Utilization of municipal solid waste incinerator fly ashes to produce cellular mortars

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1. INTRODUCTION

Cellular mortars are produced mixing very fine siliceous sand, cement, lime, anhydrite, aluminum powder and water in weight proportion 40%, 9%, 9%, 1.5%, 0.5% and 40% respectively. Once the mass has been molded and sets, it is cured in autoclave. This curing with high pressure steam avoids excessive shrinkage of the mortar.

Typical density of cellular mortars is 400-800 kg/m^{3}and compressive strength between 3 and 10 N/mm^2. Low density and low thermal conductivity makes the main application of this material to be in external walls and roofing. These properties are achieved by the reaction between aluminum and lime, releasing hydrogen that generates pores in the fresh mass. Some municipal incinerator fly ashes could be used to produce cellular mortars, because in particular cases may contain aluminum, lime, sand and anhydrite. This paper presents the results of the mix design process carried out to produce a cellular mortar using as majority component a municipal incinerator fly ash.

2. MATERIALS

The fly ash used in this study came from a municipal incinerator with previous recycling system and fluid sand furnace. Table 1 shows the results of the chemical and physical characterization of the fly ash.

Table 1 Physical and Chemical characterization of the fly ash

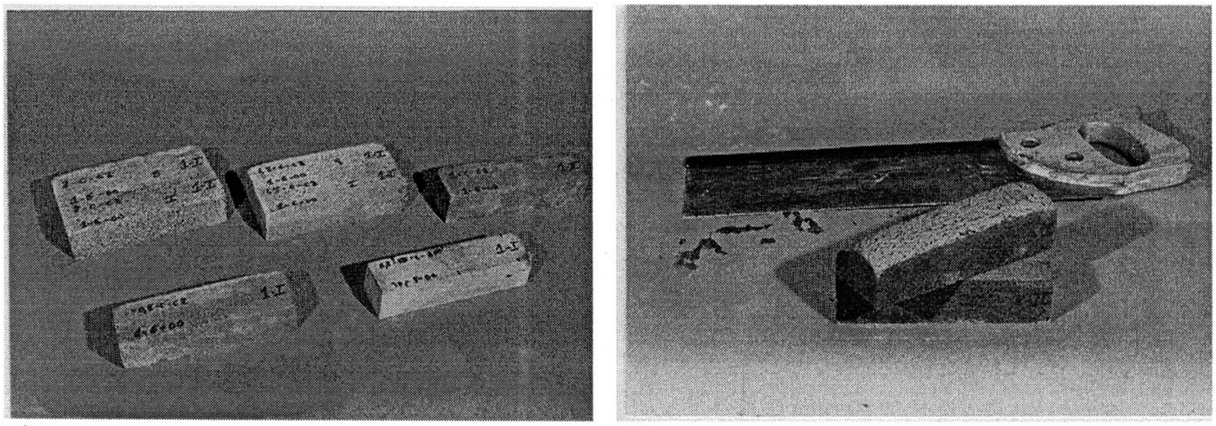
Sieve (mm)	%	P.F. (%)	2.52
5.0	100	Cl^- (%)	2.60
2.5	100	SO_3 (%)	2.94
1.25	100	SiO_2 (%)	22.92
0.63	100	CaO (%)	21.79
0.32	96.8	Al_2O_3 (%)	23.83
0.16	77.9	Fe_2O_3 (%)	17.59
0.08	43.8	MgO (%)	1.97
Density g/cm^3	2.83	Na_2O (%)	2.49
		K_2O (%)	1.74
Fineness 45 µm (%)	88.4	SiO_2 (%)	10.06
		CaO free (%)	0.80

Results of X-ray diffraction detected the presence of aluminum, anhydrite, quartz, calcite and portlandite, among others. The fly ash had no pozzolanic activity, as SiO_2 content came from the quartz of the sand used in the furnace.

3.- TEST PROGRAMME

The objective of the experimental programme was to find a mixture with density and compressive strength in the range of typical cellular mortars. Mixtures with different amounts of the components were tested: Sand from 0% to 50%, fly ash from 0% to 30%, water from 27% to 60% (percentages of mortar volume). In some mixes, lime was added in the same weight proportion of the cement. Mortars were mixed and tested for compressive strength according to EN 196 at 28 days of age.

Consistency of the mix was controlled with the shake table test. Some of the mixes exhibited a very fluid consistency not measurable, so they were described as “liquid consistency”. Over the moulds lateral walls were placed to contain the expansive mass. Final volume after the expansion, was more than twice the initial one for some mixes (Figure 1a). Specimens were stripped at 24 hours, and kept in water (20±2ºC). Those mixes with lime were kept in humidity chamber (20±2ºC, 95%). At the age of compressive strength test, specimens with high expansion were cut as can be seen in Figure 1b.



a) b)

Figure 1 a) Specimens with different expansions; b) cutting before compressive strength testing.

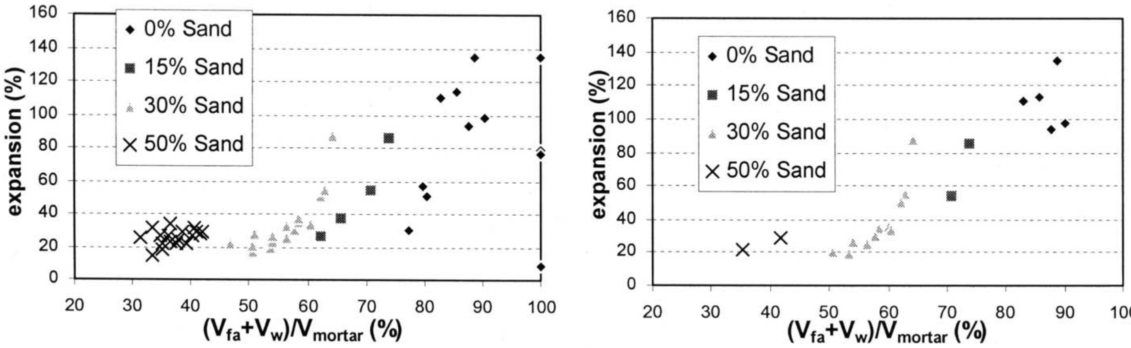
4.- STUDY OF THE EXPANSION

The expansion of the fresh mass must be maximum in order to obtain cellular mortars with very low density. In this chapter factors that influence on the expansion are described.

4.1 Expansive components

Sand, as an inert element, is the unique component of the mix that clearly does not collaborate with the expansion. Figure 2a) shows the increment of volume obtained with different amounts of sand in the mix. The expansion increases as the amount of sand in the mix decreases.

Also, in each sequence of results (same sand content), it can be observed that the expansion is higher as the content of fly ash and water increases. These means that the other two components used in the mix (cement and lime) do not contribute to generate the expansion.



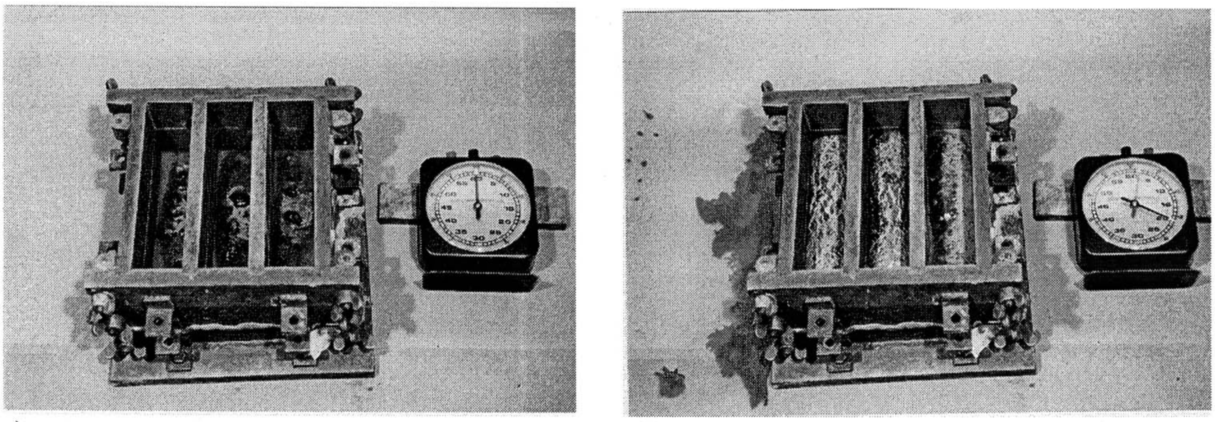
a) b)

Figure 2 a) Influence of fly ash + water in the expansion; b) only mixes with fluid consistency.

In deed, fly ashes are an auto-expansive material when mixed with water. Chemical reactions that produce the expansion are:

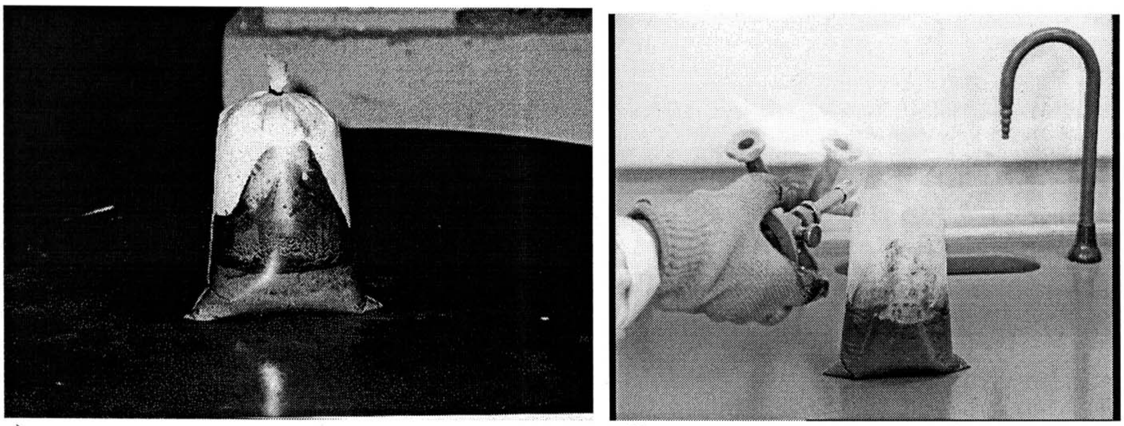
$$Al + NaOH + H_2O \rightarrow NaAlO_2 + 3/2\ H_2\uparrow$$
$$Al + KOH + H_2O \rightarrow KAlO_2 + 3/2\ H_2\uparrow$$

Metallic aluminum, Na_2O and K_2O are components of the fly ash, so only the addition of water is necessary. Hydrogen escapes from the fresh paste swelling the mass (Figure3). The release of hydrogen (inflammable gas) can be observed in Figure 4.



a) b)

Figure 3 a) Initial aspect of fly ash mortar; b) Final aspect after expansion takes place.



a) b)

Figure 4 a) The mix of water and fly ash releases hydrogen that inflates the bag; b) After cutting the bag, hydrogen can be inflamed.

4.2 Influence of the consistency

Results observed in Figure 2a) show that very different expansions can be obtained with the same content of expansive components (fly ash and water). These differences are due to a physical effect: the fresh mortar must have enough fluidity to allow the swelling when the gas escapes. A very stiff mass avoids the swelling. Figure 2b) selects only those mixes with fluid consistency (more than 170%), and the tendency to increase the expansion when the expansive components do is clear.

A big content of fly ash and water, and enough fluidity of the fresh mortar are the essential elements to get the minimum density.

5. STUDY OF THE COMPRESSIVE STRENGTH

Low density of the mortar must be accompanied of enough strength. In this chapter the influence on the strength of the different components of the mix is studied.

5.1 Influence of the fly ash content.

Figure 5 compares the water cement ratio curve of control mortars (no fly ash, no expansion) and curves obtained with different contents of fly ash. Only fly ash mortars with similar expansion (around 30%) have been selected, as this variable has an important effect on the compressive strength.

The compressive strength of fly ash mortars drops in low water cement ratios, consequence of the porosity created by the expansion. However, in high water cement ratios, there is an increase of strength in fly ash mortars, more when higher the fly ash content is.

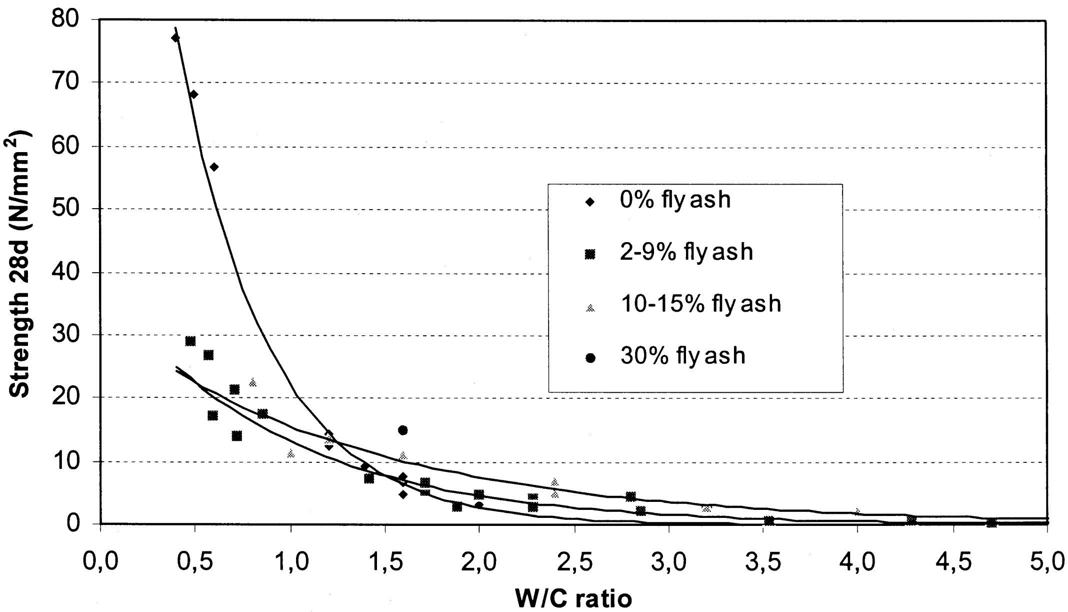


Figure 5 Water/cement curves for mortars with different fly ash content (mixes with 30% of expansion)

This means that fly ash improves the strength of mortars, and can even compensate the reduction due to the expansion in mixes with high water cement ratios. The origin of this contribution is the presence in the fly ash of some hydraulic components [4]: $2CaO.SiO_2$ and $3CaO\ Al_2O_3$.

5.2 Influence of lime

Figure 6 compares the strength results of mortars with and without lime. Between brackets there can be seen the corresponding expansion of the mix. Mortars with lime (even those with more expansion) reach higher strength than those without lime, for the same water/cement ratio. The mortar series with w/c = 1.6 shows the positive influence of the presence of lime on the strength and also the negative influence of the expansion on the strength.

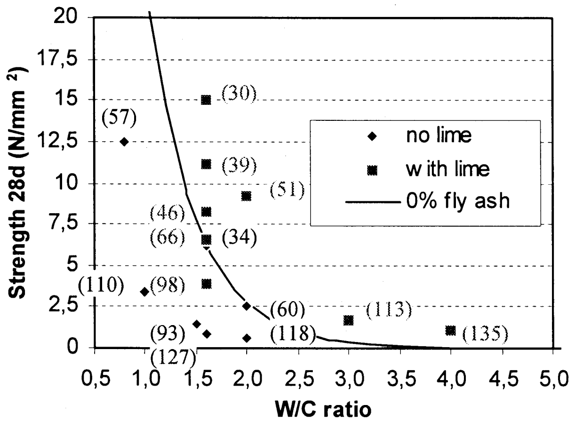


Figure 6 Influence of lime in strength. Values of expansion are shown between brackets.

5.3 Influence of sand

The best effect on strength and expansion simultaneously is obtained when sand is completely replaced by fly ash. Figure 7 shows results of strength and density in mortars with different substitution of sand by fly ash. Important increments of strength can be achieved, accompanied by an increase of expansion and so a low density, specially in mixes with not a very high w/c ratio.

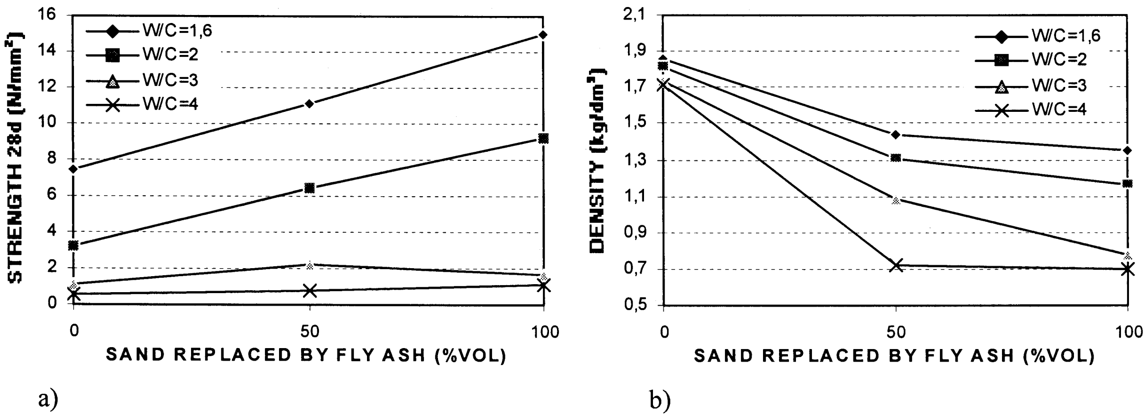


Figure 7 Influence of sand replacement by fly ash in the strength and density.

6.- FINAL ANALYSIS OF RESULTS

Table 2 summarizes the most relevant mixes in the process to obtain fly ash mortars with similar properties of the traditional cellular mortars:

1.- Complete substitution of sand by fly ash in the mortar achieves an important increase of strength, but consistency is negatively affected, so a moderate expansion is obtained.

2.- An increment in the water content, and so the cement content to maintain the w/c ratio allows a more fluid consistency that improves the expansion.
3.- More water is added with a better effect than in step 2.
4.- Partial replacement of lime by fly ash improves fluidity and also the expansion.
5.- An additional replacement of lime by fly ash increases even more the expansion, and a very low density is reached.
6.- The total elimination of lime is not recommended because of the substantial reduction of strength caused.

Table 2 Mix design process to achieve minimum density, and enough strength.

Nº	Cement (kg/m^3)	lime (kg/m^3)	Fly ash (kg/m^3)	w/c ratio	Fly ash vol.(%)	Consistency (%)	Expansion (%)	Density (kg/dm^3)	strength (N/mm^2)
0	296	296	0	1,60	0	90	0	1,64	5,3
1	296	296	801	1,60	30	60	30	1,18	11,8
2	316	296	696	1,60	26	100	39	1,09	8,5
3	341	296	570	1,60	21	120	46	1,02	5,7
4	341	236	641	1,60	24	145	66	0,88	4,4
5	341	149	745	1,60	28	149	98	0,74	3,3
6	340	0	922	1,60	35	L	127	0,67	0,85

7.- CONCLUSIONS

- Cellular mortars can be produced using municipal incinerator fly ashes as majority component.
- In these mortars fly ash and water are the expansive components.
- Mainly cement, but also the combination of fly ash and lime give the necessary strength.
- The mix design process has been detailed in the paper.
- Mortars with final dry density between 0.74 and 1.09 kg/dm^3 and strengths between 3.9 and 8.5 N/mm^2 have been obtained.

8.- FUTURE RESEARCH

There are technical and environmental aspects that must be covered in a future research:

- Mortars with lower density could be obtained introducing chemical admixtures in the mix.
- Other properties of these mortars must be studied: thermal conductivity, shrinkage, and effect of autoclave curing.
- Study on the leachates from the cellular mortar must be carried out.

9.- REFERENCES

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