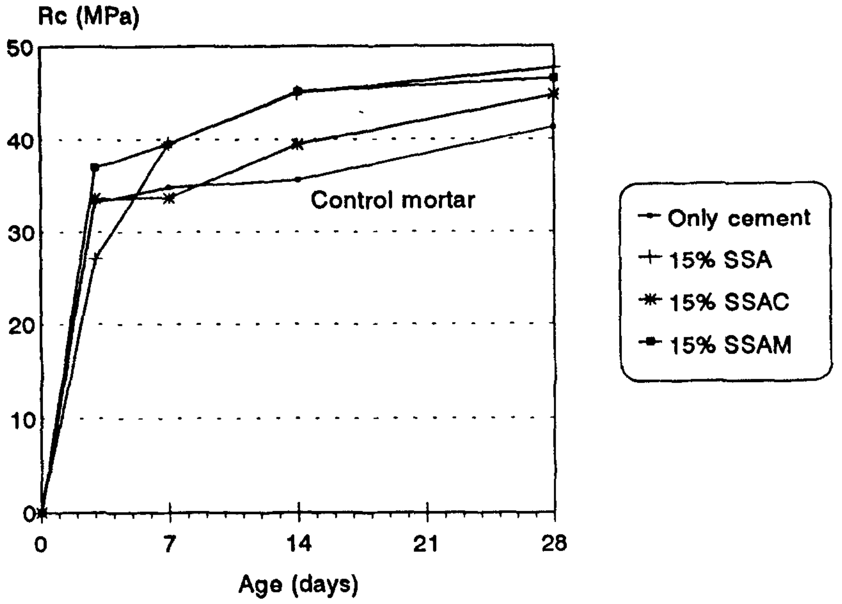

FIG. 6.
Compressive strength development for mortars containing 15% of ash cured at 40°C.

ashes (11). Additionally when fly ashes were ground (12) workability of ground fly ashes-cement mortars was being greater than control mortar; in the present case, workability of SSA-cement mortars is lower than cement mortars, indicating that morphology of SSA particles implies a more negative influence than portland cement particles. No significant differences were observed among mortars containing SSA and sized fractions (SSAC and SSAM) when low water volumes were added (200-208 mL). Higher water volumes (216-225 mL) showed little FTS differences, that do not permit to establish conclusions related with ash size particles.

TABLE 4
Percentage of Strength Respecting Control Mortar

	% Compressive strength respecting control mortar			
	3d	7d	14d	28d
15% SSA	-18.6	+13.5	+26.4	+15.3
15% SSAC	+1.2	-3.3	+10.8	+8.3
15% SSAM	+11.3	+13.4	+26.7	+12.5
	% Flexural strength respecting control mortar			
	3d	7d	14d	28d
15% SSA	-8.2	+4.1	+14.9	+4.9
15% SSAC	+6.9	+3.5	+22.9	+3.1
15% SSAM	+18.8	+11.9	+11.4	-1.4

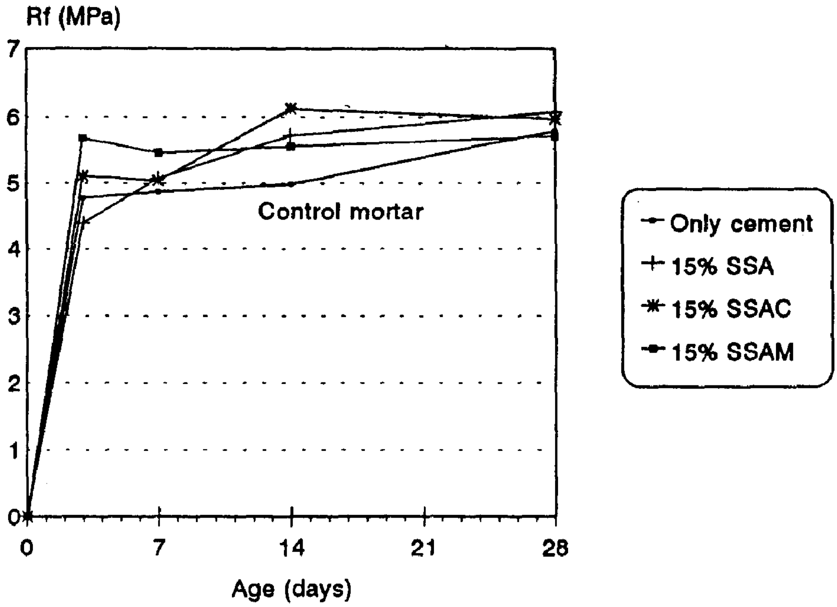

FIG. 7.
Flexural strength development for mortars containing 15% of ash cured at 40°C.

Compressive Strength Development (R_c). The influence of SSA and sized fractions on compressive strength of mortars has been studied. Mortars containing 15% of ash were cured at 40°C and tested at 3, 7, 14 and 28 days (figure 6). Preliminary and qualitative studies demonstrated that, in first place, SSA did not present autocementitious hardening, whereas, secondly, mixtures of $Ca(OH)_2$ -SSA hardened in few days. This behaviour indicated that SSA could present pozzolanic activity. The results obtained showed a sharp increase of R_c in the first three days of curing, for this age mortars containing 15% of SSAM exceed control

TABLE 5
Mean Values of Strength Including Standard Deviations

	Compressive Strength, MPa, (R_c±σ)*			
	3d	7d	14d	28d
Control mortar	33.2±1.5	34.8±1.2	36±2	41.4±0.8
15% SSA	27.1±0.7	39.6±0.5	45±2	47.7±0.4
15% SSAC	33.6±0.4	33.7±0.6	39.5±1.6	44.8±1.2
15% SSAM	37.0±0.5	39.5±0.8	45.1±0.7	46.5±0.8
	Flexural Strength, MPa, (R_f±σ)**			
	3d	7d	14d	28d
Control mortar	4.79±0.16	4.87±0.07	4.98±0.05	5.8±0.3
15% SSA	4.4±0.2	5.1±0.3	5.7±0.4	6.1±0.3
15% SSAC	5.1±0.2	5.0±0.2	6.1±0.3	6.0±0.5
15% SSAM	5.68±0.12	5.45±0.16	5.55±0.18	5.7±0.4

* Mean values of six specimens including standards deviations
** Mean values of three specimens including standards deviations

mortar. For 14 and 28 days curing time all the mortars containing SSA and sized fractions (SSAC and SSAM) exceed control mortar, this results makes clear the pozzolanic behaviour of these ashes. When R_c of mortars containing 15% of SSA, SSAC and SSAM are compared, can be stablished that R_c increases when fineness.

Flexural Strength Development (R_f). The influence of SSA and sized fractions on R_f of mortars has been studied (figure 7). Similar behaviour of R_c respecting control mortar was observed, but among mortars containing ash no defined tendency is observed. Table 4. shows the an increase or decrease of mortars stregth containing ash respecting control mortar. In the majority of cases the inclusion of ash produces a increase of stregth. Table 5. shows mean values of strength including standards deviations.

Conclusions

The following conclusions can be made from the studies carried out:

1. An irregular distribution of some chemical compounds like sulfates and SiO_2 among sized fractions was observed.
2. The shape of sewage sludge ash particles is not spherical like most of coal fly ash. This fact has a negative influence on workability of mortars containing SSA (no "lubricant effect" is produced). The range of volumes studied do not permit to establish significative workability differences among original ash and sized fractions.
3. A sharp increase of Rc in mortars containing SSAC and SSAM is observed for short curing times (3 days) exceeding control mortar. For higher curing times (14 and 28 days) all the mortars containing ashes exceeded control mortar. An increase of R_c is observed when fineness do. These results, make clear that pozzolanic reactions are possible in this kind of ashes.
4. No clear tendency is observed for R_f in mortars containing sewage sludge ashes, but in almost all the experiences developed mortars containing ash exceeded control mortar.

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