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Enhanced conductivity measurement techniques for evaluation of fly ash pozzolanic activity

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Abstract

Evaluation of pozzolanic activity of low-lime fly ashes was carried out by means monitoring of conductivity of fly ash suspensions in calcium hydroxide solution. Contribution of soluble salts from fly ashes to conductivity may be taken into account for evaluating pozzolanic properties of fly ashes. The pozzolanic activity was calculated as the percentage of loss in conductivity, %LC, prior the corresponding salinity correction, at several reaction times (100, 1000 and 10 000 s) and at different reaction temperatures (40°C, 60°C and 80°C). Considerations about the influence of hydrated lime/fly ash ratio in conductivity measurements have been described, and 0.04:1 ratio was proposed for yielding best results. Finally, no suitability of the proposed methodology for high-lime fly ashes was demonstrated. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: $Ca(OH)_2$; Fly ash; Pozzolan; Conductivity

1. Introduction

Evaluation of pozzolanic properties of finely divided materials can be carried out by several procedures and using different techniques. For some techniques, a long period of testing is required, for example, when pozzolanic activity of fly ashes is determined by means of compressive strength development with time of fly ash/hydrated lime or fly ash/cement paste, mortar or concrete [1–4], as well as by determination of calcium hydroxide content by thermal analysis techniques [5] in the above mentioned mixtures. The pozzolanic reaction can be achieved when cement or lime mixes are cured at higher temperatures. In this manner, the test period for determining pozzolanic activity is decreased. Thus, Tashiro et al. [6] proposed a method for evaluating pozzolanic activity by measuring the electric resistance of cement pastes containing a pozzolan. The experiment was performed under steam curing at 70°C and only 72 h for testing were required.

For another group of techniques, a very short period of testing is required and, consequently, becomes very useful tests for a rapid evaluation of pozzolanic activity of some materials.

Sharma et al. [7] proposed a semitheoretical method in which an empirical correlation between pozzolanic properties of fly ashes determined by compressive strength of mortars, and fineness and soluble silica content of fly ash.

Raask and Bhaskar [8,9] applied conductimetric technique as indirect method for evaluating pozzolanic activity of fly ashes. In this method, electrical conductivity of a suspension of the pozzolan in 0.1 M hydrofluoric acid (HF) solution was monitored. The electrical conductivity increasing was correlated to silica solubility. This method requires 10 min monitoring time for obtaining the rate coefficient of dissolution as the pozzolanic index, which can be used to select fly ashes for use in concrete mixes.

In 1989, Luxán et al. [10] proposed a very simple, rapid and brilliant method, also based on electrical conductivity measurement of aqueous suspensions for evaluating the pozzolanic activity of natural pozzolans (NPs). These authors starting out from the measurements of the conductivity variations of natural pozzolanic materials in different aqueous media and taking into account the theoretical

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Table 1
Sources and physical characteristics of fly ashes

Fly ash	Location of the thermoelectric power plant of origin	Blaine fineness (cm^2/g)	Specific gravity (kg/m^3)	ASTM C-618 type
FA1	Andorra-Teruel (Spain)	3000	2520	F
FA2	Pasajes-País Vasco (Spain)	3560	2060	F
FA3	Puentenuevo-Córdoba (Spain)	1840	2080	F
FA4	Avilés-Asturias (Spain)	2520	1850	F
FA5	Carboneras-Almería (Spain)	2360	2160	F
FA6	Jorf Lasfar (Morocco)	2650	2070	F
FA7	As Pontes de G.R.-La Coruña (Spain)	2240	2040	F
FA8	Guardo-Palencia (Spain)	2490	2220	F
FA9	Compostilla-León (Spain)	2130	2250	F
FA10	Los Barrios-Cádiz (Spain)	2400	2770	C

definition of pozzolanicity, established the following facts related with their proposed method:

(a) The reaction between calcium hydroxide in aqueous solution and pozzolanic material as finely divided powder produces a decrease in electrical conductivity of the suspension. This behaviour is attributed to fixation of dissolved $Ca(OH)_2$ by pozzolan particle surface.
(b) Only 120 s were necessary for evaluating pozzolanicity of tested natural products, and the pozzolanic material was classified in function of variation in conductivity according to the proposed method.
(c) The proposed method only can be applied to natural products, so that opaline rock, diatomite earth, tuff, ... However, the method did not offer good results for evaluating pozzolanic activity of fly ashes.

Afterwards, Sugita et al. [11,12] evaluated pozzolanic activity of rice husk ash (RHA) according to Luxan's method, finding a good correlation between noncrystalline silica content in RHA sample and variation in electric conductivity of RHA/saturated lime suspensions.

Finally, conductimetric test [13] has also been applied for studying ordinary Portland cement hydration. In these cases, a rapid supersaturation of aqueous solution occurs.

This paper presents a contribution for applying a conductimetric methodology based on Luxán's method in the study of pozzolanic activity of fly ashes.

2. Experimental

2.1. Materials

Sources and physical characteristics of fly ashes are summarized in Table 1. Chemical compositions for fly ashes are listed in Table 2. Silica fume (SF) was obtained from Ferroatlántica (Sabón, Spain), and used as received. The source of the NP of volcanic origin was Almagro-Ciudad Real (Spain) and was ground using a laboratory ball mill. The RHA was prepared by combustion into a laboratory furnace at 600°C for 1 h. Toluene (Panreac) for gravity determination and calcium hydroxide (96%, Aldrich) for conductivity measurements and preparation of pastes were analytical-grade reagents and were used as received. The cement used for preparing pastes was an ASTM type I Portland cement with the following chemical composition: 20.21% SiO_2, 4.94% Al_2O_3, 2.85% Fe_2O_3, 62.87% CaO, 1.05% MgO, 3.54% SO_3, 0.95% K_2O, 0.10% Na_2O, 3.02% loss on ignition and 0.95% insoluble residue.

2.2. Apparatus and procedures

A Crison microCM2201 conductimeter and a Crison micropH2001 pH-meter were used for conductivity and pH measurements, respectively, which had RS 232 C outputs. The experimental design is shown in Fig. 1. Reactions were carried out using a reaction vessel water-thermostated at different temperatures. The suspension was magnetically stirred during the measurements. Conductivity and pH cells were connected to a conductimeter and to a pH-meter, respectively, which had a RS 232 C output. The measurement system was automatically controlled by a personal computer using a software program, reading (via interface) and transforming conductimeter and pH-meter outputs every so often. FA10 hydration process was studied on fly ash/water paste cured at 20°C. Prepared paste was put into a plastic tube, which was sealed and submerged in water at 20°C. Small quantity of cured paste (ca. 200 mg) was crushed in agate mortar, hydration stopped by acetone

Table 2
Chemical parameters for fly ashes

Fly ash	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
FA1	2.44	40.94	24.65	13.59	9.83	1.59	1.60	0.34	1.40
FA2	7.85	47.80	30.69	3.66	4.93	1.28	0.06	0.38	0.78
FA3	3.54	52.63	26.03	5.68	2.13	1.50	0.08	0.43	3.77
FA4	5.72	48.77	27.11	6.43	3.86	1.49	0.16	0.53	4.03
FA5	8.16	45.51	30.97	3.34	7.14	1.49	0.07	3.00	0.55
FA6	6.03	46.04	37.76	2.67	6.41	1.61	1.36	0.05	0.56
FA7	2.28	44.34	33.48	6.35	6.28	1.19	0.84	0.24	1.16
FA8	10.71	48.14	23.20	8.22	6.06	1.39	0.16	0.17	3.10
FA9	8.44	51.54	25.73	6.70	2.40	1.79	0.13	0.25	4.35
FA10	4.62	30.94	9.06	2.56	46.51	1.71	1.74	0.19	1.01

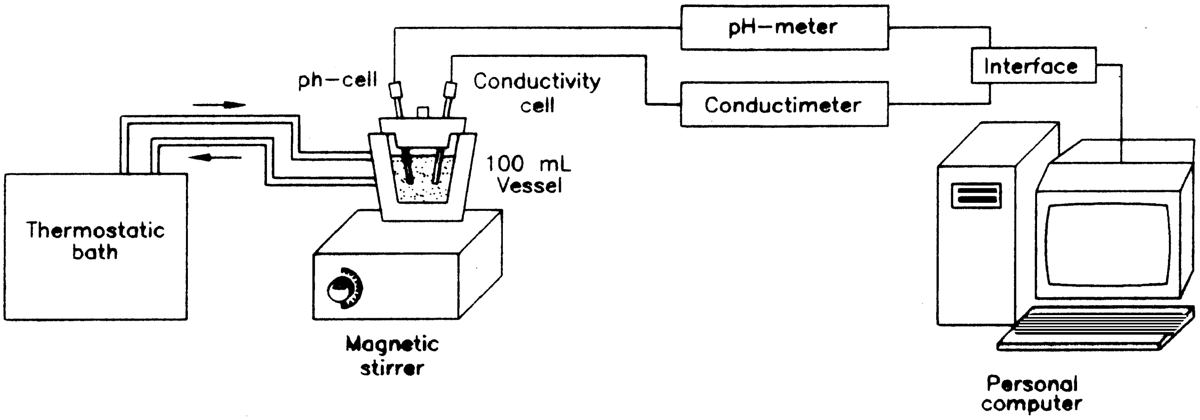


Fig. 1. Experimental scheme.

adding and the powder was dried at 105°C for 30 min. The resulting powder was studied by thermogravimetric (TG) analysis using a Mettler-Toledo TGA 850 module, equipped with an ultramicrobalance (resolution of the balance: 0.1 μg), with a horizontal furnace. Powder sample (ca. 40 mg) was put into a 70-μl alumina crucible. The sample was heated at 20°C/min heating rate in a nitrogen flowing atmosphere (flow gas: 75 ml/min). TG curve was registered in the 35–600°C range. For evaluating data, Mettler-Toledo Star Software was used.

3. Results and discussion

3.1. Considerations about the proposed experimental method

Luxán et al. [10] proposed the use of a saturated lime solution (at 40°C) as reactive towards the pozzolan. The preparation of a saturated solution of calcium hydroxide is a trying step because the dissolution rate of $Ca(OH)_2$ is low at 40°C, and saturation equilibrium is reached after several days. On the other hand, additional difficulty is found when an aliquot of the liquid without solid may be taken. The use of unsaturated lime solution [14] in a concentration of 800 mg $Ca(OH)_2$/l of deionized water is proposed by the authors. Hence, the dissolution of lime in water may be carried out in situ into 100 ml vessel: 40 mg of $Ca(OH)_2$ were added to 50 ml of deionized water and the vessel was sealed. The temperature of the solution was raised to 80°C by means water-thermostating system, and the dissolution rate increased notably. Afterwards, the temperature of lime insaturated solution was changed to the temperature of the experiment with the pozzolan. The conductivity of this lime solution at 40°C was about 5700 μS/cm in conductivity (with no temperature correction) and the pH value was about 11.47. This procedure allows us to prepare lime solution in situ and only 1 h is required. Additionally, the possibility of carbonation process would be more easily prevented.

On the other hand, Luxán et al. [10] established a classification of the material from the pozzolanic activity point of view according to the value of variation in conductivity (after 120 s) of the suspension. However, they did not take into account the presence of water soluble salts in the studied material. Probably, the contribution to the conductivity value of natural products studied by Luxán et al. was negligible. This situation cannot be assumed when fly ashes are tested by conductimetric methods because of the presence of relatively high amount of soluble salts in fly ash particles, particularly deposited on the surface. Thus, it is generally accepted that mostly alkali metals (sodium and potassium) and partly calcium appear as submicron particles adhered on fly ash particle surface as sulphate compounds, Na_2SO_4, K_2SO_4 and $CaSO_4$, respectively [15–18]. These sulphate compounds constitute chiefly the water-soluble fraction of fly ash, although alkali chloride and a small quantity of leachable glassy material could be also present. In this manner, the conductivity of fly ash/water suspensions will be proportional to the concentration and type of ions in solution, and a rapid conductimetric method has been proposed for monitoring the soluble sulphate content in fly ashes [15,16].

Raask [15] found high conductivity values for fly ash/water (1:100 ratio) suspensions after 30 min of stirring: the values were in the 104–245 μS/cm range. Whereas, Payá et al. [19] found conductivity values near to 1000 μS/cm when fly ash/water suspensions (10:100 ratio) were stirred for 100 min at room temperature. These observations suggest that when fly ash is tested by Luxan's method, contribution to conductivity due to dissolution of soluble salts in fly ash may be considered.

Different pozzolans are tested for comparing their behaviour and influence in conductivity of their water suspensions. Therefore, a NP of volcanic origin, RHA, SF and a low-calcium fly ash (FA1) were tested. Suspensions at 60°C of pozzolan/water in the 2:100 ratio were monitored in conductivity and potentiometric (pH) properties with time. Fig. 2a shows conductivity vs. time curves of the suspensions. It is noticeable the difference in water-soluble salt

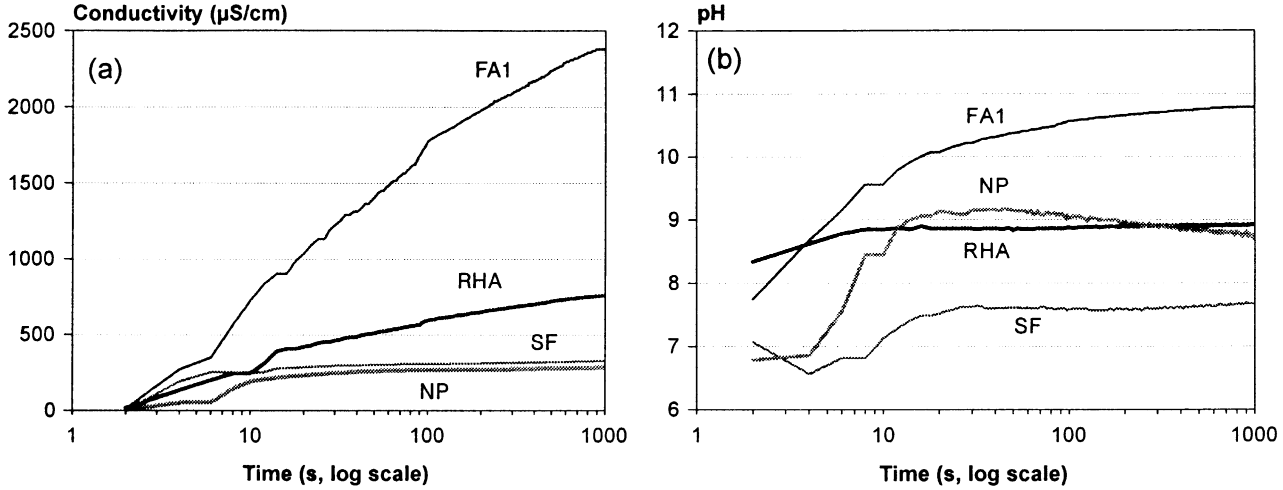


Fig. 2. Pozzolan/water suspensions at 60°C (2:100 solid/water ratio): (a) conductivity curves; (b) pH curves.

content between fly ash and other tested pozzolans. Thus, NP and SF suspensions reached, at 10 s, 250 µS/cm, and this value is maintained for a longer period. RHA suspension reached higher values in conductivity and solubilization of the salts is a continuous process in the studied period. However, FA1 suspension reached highest conductivity value for any time and the final conductivity value after 1000 s of stirring time was 10 times greater than that reached by NP and SF, and three times greater than RHA suspensions. This observation proves that water-soluble salt content in fly ashes become a crucial parameter for studying fly ash reactivity towards lime by means conductivity measurement.

Additionally, pH values were monitored for the above suspensions. Fig. 2b shows pH vs. time curves for FA1, NP, SF and RHA suspensions. The high pH value reached for FA1 suspension compared to the other tested materials is remarkable. As Raask [15] proposed, the alkaline solution obtained when fly ash is suspended in water would be attributable to leaching of alkali metals (Na, K) or calcium from vitreous aluminosilicate fractions of fly ash particles. The hydrolysis reaction of these aluminosilicates would increase hydroxyl (OH^-) concentration in solution. Therefore, the partial solubilization of fly ash particles, that is the dissolution of sodium, potassium and calcium salts [15–18], increase the concentration of Ca^{+2} and OH^- ions, and, consequently, this situation will affect to solubility of calcium hydroxide in water. Therefore, when fly ash is added to saturated calcium hydroxide solution, a precipitation of $Ca(OH)_2$ will be produced because the ionic product becomes greater than solubility product K_{ps}. This phenomena could be avoided when fly ash is added to insaturated $Ca(OH)_2$ solution, and, therefore, the reactive would remain completely in solution.

3.2. Determination of loss in conductivity for fly ash/hydrated lime suspensions

Due to high salinity of fly ash/water suspension, authors propose that for measuring the variation in conductivity for

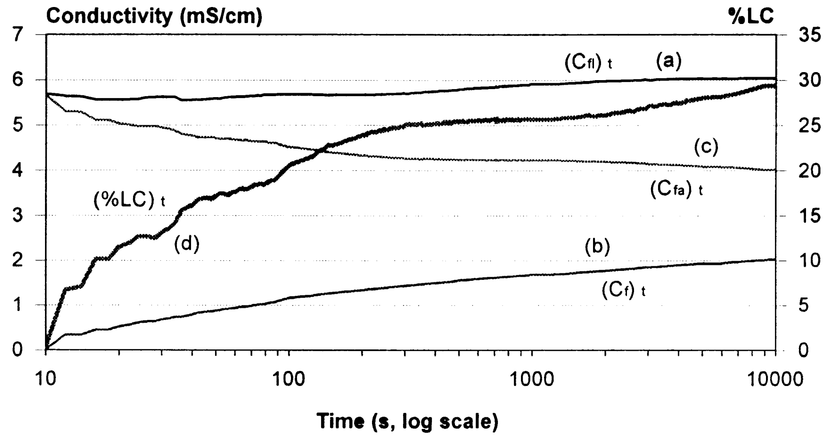


Fig. 3. Curves for FA1 fly ash at 40°C in the 10–10000-s period: (a) fly ash/hydrated lime suspension, $(C_{fl})_t$; (b) fly ash aqueous suspension, $(C_f)_t$; (c) curve a minus curve b, $(C_{fa})_t$; and (d) relative loss in conductivity curve, $(\%LC)_t$.

fly ash/hydrated lime solution system, the contribution to conductivity of fly ash may be subtracted. In Fig. 3, conductivity vs. time curves of fly ash/lime solution, $(C_{\mathrm{fl}})_t$ (curve a), and fly ash/water, $(C_{\mathrm{f}})_t$ (curve b), systems at 40°C are plotted. Additionally, corrected conductivity curve (curve c) obtained as subtraction (curve a minus curve b, $(C_{\mathrm{fl}})_t - (C_{\mathrm{f}})_t = (C_{\mathrm{fa}})_t$) is also depicted in Fig. 3.

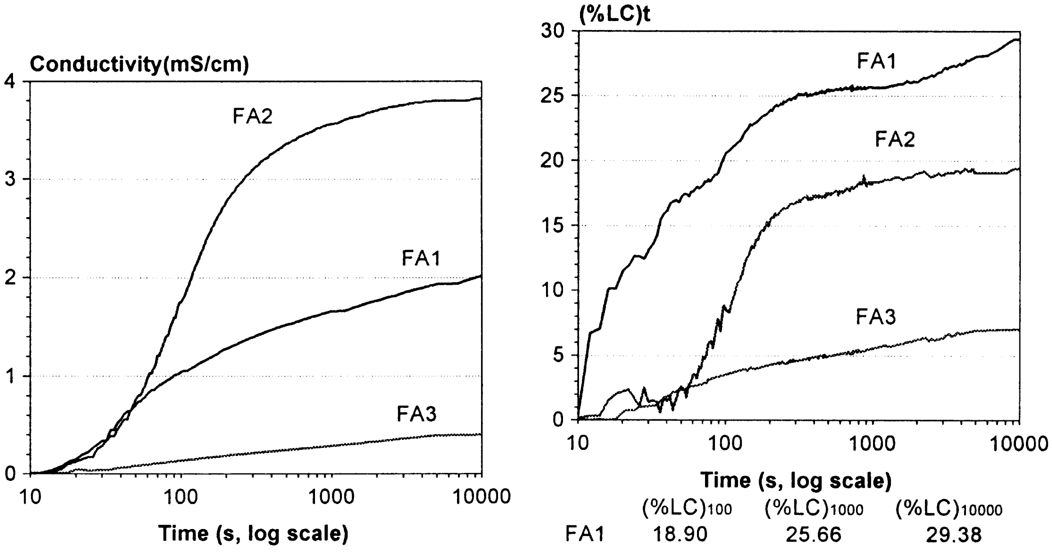
Curve c, $(C_{\mathrm{fa}})_t$, would represent the absolute loss in conductivity due to lime fixation. However, for comparing data, this loss may be calculated as percentage according to the following equation:

$$(\%\mathrm{LC})_t = \frac{C_0 - (C_{\mathrm{fa}})_t}{C_0} 100 \qquad (1)$$

where $(\%\mathrm{LC})_t$ is the percentage of loss in conductivity for a given suspension and a given time t, C_0 the conductivity of lime solution before fly ash addition and $(C_{\mathrm{fa}})_t$ the absolute loss in conductivity for fly ash/lime suspension at a given time t. Obviously, $(\%\mathrm{LC})_t$ values will also depend on temperature of the reaction and the fly ash/lime/water ratio used for the experimental determination. Curve d in Fig. 3 represents the $(\%\mathrm{LC})_t$ curve.

3.3. Relative loss in conductivity (%LC) vs. time

As mentioned above, the conductivity of fly ash/lime aqueous suspension and fly ash aqueous suspension varied with time. These variations depend on the soluble saline content of fly ashes and the pozzolanic activity of them. The proposed salinity correction and the calculation according to Eq. (1) of relative loss in conductivity (%LC) of fly ash/lime suspensions permitted to evaluate the lime fixation for a given time. Luxán et al. [10] proposed a period of 120 s for calculating the variation in conductivity for NPs. Initially, longer periods for fly ashes may be studied by several reasons (Fig. 2a). Firstly, the high-ion releasing process (initial period, 120 s) from fly ash particles could alter the fixation of lime. Secondly, at the initial stage, only superficial reaction would take place, but inner reactive glassy material of fly ash particles is not reacted. Thirdly, most fly ashes show their pozzolanic properties for medium- and long-term stages. Thus, we propose the measurement of %LC values for 10 000 s in order to evaluate pozzolanic activity. Fig. 4a shows the variation in conductivity of fly ash water suspensions for experiences carried out at 40°C, and Fig. 4b shows the $(\%\mathrm{LC})_t$ curves for fly ashes with different reactivity: FA1, FA2 and FA3. In this figure, %LC values are indicated for each fly ash at 100 s, $(\%\mathrm{LC})_{100}$, 1000 s, $(\%\mathrm{LC})_{1000}$ and 10 000 s, $(\%\mathrm{LC})_{10\,000}$. It can be noticed that FA1 fly ash showed the highest reactivity, finding a 18.9% for $(\%\mathrm{LC})_{100}$. However, FA3 fly ash showed lowest reactivity. Finally, FA2 fly ash showed a different behaviour. The %LC at 100 s was only 8.78%, whereas for the 1000 s experiment time, the value increased to 18.23%. This behaviour may be justified taken into account the initial step (10–100 s) in which high amount of saline material was dissolved as can be seen in Fig. 4a (increase of conductivity ca. 2000 μS/cm for this interval). The dissolution process of fly ashes hindered the uptake of lime, and the pozzolanic reaction was consequently delayed. For a longer time than 100 s, the uptake of lime was important, and for the 100–200-s interval, the %LC increased notably as can be seen in Fig. 4b.



	$(\%\mathrm{LC})_{100}$	$(\%\mathrm{LC})_{1000}$	$(\%\mathrm{LC})_{10000}$
FA1	18.90	25.66	29.38
FA2	8.70	18.23	19.08
FA3	3.51	5.56	7.17

Fig. 4. Comparison of curves for FA1, FA2 and FA3 fly ashes at 40°C: (a) fly ash aqueous suspension, $(C_{\mathrm{f}})_t$ curves; (b) relative loss in conductivity, $(\%\mathrm{LC})_t$ curves.

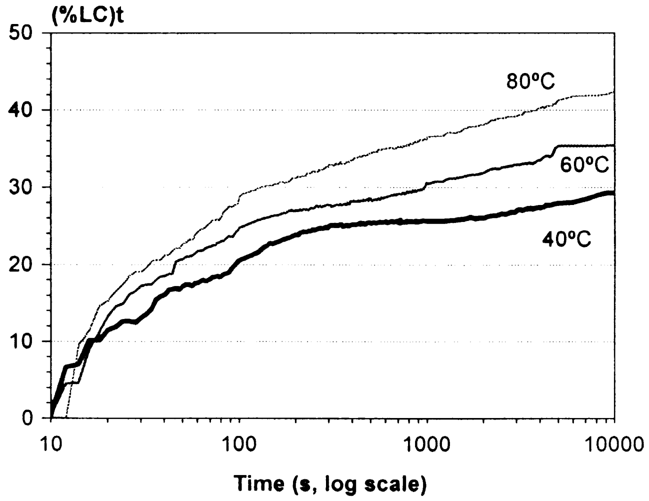


Fig. 5. Relative loss in conductivity for FA1 measured at: (a) 40°C; (b) 60°C; and (c) 80°C.

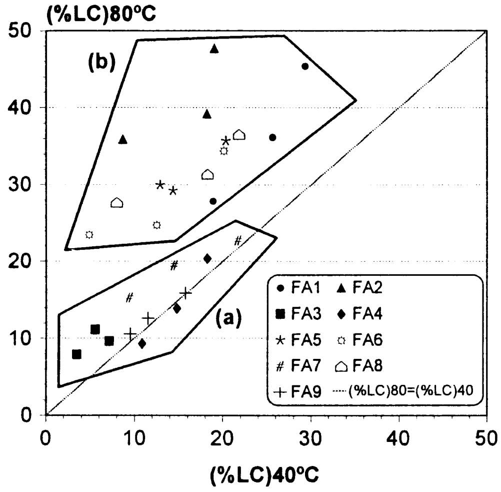


Fig. 6. Comparison of %LC values at 80°C and 40°C. Fly ashes with: (a) no-dependence temperature reactivity; (b) strong-dependence temperature reactivity.

3.4. The influence of water suspension temperature

The chemical reaction rate between dissolved lime and fly ash particles, and the dissolution rate of saline compounds from fly ash particles, will be influenced by the temperature of the suspension. Obviously, the increase of the temperature would favour both processes and, consequently, the reaction degree at a given time would be larger with this temperature increase. Despite of conductivity of solutions increase with temperature, in this case, the conductivity measurements at different temperatures were not temperature-compensated because %LC value was given as a ratio of conductivity data [see Eq. (1)]. The designed system permits to carry out experiences at temperatures in the 0–100°C range. However, low-temperature experiences (0–40°C) were not carried out because the slowness of pozzolanic reaction. In addition, experiences at temperature higher than 80°C gave technical difficulties due to high water vapor pressure and water losses from thermostated vessel. The possibility of testing the process at different temperatures permits to study the reactivity of fly ashes for shorter period or, alternately, to study the maximum reaction degree for longer period. Fig. 5 shows %LC curves for FA1 fly ash tested at 40°C, 60°C and 80°C temperatures. Table 3 summarises %LC values for all tested fly ashes.

It can be noticed that, in general, the %LC values are similar or greater when experiment temperature is raised, and the %LC values increase with time. FA1, FA2, FA5, FA6 and FA8 showed high reactivity, yielding %LC values at 80°C and 10 000 s greater than 30%. On the other hand, some fly ashes did not increase notably their reactivity towards lime when temperature was raised. Fig. 6 depicted the comparison between $(\%LC)^{40^\circ C}$ and $(\%LC)^{80^\circ C}$ values for 100, 1000 and 10 000 s. FA3, FA4, FA7 and FA9 showed no dependence of the reactivity with temperature, whereas the rest of fly ashes (FA1, FA2, FA5, FA6 and FA8) yielded clearly greatest %LC values for 80°C, suggesting the temperature dependence of their reactivity. This behaviour has been attributed to the salinity of fly ashes, that is the release of ions from fly ash in the water suspension. FA3, FA4, FA7 and FA9 presented low saline content (conductivity values for fly ash aqueous suspensions at 40°C and 10 000 s were in the 300–1200-μS/cm range), whereas conductivity values for aqueous suspen-

Table 3
Relative loss in conductivity values for studied fly ashes (FA1 to FA9) at different temperatures $(\%LC)^T$

	$(\%LC)^{40^\circ C}$ values			$(\%LC)^{60^\circ C}$ values			$(\%LC)^{80^\circ C}$ values		
Fly ash	100 s	1000 s	10 000 s	100 s	1000 s	10 000 s	100 s	1000 s	10 000 s
FA1	18.9	25.66	29.35	28.065	32.97	38.69	27.84	36.20	45.44
FA2	8.70	18.23	19.08	30.44	33.38	33.82	35.93	39.27	47.73
FA3	3.51	5.56	7.17	5.16	7.97	9.46	7.89	11.16	9.61
FA4	10.91	14.84	18.25	11.57	14.39	16.10	9.31	13.88	20.35
FA5	14.37	12.92	20.35	14.94	17.83	25.46	29.22	30.00	35.71
FA6	4.87	12.51	20.18	14.78	20.26	21.97	23.45	24.72	34.43
FA7	9.40	14.44	21.72	11.61	18.37	22.77	15.27	19.46	22.74
FA8	8.0	18.30	21.87	22.68	25.27	27.70	27.71	31.40	36.58
FA9	9.53	11.50	15.74	10.70	11.72	13.41	10.58	12.60	15.86

Table 4
%LC values for different hydrated lime/fly ash ratios

Amount of fly ash (g)	$(\%LC)_t$ values for FA1			$(\%LC)_t$ values for FA6		
	100 s	1000 s	10 000 s	100 s	1000 s	10 000 s
0.25	9.51	11.88	15.36	3.3	6.38	7.27
0.50	14.87	20.31	25.41	5.7	11.45	12.20
0.75	20.76	27.51	28.94	11.88	16.11	17.84
1.00	28.06	32.97	38.69	14.78	20.26	21.97
1.50	30.03	35.25	36.46	20.49	26.31	29.79
2.00	33.87	38.83	37.52	24.86	33.57	37.28
3.00	41.49	39.66	40.08	31.67	41.62	47.16

Experiences carried out at 60°C, using 50 ml of deionized water and 40 mg of $Ca(OH)_2$.

sions were in the 2100–3400-μS/cm range in the same experimental conditions for FA1, FA2, FA6 and FA8 fly ashes. On the one hand, the dissolution process from surface of the particles left more "active sites" in the glassy material towards lime. On the other hand, an improvement of the reactivity of fly ashes has been reported [20] when chemical activators as sulphate and chloride salts are present, especially at early ages.

3.5. Influence of hydrated lime/fly ash ratio

The hydrated lime/fly ash ratio used in the experience is very decisive because highly reactive fly ashes consume rapidly the hydrated lime and, consequently, an important decrease in %LC would take place in few seconds. In this manner, no significant variation in %LC would be observed with time if high amount of a fly ash would be used. Thus, hydrated lime/fly ash ratio influence was studied for establishing the optimum amount of fly ash used. Table 4 summarizes %LC values for FA1 and FA6 fly ashes using different hydrated lime/fly ash ratios. For a given amount of hydrated lime (40 mg) in 50 ml of water at 60°C, several amounts of fly ash (0.25–3 g) were added to the solution and monitored for 10–10 000 s. In general, an increase on %LC values was observed when amount of fly ash used was increased. According to the above experimental data, FA1 showed higher reactivity at 60°C than FA6. For highest reactive fly ash, FA1, little variation in %LC with time was measured for amount higher than 1.5 g, suggesting that there was an excess of pozzolan respect to hydrated lime. The results suggest that 0.04:1 hydrate lime/fly ash ratio was suitable for evaluating pozzolanic activity of fly ashes.

3.6. Low-lime and high-lime fly ashes

At the moment, all tested fly ashes were low-lime fly ashes (ASTM class F), finding a similar behaviour in saline dissolution process for fly ash water suspensions. However, when a high-lime fly ash is tested (ASTM class C, FA10 fly ash), the behaviour was completely different. It may be taken into account that high-lime fly ashes are intrinsically hydraulic and possess, in addition, pozzolanic properties. Thus, when 1 g of FA10 fly ash, which was a high-lime fly ash, was suspended in 50 ml of deionized water at 40°C, the pH is raised to 11.41 units at 100 s, and to 12.15 units at 10 000 s. Additionally, conductivity values were respectively 3270 and 8560 μS/cm. In Fig. 7a and b, selected pH and conductivity values for fly ash suspensions at 40°C are compared. FA10 fly ash reached highest pH and conductivity values. These observations are in good agreement with the hydration reaction of calcium silicates and calcium oxide present in FA10 fly ash, yielding the corresponding calcium silicate hydrates and hydrated lime. This last compound was dissolved and the solution trend to saturation or supersaturation. This behaviour does not permit to carry out the conductivity test with high-lime fly ashes because an excess of $Ca(OH)_2$ would take place and the calculation of %LC would be meaningless. Moreover, $Ca(OH)_2$ formed from fly ash reaction with water could be consumed by pozzolanic fraction of fly ash. The formation of $Ca(OH)_2$

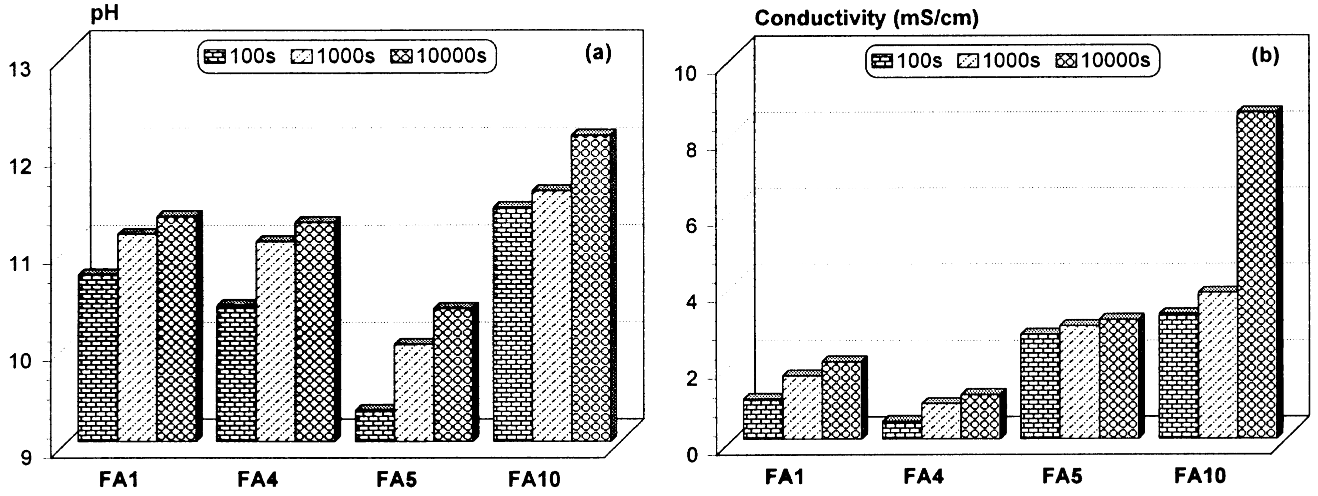


Fig. 7. Fly ash aqueous suspensions at 40°C at different experiment times: (a) pH values; (b) conductivity values.

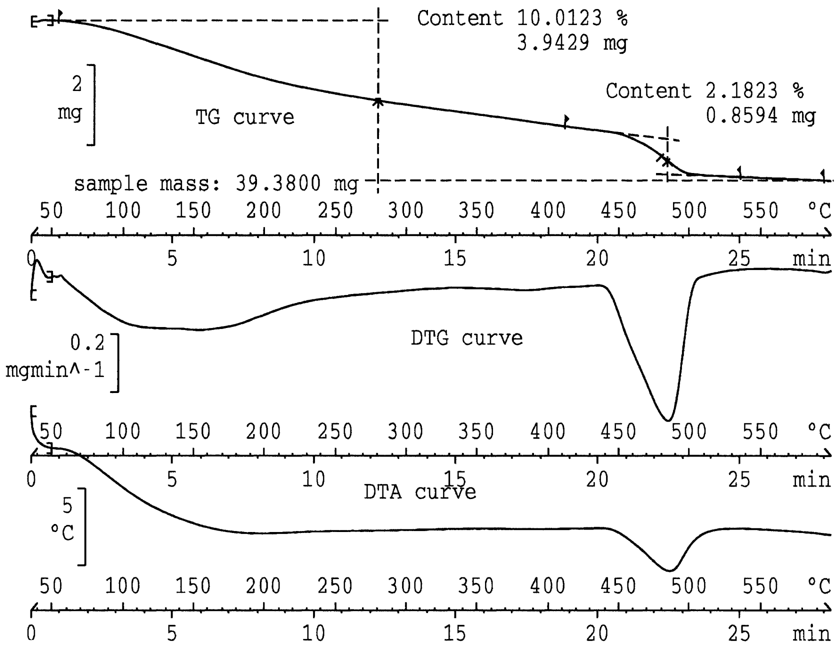


Fig. 8. TG, DTG and DTA curves for FA10 paste cured at 40°C for 48 h.

when FA10 was mixed with water was confirmed by thermal analysis. A paste of FA10 (4:10 water/fly ash ratio) was cured at 40°C for 48 h. An aliquot of this paste was taken, hydration stopped with acetone and dried at 105°C for 30 min. Fig. 8 plots the TG curve, its derivative curve (DTG) and the differential thermal analysis curve (DTA). The TG curve shows a weight loss between 35°C and 600°C above 10.01%. Part of this loss is attributed to calcium hydroxide decomposition in the 450–500°C range (2.18% loss, which is equivalent to 8.96% of $Ca(OH)_2$). The rest of loss is attributed to the presence of hydrated calcium silicates and aluminates due to hydration of anhydrous compounds in FA10 and the corresponding products according to pozzolanic reaction. DTG and DTA curves showed clearly the presence of calcium hydroxide after reaction with water.

4. Conclusions

1. An enhanced methodology for preparing hydrated lime solutions and for monitoring its reactivity towards fly ashes was proposed.
2. Conductivity of fly ash/hydrated lime suspensions may be measured for evaluating lime fixation by fly ash. The salinity of fly ashes (ion releasing to the aqueous medium) may be taken into account.
3. Relative loss in conductivity (%LC) parameter was established for comparing data. The determination of this parameter at 100, 1000 and 10 000 s experiment times for evaluating pozzolanic activity was proposed.
4. Experimental design permits one to record conductivity curves at different temperatures. Comparisons between data obtained at 40°C and 80°C showed a clear difference in reactivity for fly ashes with high and low salinity content.
5. The proposed methodology was not suitable for evaluating pozzolanic activity of high-lime fly ashes.

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