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Hospital waste ashes in Portland cement mortars

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Abstract

Nowadays, most concretes incorporate mineral additions such as pozzolans, fly ash, silica fume, blast furnace slag, and calcareous filler among others. Although the technological and economical benefits were the main reasons for the use of mineral additions, the prevention of environmental contamination by means of proper waste disposal becomes a priority. The chance of incorporating hospital waste ashes in Portland cement-based materials is presented here. Ash characterization was performed by chemical analysis, X-ray diffraction, radioactive material detection, and fineness and density tests. Conduction calorimetry and setting time tests were developed on pastes including ash contents from 0% to 100%. Mortars were prepared including ash contents up to 50% of cement. The results of setting time, temperature development, flexural and compressive strengths, water absorption, density, and leachability are analyzed. Results indicate that Portland cement systems could become an alternative for the disposal of this type of ashes.

Keywords: Ashes; Heavy metals; Leachability; Portland cement; Waste disposal

1. Introduction

Nowadays, most concretes are prepared incorporating mineral additions in their composition. Different types of additions such as natural pozzolan, fly ash, silica fume, blast furnace slag, calcareous filler among others are usually included. Although the technological and economical benefits were the main reasons for the use of mineral additions, it is very important in many cases (specially with fly ashes) to prevent environmental contamination by means of proper waste disposal. Structural concretes have been designed including very high volumes of fly ash or blast furnace slag [1]. In this sense, Portland cement materials appear as an alternative for finding ecological solutions to safe disposal of waste materials [2,3].

Wainwright and Boni [4] reported results from laboratory tests on the use of sintered domestic refuse as aggregate in concrete. Berg and Neal [5] analyzed the possible use of municipal solid waste for the elaboration of concrete masonry. Ali and Chang [6] studied the strength and durability of bricks containing ash from incineration of municipal solid waste. Hamernik and Frantz [7,8] analyzed the characteristics of different municipal solid waste and the properties of concretes replacing up to 60% of cement by ashes. Detrimental effects of ashes on the setting time have been reported in accordance with the observations of Lavat and Trezza [9] on the influence of Pb in the inhibition of early cement hydration.

The influence of Cr, Ni, and Zn on the structure and reactivity of clinker phases was analyzed by Stephan et al. [10–12]. It was observed that these heavy metals have only minor effects on setting and hydration of cement mortars even at concentrations 10–20 times higher than those usually present in Portland cement. At very high concentrations of Cr, the rate of setting and hydration reactions increases and strength decreases. On the contrary, high contents of Zn delay setting and hydration and increase the strength. No significant effects were observed even incorporating high contents of Ni. Long-term leaching

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studies on municipal solid waste were performed by Andac and Glasser [13] and Hillier et al. [14] showing that toxic metals such as Sb, As, Cd, Cr, Hg, Ni, Pb, and Se were not detected probably due to a very low concentration into the cementitious matrix or to the formation of insoluble compounds that retain these metals. The environmental factors related to the waste disposal in concrete have also been discussed by Klich et al. [15].

It is evident that the problem of recycling and proper disposal of waste and by-product materials is a very important community priority to take into account.

This paper presents a study on the alternatives for incorporating ashes from hospital waste incineration in cement Portland-based materials. Results from ashes characterization, hydration processes on cement pastes, and the evaluation of the physical, mechanical, and chemical properties of mortars replacing up to 50% of cement with hospital waste ash are analyzed. Leachability of heavy metals from these mortars was also measured.

2. Experimental study

2.1. Ash characterization

Experiments were done using ash resulting from the incineration of hospital waste in a local facility in the La Plata area (Province of Buenos Aires, Argentina). Sample material was homogenized and sieved in the laboratory through a 2-mm mesh sieve. Table 1 shows the composition, density, and the particle size distribution of the ashes. The absence of radioactive material in the ash was verified. The results show that ash from local waste incineration contains Zn, Cr, Cu, Cd, and Pb in concentrations of 2.8, 107.6, 628.5, 6.2, and 490.3 mg/kg, respectively.

The analysis of Ca, Cd, Cr, Cu, Fe, Mg, Mn, Pb, and Zn was done using an atomic absorption spectrophotometer (Varian SpectraAA) with air–acetylene flame according to standard techniques previous acid sample digestion [16]. In the case of Al, nitrous oxide–acetylene flame was used. The content of K and Na was performed with the same instrument using the emission mode.

Chloride content in the acid digest was analyzed by an argentometric method [17]. The content of Si by the molybdosilicate test [18] and NO3- by the UV selective method [19] was performed using a UV-visible Shimadzu 1203 instrument. Concentration of PO_4^{-3} and $SO_4^{=}$ was measured by the gravimetric techniques [20]. Chemical analysis was done using the ash fractions below 300 μm. Moisture content was determined to constant weight at 100 °C. Loss on ignition at 550 and 850 °C was also measured.

Ash X-ray diffraction analysis was performed by an RX Rigaku, D-max III C equipment with Cu radiation and graphite monochromator (35 kV and 15 mA). It appeared as an amorphous material and the mean peaks detected correspond to $CaSO_4$ (S), quartz -SiO_2- (Q), $CaCO_3$ (C), hematite (H), feldspars (F), and traces of Portlandite $Ca(OH)_2$ (P).

Table 1
Physical properties and chemical analysis of the ash

Physical properties		Compound	Content (%)
Particle size distribution		CaO	33.18
Sieve number	Pass (%)	MgO	2.81
		Al_2O_3	14.34
		Fe_2O_3	4.64
8	100	MnO_2	1.41
16	83	Na_2O	3.64
30	67	K_2O	0.6
50	49	SiO_2	0.39
100	32	Heavy metals	0.56
Moisture content	7.53	(ZnO>CuO>PbO>Cr_2O_3>CdO)	
		$SO_4^{=}$	4.10
		Cl^-	0.96
		NO_3^-	0.65
Density	2.5	PO_4^{-3}	1.10
		$CO_3^{=}$ (from LOI)	17.47

Table 2
Physical properties and chemical analysis of cement

Physical properties			
Retained # 75 μm (%)			3.1
Specific surface area Blaine m^2/kg			327
Water for normal consistency (%)			24.3
Setting time (h:m)	Initial		03:05
	Final		04:05
Compressive strength (MPa)	1 day		11.8
	7 days		34.4
	28 days		43.9
Autoclave expansion (%)			0.02
Chemical analysis			
SO_3 (%)	2.70	Heavy metals (%)	
CaO (%)	64.55		
MgO(%)	0.52	Cd	0.00025
Na_2O (%)	0.05	Cr	0.00200
K_2O (%)	1.08	Cu	0.00100
Fe_2O_3 (%)	4.03	Pb	0.00050
SiO_2 (%)	21.28	Zn	0.00405
Al_2O_3 (%)	3.96	Total	0.0078
Loss on ignition (%)			1.43
Insoluble residue (%)			0.31

2.2. Studies on cement pastes

2.2.1. Materials and methods

Two series of pastes (p1 and p2) were prepared using normal Portland cement (Type I ASTM) and content of ashes variables from 0% to 100% of cement to study the hydration and setting processes. Physical properties and chemical analysis of the cement are given in Table 2.

Series p1 was prepared to analyze the development of the hydration heat. A conduction calorimeter [21] was used recording data in continuous way for 72 h. The pastes were made using 20 g of binder and 10 g of

Table 3
Cement–ash pastes: heat of hydration (Series p1) and setting time (Series p2)

Pastes	Ash content	w/c	w/(c + a)	Tests performed	
Series p1				Heat of hydration (J/g)	
				1 h	72 h
p1	0%	0.50	0.50	2.7	164
p1-25A	25%	0.66	0.50	4.5	174
p1-50A	50%	1.00	0.50	4.9	157
p1-85A	85%	3.33	0.50	6.3	119
p1-100A	100%	–	0.50	5.1	124
Series p2				Setting time (h:m)	
				Initial	Final
p2	0%	0.23	0.23	1:50	5:10
p2-25A	25%	0.36	0.27	3:00	5:50
p2-50A	50%	0.66	0.33	3:00	6:15
p2-85A	85%	3.13	0.47	3:15	10:00
p2-100A	100%	–	0.48	3:20	10:20

distilled water and ash contents of 0%, 25%, 50%, 85%, and 100% (Table 3).

Series p2 was prepared to evaluate the setting time according to ASTM C 191-99 [22]. Again, ash contents of 0%, 25%, 50%, 85%, and 100% were used. Water was added until a penetration of 10 ± 1 mm was obtained. Then, the water/(cement + ash) ratio [w/(c + a)] varies from 0.23 to 0.48, increasing as ash content increases (see Table 3).

2.2.2. Results

The results of accumulated heat of hydration are plotted in Fig. 1. It can be seen that after the binder is in contact with water, there are some reactions during the first hours even before temperature elevation corresponding to cement hydration starts. It must be noted that paste incorporating 25% of ash (p1-25A) shows greater heat development than the paste without ashes.

Initial and final setting values (Vicat) are included in Table 3. Each value is a mean of three determinations. It can be seen that the initial setting times are similar despite the differences in the w/(c + a) ratios of the pastes. On the contrary, the values of final setting time reflect the lower strength development of the pastes as ash content increases.

In Series p2, it was also observed that the volume and temperature of the pastes increase during setting. Some difficulties to define setting time appear, as there are heterogeneous hardened nuclei probably due to the development of alkaline sulphates. In paste p2-100A, it was difficult to follow the setting. The measurements were continued until 30 h but after 20 h, although it was stiff, the needle continue to impress the surface.

2.3. Studies on mortars

2.3.1. Materials and methods

Two series of mortars with different w/(c + a) ratios were prepared (m1 = 0.35, m2 = 0.50) replacing 10%, 25%, or 50% of the weight of cement by hospital waste ashes. In each case, a reference mortar (without ash) was included. The same Portland cement and natural siliceous river sand were used. For the lowest w/(c + a) ratio, a naphthalene-based superplasticizer was added. Mortars were prepared using conventional techniques in a Hobart mixer. Mixture proportions of the mortars are presented in Table 4.

To analyze the effect of the inclusion of ashes on the cement hydration process, the increase of temperature during the first hours and setting time were measured. Different specimens were cast to study the behavior of hardened mortars. All of them were stored in individually sealed containers at 20 °C over a layer of distilled water to keep the samples saturated until the ages of testing. The evaluations included flexural and compressive strength, absorption, density, and water permeability. With the aim of analyzing the environmental impact of the incorporation of the ashes in cementitious materials, leaching tests and chemical analysis of the collected water that passed through the samples during the permeability tests were performed. Finally, mortars m2, m2-25 y m2-50, were repeated to develop long-term leaching tests.

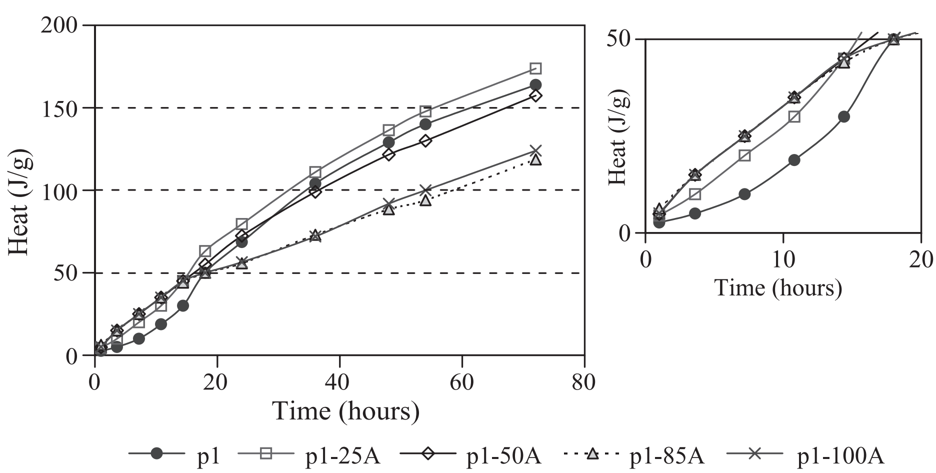

Fig. 1. Accumulated heat of hydration. Series p1.

Table 4
Mortar mixture proportions

Mortar	w/(c + a)	Ash (g)	Cement (g)	Sand (g)	Superplasticizer (ml)	Water (ml)
m1	0.35	–	1400	2800	10.0	490
m1-A10		140	1260		8.3	
m1-A25		350	1050		33.6	
m1-A50		700	700		27.7	
m2	0.50	–	1200	3300	–	600
m2-A10		120	1080	3300		
m2-A25		300	900	3300		
m2-A50		600	600	3050		

The evaluations on Series m1 and m2 are described as follows.

2.3.1.1. Evolution of temperature and setting time. The evolution of temperature was measured on samples of 600 cm^3, placed in a thermally isolated container, with a thermocouple immersed in the center to record the elevation of temperature during the first 30 h. Measurements were done every 30 min with sensitivity of 1 °C. The setting time of mortars was measured by a penetration test according to ASTM C 403 [23].

2.3.1.2. Flexural and compressive strength. Prisms of 4 × 4 × 16 cm were cast for the evaluation of flexural and compressive strength at the ages of 28 and 110 days [24]. The flexural strength was measured using middle point loading configuration with a span of 10 cm. Each value was calculated as a mean of three tests. After this test, compressive strength was determined on four of the halves resulting from the first test.

2.3.1.3. Absorption, density, and air content. The evaluation of the absorption (24 h in water) and density was performed on cubes of 4 cm following the guidelines given by ASTM C 127 [25]. Air content was obtained using the gravimetric method (ASTM C 138 [26]).

2.3.1.4. Leaching test. Crushed and sieved samples from 110 days specimens used for compressive strength and fly ashes were extracted in acetic acid aqueous solution kept at pH 5.5 during 24 h shaking according to a standard procedure [27]. Analysis of heavy metal content in the aqueous extract was performed by the same method as previously described.

2.3.1.5. Water permeability. Specimens 150-mm diameter and 25-mm height were cast with the aim of analyzing the effect of ash incorporation on the permeability of mortars. The coefficient of water permeability and the amount of metals that can be dissolved by the flow of water through the mass of mortar were measured. Permeability tests were performed based on the general guidelines of RILEM recommendation CPC-13.1 [28] Rubber joints were interposed between both ends of the specimens and the steel plates to assure water tightness. To determine the coefficient of permeability of concrete, the samples were exposed to a pressure of 0.015 MPa. They were covered at the sides with an epoxy paint to avoid losses due to radial flow that could lead to mistakes in the calculation of the permeability coefficient.

2.3.1.6. Long-term leaching tests. Mortar cubes of 7 cm side were cast. Each mould was covered inside with a clingfilm (non-demoulding oil was used to avoid contamination of the sample surface). After demoulding, each sample was covered with a film and maintained in a moist room (95% RH, 23 °C). At 28 days, each specimen was immersed inside a separate container (4 l) with different solutions. Three aqueous media were adopted simulating different environments: distilled water (as pure water), distilled water + air bubbling (rainwater), and distilled water + salts (seawater). The analysis of the heavy metals content was done on leachate samples extracted at 6 and 24 h and 4, 16, 64, and 256 days.

2.3.2. Results

No significant effects were observed by the incorporation of ashes on workability of mortars. The specimens were cast and compacted without problems. However, some increases in the superplasticizer content were necessary for the lowest w/(c + a) ratio. In the case of m2-50A mortar series, it was necessary to make some reductions in the sand content. A notable amount of air was incorporated when ashes were included, which strongly increased as ash content increased. As it will be discussed later, in the case of the highest ash contents, an important temperature elevation and material expansion had taken place during the first hours after mixing. This fact is coherent with previous observations

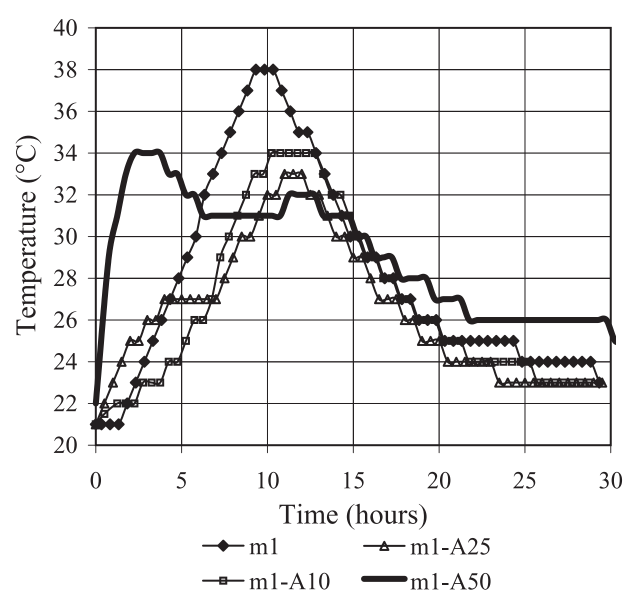

Fig. 2. Evolution of temperature during the first hours. Series m1, w/(c + a) = 0.35.

Table 5
Physicomechanical properties of mortars

Mortar	IST (h:m)	FST (h:m)	Density	Abs (%)	Air (%)	MR (MPa)		f′c (MPa)	
						28 days	110 days	28 days	110 days
m1	04:10	05:30	2.12	7.3	9.4	9.3	11.4	56.6	63.9
m1-A10	06:05	08:10	1.94	8.6	16.7	6.0	7.1	26.2	33.7
m1-A25	06:55	09:20	1.80	9.4	21.4	4.4	5.4	17.6	21.0
m1-A50	06:05	11:50	1.72	9.8	24.3	4.1	4.7	14.0	19.7
m2	06:00	08:35	2.12	8.2	7.0	8.4	8.4	39.9	41.8
m2-A10	06:20	10:05	1.88	9.8	17.2	4.9	5.9	20.1	24.3
m2-A25	08:50	12:45	1.74	10.8	23.0	3.8	4.9	11.7	17.1
m2-A50	08:45	13:50	1.67	10.9	24.4	2.9	4.4	8.9	13.5

IST = initial setting time, FST = final setting time, MR = modulus of rupture, f′c = compressive strength, Abs = absorption.

on pastes (it must be assumed as a consequence of the ash composition, specially the Al content).

Some efflorescences of calcium products were detected on the surface of the specimens after demoulding. The amount of these efflorescences increased as ash content increased.

Regarding the measurement of the evolution of temperature during the first hours, it is interesting to note that in mortars incorporating ashes, it was possible to observe a peak of temperature previous to the one corresponding to cement hydration. This peak was accompanied by an expansion, which was more significant as w/(c + a) ratio decreased and as the percentage of cement replaced by ashes increased.

As an example, Fig. 2 shows the evolution of temperature with time corresponding to Series m1 [w/(c + a) = 0.35]. It can be seen that the peak of temperature corresponding to the hydration of cement decreased as the percentage of ash increased. On the contrary, the peak of temperature produced by the reaction of the ash (first peak) clearly increased with ash content. In the case of m1-A50, the first peak was even 2 °C higher than the second one.

In the series of mortars m2 [w/(c + a) = 0.50], the first peak of temperature elevation corresponding to the ash reaction was observed only in mortar m2-50A. This peak was not evident in mortars with 10% of ashes of both series. The time corresponding to the ash reaction peak ranged between 1 and 4 h; the peaks corresponding to cement hydration appeared between 8 and 11 h after mixing.

Table 5 shows the physicomechanical properties of mortars including the values of initial and final setting time. There was a delay in the time of setting as the ash content increased, and as it was expected that the setting took place earlier in Series m1 with the lowest w/(c + a) ratio. The table also shows the results of flexural and compressive strength at the ages of 28 and 110 days. It can be seen that the incorporation of ashes decreased the strength, being very significant of the loss as the percentages of replacement increased.

When the results of density and absorption are compared (each value is the mean of two specimens, determined at the age of 110 days), it can be seen that as ash content increased, water absorption increased and density diminished. Finally, Table 5 also includes mortars air content; there was a very important increment in the percentage of air as cement was replaced by the ashes, increasing the porosity with the amount of ashes in accordance with the decrease in strength.

Table 6 shows the results obtained from leaching test. It can be seen that the values of Cr, Cd, and Cu measured on mortars were similar to those corresponding to ashes themselves, but there was a slight decrease in Pb content and a strong decrease in Zn content.

The coefficients of permeability (k) measured during the first 24 h are also shown in Table 6. As there was a great variability of results in the determinations made on different specimens of each type of mortar, a range of variation of each coefficient is presented. It can be seen that the incorporation of ashes strongly affected the permeability of mortars, obtaining very high coefficients. It must be noted that it was not possible to establish a tendency produced by ash content or even by w/(c + a) ratio (it is well known that the coefficient of permeability decreases as water/cement ratio decreases) as there are important internal defects as it will be discussed later. In the cases of reference mortars or some low-ash content (10%), no water passed through the specimens.

Table 6
Chemical analysis of water after leachability and permeability tests and coefficients of permeability

Sample	Cd (mg/l)		Cr (mg/l)		Cu (mg/l)		Pb (mg/l)		Zn (mg/l)		K (10^{-9}m/s)
	L	P	L	P	L	P	L	P	L	P	
Cement	0.08	–	0.8	–	0.3	–	0.9	–	0.66	–	–
Ash	0.04	–	0.2	–	0.1	–	0.9	–	50	–	–
m1	0.03	np	0.2	np	0.1	np	0.5	np	< 0.02	np	–
m1-A10	nm	< 0.02	nm	0.1	nm	0.5	nm	< 0.25	nm	< 0.02	np-10
m1-A25	< 0.02	< 0.02	0.1	0.1	0.3	< 0.1	0.6	< 0.25	0.3	0.04	6-10
m1-A50	0.04	< 0.02	0.1	0.1	0.7	0.1	0.7	< 0.25	1.3	0.13	150-300
m2	0.03	np	0.2	np	< 0.1	np	0.3	np	0.03	np	–
m2-A10	0.02	np	0.2	np	< 0.1	np	0.3	np	0.04	np	np-4
m2-A25	nm	0.02	nm	0.4	nm	1.5	nm	0.25	nm	0.78	2–6
m2-A50	0.03	< 0.02	0.4	< 0.1	0.1	< 0.1	0.3	< 0.25	0.15	< 0.02	25-300

L = leachability test, P = permeability test, K = coefficient of permeability, nm = not measured, np = no water passed through the specimen.

Finally, the chemical analysis of the collected water was made and the results are also given in Table 6. The content of heavy metals determined was lower than those obtained in the leaching test, especially Zn and Pb. In the case of Zn, it decreased in more than one order. This last behavior could be attributed to the formation of an insoluble $Zn(OH)_2$. It must be mentioned that the chemical analysis was made on water collected during the first hours of the test.

3. Discussion

Chemical analysis shows that the total content of heavy metals (Zn>Cu>Pb>Cr>Cd) in the ashes is 0.40% w/w. The most leachable metals are Zn and Pb. Comparing the concentration of Zn in the leachate of the ash alone and in the leachate of the different mortars, it appeared a significant reduction when mortars were analyzed, being Zn concentrations 50 mg/l and less than 1.3 mg/l, respectively. This difference can be explained considering that, in accordance to Lavat et al. _Hlt39323695 [9] and Poon et al. [29], significant proportions of Zn were fixed. In water collected by means of the permeability test, the concentration of heavy metals was generally lower than that one resulting from leaching tests. The contents of Pb and Zn are especially reduced.

In general, as the percentage of cement replaced by ashes in mortars increased, the leachability of heavy metals also increased. Nevertheless, the values of leachability of mortars were always lower than the established limits [30] for Zn: 500 mg/l, Cu: 100 mg/l, Pb: 1 mg/l, Cr: 5 mg/l, Cd: 0.5 mg/l.

It must be mentioned that the analysis of heavy metals of the long-term leaching tests during the first 64 days indicates a very low metal content in the leachate (Zn < 0.01 mg/l, Cu < 0.1 mg/l, Pb < 0.2 mg/l, Cr < 0.1 mg/l, Cd < 0.02 mg/l).

The results of conduction calorimetry tests and setting time performed on cement–ash pastes agree with the studies on mortars. They show that there are ash–water reactions previous to the development of cement hydration.

As it was said, setting time increased as ash and water contents increased. It is interesting to note that although final setting time always increased with ash content, the initial setting did not increase in the case of mortars incorporating 50% of ash. This fact is indicating that the reaction of the ash is contributing to the stiffening of the paste. At the same time, the delays produced in mortars with lower water binder ratio were the greatest.

Related with the development of the different reactions that take place in the cement pastes and mortars appears the evolution of temperature. Conduction calorimetry tests clearly indicate the ash reaction in contact with water. It was evident that this can accelerate the cement reaction when both materials are combined.

As it was mentioned, in mortars incorporating ashes, it was possible to observe a peak of heat previous to the one corresponding to cement hydration, indicating a reaction with the ashes. In this way, two peaks can be detected in the curves. The peak of temperature corresponding to the hydration of cement (second peak) decreased as the percentage of ash increased and it appeared later. On the contrary, the peak of temperature produced by the reaction of the ash (first peak) clearly increased with ash content. This peak was not evident in mortars with 10% of ashes.

In reference mortars, it was verified a good correlation between the starting of heat elevation and the setting time. In the cases of mortars incorporating ashes, the correlation was no longer present.

Four additional mortars prepared with the following binders were made: 100% ash, 50% ash–50% cement, 100% lime [$Ca(OH)_2$], and 50% ashes–50% lime; all of them with a water/binder ratio of 0.35. Fig. 3 shows the obtained results. It is evident that there was a specific reaction that is verified in the mortar with 100% of ash. After 48 h, this mortar appeared rigid with the difference of the mortar prepared with 100% lime as binder, which remained plastic. Nevertheless, the strength developed by the 100% ash mortar was very low. On the other hand, comparing Figs. 2 and 3, the behavior of mortar 50% cement–50% ash (m2-A50) is verified.

Fig. 4 shows for each water/cementitious material ratio the variation of flexural and compressive strength with ash content measured at the ages of 28 and 110 days. The inclusion of ashes notably reduced the strength of mortars, varying the loss of strength in a nonlinear way with the percentage of ash. Regarding this tendency, it appears that the use of very low contents of ashes (10%) is not a very good option, as the reductions of strength in these cases were near 50%. These important decreases in strength produced when low percentages of ash were incorporated

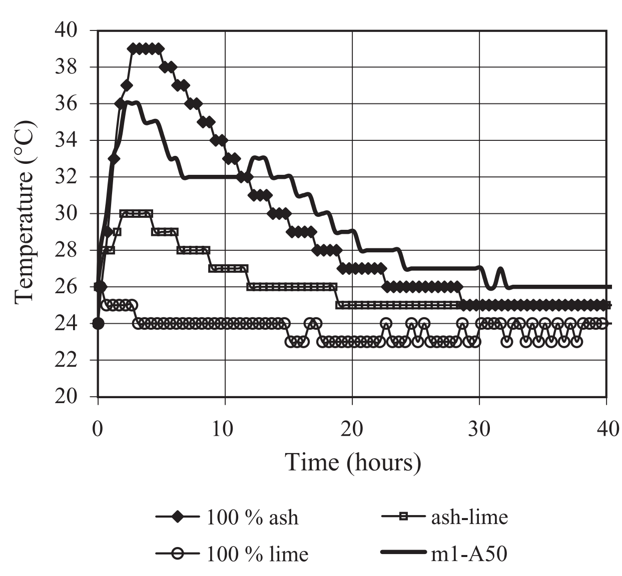

Fig. 3. Evolution of temperature during the first hours in mortars prepared with different types of binder (100% ash, 100% lime, 50% lime–50% ash, 50% cement–50% ash).

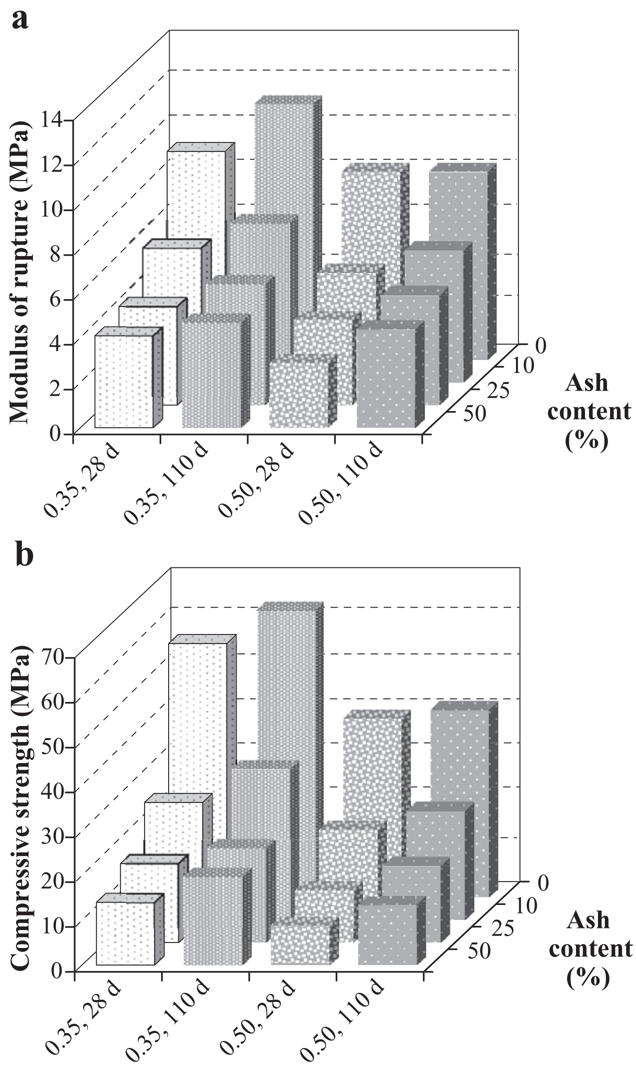

Fig. 4. Variation of flexural and compressive strength with ash content.

are due to the presence of big defects and voids generated by the reactions of the ash in the cementitious system. It is verified that as the volume of ashes increased, water absorption also increased and density decreased, which is coherent with the results of strength. However, it must be noted that mortars with compressive strength levels near to 10 MPa at 28 days can be prepared; this indicates that many practical alternative applications could be performed like masonry, blocks, filling mixtures, etc.

The reaction of the ash affected the development of cement hydration and increased the porosity and voids of the system. As there appeared big defects (voids), the absorption is not so affected as the strength. As a result of this kind of defects, there is great variability in the internal structure and consequently in the permeability. Although the amount of leached metals do not appeared as dangerous, it is clear that the permeability can increase in two or three orders of magnitude with respect to a mortar without ashes where coefficients of permeability are usually in the order of 10^{-11} m/s. In mortars incorporating ashes, the coefficients of permeability were over 10^{-9} m/s. In Portland cement mortars and concretes, the coefficient of permeability diminished with time due to the swelling of some hydration products. In this case, important decreases appeared during the first hours. It is important to note that in these experiments, it was necessary to adopt for the permeability tests pressures lower than those used to test conventional concretes and mortars (0.2–0.5 MPa). As it can be observed in Table 6, the coefficients of permeability of mortars with $w/(c+a)=0.35$ were higher than those corresponding to $w/(c+a)=0.50$. Although the original system had very low porosity, the higher unitary content of binder enhanced the potential reaction with the ash generating more defects. In addition, as it was mentioned, in this group of mortars, there was a greater increase in temperature, expansions, followed by stiffening, and generation of voids during the first peak of temperature, which lead to great variability of its physical properties, especially the permeability.

These observations have been confirmed by other tests performed on similar mortars prepared with other two different types of cement.

4. Concluding remarks

The results of the chemical analysis and the physicomechanical properties of the mortars are indicating that Portland cement systems could become an alternative for the disposal of ashes from the incineration of hospital waste. Nevertheless, it is evident that very important aspects as the variability in the characteristics of the ashes and their effects on mortars and concretes must be more deeply analyzed. Particularly, it is considered necessary to continue with the durability studies of mortars incorporating this kind of ashes.

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