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Investigations on the use of electric-arc furnace dust (EAFD) in Pozzolan-modified Portland cement I (MP) pastes

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Abstract

The use of electric-arc furnace dust (EAFD) in civil construction is not common. In countries where this waste is collected, it is used in the recovery process of heavy metals, such as Zn, Cd, Pb, and Cr. In Brazil, these processes are still not used, because the percentages of heavy metals of commercial value are not economically feasible (e.g. zinc with only 13% of mass). Thus, more studies are necessary aimed at making EAFD a subproduct for civil construction. For this reason, the waste behavior was evaluated in Pozzolan-modified Portland cement I (MP) pastes. Setting time and hydration heat were determined, as well as mineralogical and microstructural characterization, in order to better understand the residue's effect upon cement paste's properties, both in fresh and hardened states. The results showed that EAFD slows down the Portland cement's hydration reactions. This behavior is better verified using hydration heat curves as compared to the Vicat equipment. As of the mechanical performance, it was verified that even though the EAFD retards the hydration reaction of the cement in its initial ages, in more advanced ages the trend is having significant gain of resistance in pastes containing EAFD.

Keywords: Electric-arc furnace dust; Wastes; Setting time; Hydration heat

1. Introduction

Electric-arc furnace dust (EAFD) is a type of waste generated by steel production industries. EAFD contains different hazardous oxides such as Zn, Cd, Pb, and Cr. Countries that use EAFD, usually collect these oxides through pyrometallurgical process, hydrometallurgical process or both. However, in Brazil these processes are still not in use, since the percentages of heavy metals of commercial value are not economically feasible (e.g. zinc with only 13% of mass). Therefore, it is necessary to create alternatives in order to reuse the EAFD in other industries, e.g., construction. Several studies have evaluated EAFD as an admixture in the cement clinker production [1,2]. Other studies have evaluated the mechanical behavior of the cementitious matrix containing the EAFD [3–7]. In these studies, it was observed that the samples containing EAFD dust presented a superior mechanical behavior when compared to the reference samples. Nevertheless, the EAFD retarded the cement hydration reactions. The main element thought to be responsible for this phenomenon is zinc [8–16].

Thus, the aim of this work is to get a better understanding of the influence of EAFD on the properties of Portland cement paste, both in fresh and hardened states, making its use viable for civil construction. Portland cement pastes with different contents of EAFD were cast, and the initial and final setting times and hydration heat were determined. A mineralogical and microstructural characterization was done for pastes at the ages of 7 and 28 days. The pastes' compressive strength was determined at the ages of 3, 7 and 28 days.

2. Experimental investigation

2.1. Materials

The EAFD used was generated by a semi-integrated steel plant, and collected by means of a socket filter. The chemical composition of the EAFD used in this research is shown in

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Table 1
Electric-arc furnace dust (EAFD) chemical composition (%)

Fe	42.00	Mg	1.61	Cr	1.05	Cu	0.24	Mo	0.07
Zn	13.30	Pb	1.34	K	0.97	Ni	0.19	Al	0.29
Ca	4.28	Si	1.29	Na	0.84	P	0.17	Co	0.05
Mn	1.90	C	1.10	S	0.32	Cd	0.11	–	–

Table 1. The total amount of the EAFD sample used was obtained by means of mixing and homogenization of 11 samples of 28 kg of dust each, collected in a period of 2 months, totaling 308 kg. No milling was performed. The EAFD grading curve was carried out using a 1064 Cilas laser diffraction grain meter. The mean diameter value was 0.83 µm, and 90% of the particles were smaller than 3.60 µm.

For the determination of the specific gravity, the procedures in the Brazilian Standard NBR 6474 were used. The result was 4.23 g/cm^3. Table 2 presents the EAFD's leached extract—procedures NBR 10005 [18]. Other physical characteristics are shown in Table 3.

To evaluate the particles morphology that composes the EAFD, scanning electron microscopy (SEM) by secondary electrons was carried out. Fig. 1 shows the EAFD image.

A large number of peaks were identified by the X-ray diffraction, which indicates that the EAFD structure is crystalline. The presence of several compounds can be observed, especially zinc and iron oxides (Fig. 2).

The cement used was Pozzolan-modified Portland cement I (MP). The physical characteristics of this cement are show in Table 3 and its chemical characterization is presented in Table 4. The water used was from the local water supply company.

2.2. Method

A reference Pozzolan-modified Portland cement I (MP) paste (0%) was adopted and contents of EAFD were added at 5%, 15% and 25% of MP cement mass. These amounts were chosen based on the literature, where the waste proportions used were, by cement substitution, from 1% [6] up to 40% [19] and 46% [20]. These EAFD contents used were chosen in order to identify the lower and upper limits of the EAFD in the pastes. Contents around 40% were considered too high, since Barbosa [19] and Castellote et al. [20] verified that the EAFD retarded the cement setting times. Initial set times (up to 96 h) and final set times (up to 288 h) are far beyond the limits of Brazilian Standard NBR 5732 [21] that specifies initial setting time at ≥1 h and final setting time at ≤10 h.

Table 2
EAFD's leached extract

Elements	F$^-$ (mg/L)	Cd (mg/L)	Pb (mg/L)	Cr (mg/L)	Cr^{+6} (mg/L)	Ba (mg/L)	Ag (mg/L)	Hg (µg/L)
EAFD [a]	8	7.5	13.00	<0.02	0.01	<1.00	<0.01	<0.1
NBR 10004 [b]	150	0.5	5.00	5.00	NN [c]	100	5.00	100

[a] Electric-arc furnace dust.
[b] NBR 10004 [22]–Brazilian Standard–various limits permitted.
[c] NN—non-normalized value.

Table 3
Physical characteristics of material mixtures

	EAFD	Cement	Cement+		
			5% EAFD	15% EAFD	25% EAFD
Specific gravity (g/cm^3)	4.23	2.94	3.06	3.16	3.24
Specific surface (Blaine—cm^2/g)	4770	3806	4550	5020	5500

2.2.1. Setting time determination

The evaluation of the EAFD influence on the setting time of the MP cement paste was determined by the procedures in the Brazilian Standard NBR 11581 [23] using the Vicat needle.

2.2.2. Hydration heat determination

To determine the hydration heat, a reference paste was initially adopted with 1 kg of MP cement and a fixed water/cement ratio (w/c) of 0.31. From this paste, three others were prepared with the same MP cement and w/c amounts, varying the EAFD contents at 5%, 15% and 25% by MP cement mass, and then being well homogenized. The pastes were cast in metallic flasks and a thermo-resistor PT 100 (platinum with 100 Ω resistance at 0 °C) was introduced into each paste. Then, the flasks were placed in semi-adiabatic bottles and hermetically closed. Each thermo-resistor was connected to a date acquisition system (DAS), which provided continuous monitoring. The testing time was 96 h. Since the DAS has four independent channels, MP cement pastes with different EAFD contents were tested simultaneously.

2.2.3. Mineralogical analysis

For the mineralogical characterizations, the same MP cement pastes were molded with the same EAFD contents used for the setting time determination. The w/c ratio used for each paste was defined in the Standard Test for the Normal Consistence Determination [24]. Those pastes were placed in plastic containers with a 20 mm diameter and height of 40 mm which were placed in a

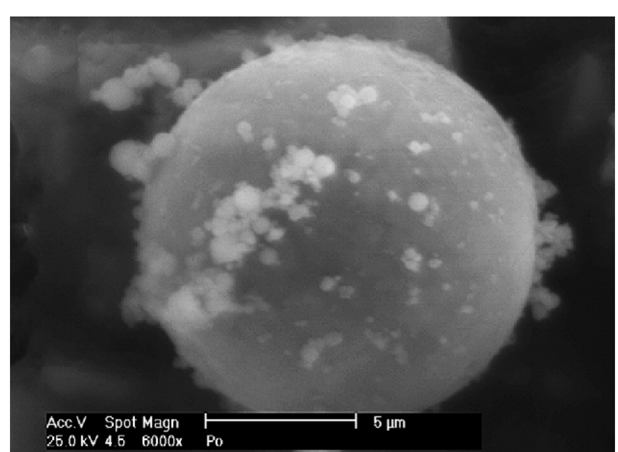

Fig. 1. Scanning electron microscopy by secondary electrons of an EAFD sample: (a) 3000×, (b) 6000×.

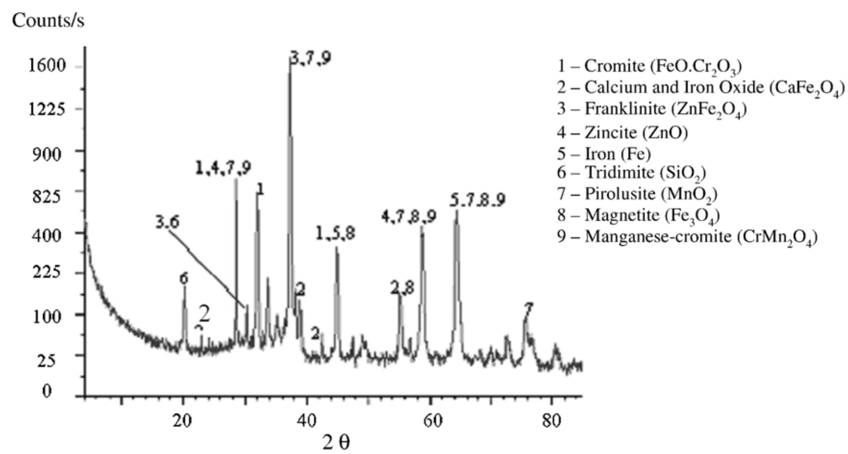

Fig. 2. Chemical compound of electric-arc furnace dust (EAFD) determined in X-ray diffraction.

humidity chamber, with a relative humidity higher than 95% and temperature at 23±2 °C, until they reached the determined time for the characterizations (7 and 28 days). At those ages, the samples were crushed to reduce the grains' size to below #200 sieve and analyzed with a Siemens Difraktomer D500 X-ray diffraction. The diffraction analysis was carried out using Philips X-Pert software.

2.2.4. Microstructural analysis

The procedures used for the microstructural characterizations were the same as those used for the MP cement paste samples already presented in Section 2.2.3, differing just on the fact that the samples at the analyzed ages (7 and 28 days) were not crushed, but more fractured, immersed in acetone to remove the humidity and finally placed in a drier. After that, the samples were superficially covered with carbon and then examined with the scanning electron microscope (SEM) equipped with Philips energy dispersive spectrometer (EDS). The aim is to observe the microstructure and compounds formation with Zn in the pastes with EAFD.

2.2.5. Compressive strength

The mechanical behavior of the reference MP cement pastes (0%) and the MP cement pastes containing EAFD was determined in a compressive strength test. Pastes containing the same proportions used in the hydration heat test were used.

The compressive strength test was conducted on cylinders (40 mm×80 mm), and a total of three cylinders were tested for each data point. The cylinders were stored in a room where temperature was maintained at 23±1 °C and relative humidity was maintained at 95±1% until the determined age: 3, 7 and 28 days.

Table 4
Pozzolan-modified Portland cement I (MP) chemical composition (%)

SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	Loss ignition	Insoluble residue
36.38	8.53	50.04	3.05	4.30	1.05	0.13	3.00	2.99	14.61

3. Results and analysis

3.1. Setting and hydration times determination

The determination of the setting time for the reference MP cement pastes (0%) and for the MP cement pastes with contents of 5%, 15% and 25% of EAFD are presented in Table 5.

The initial and final set times of the MP cement paste are as established by the Brazilian Standard NBR 11581 [23].

However, according to what was verified in Table 5, the results obtained for the MP Portland cement pastes containing an addition of EAFD presented values which were much superior to the times verified in the reference paste, showing that the EAFD interferes in the cement's hydration reactions, as shown in Figs. 3 and 8.

Although the MP Portland cement pastes with 5%, 15% and 25% EAFD could reach the final ending setting time, they were parched and very friable, confirming the results obtained by Leite et al. [25].

3.2. Hydration heat determination

The cement paste hydration heat was determined for the reference MP cement paste (0%) and for the MP cement pastes with EAFD additions. These results, in a 96 h period, are shown in Fig. 3.

Table 5
Values of water for the normal consistence test and setting time for the reference MP cement pastes (0%) and for the MP cement pastes with 5%, 15% and 25% of electric-arc furnace dust (EAFD) addition by cement mass

EAFD rate (%)	C (g)	EAFD (g)	C+EAFD (g)	w/c ratio	Setting time (h:min)	
					Initial	End
0	500.0	0.0	500.0	0.310	03:44	05:12
5		25.0	525.0	0.300	11:00	16:00
15		75.0	575.0	0.290	12:00	24:00
25		125.0	625.0	0.265	16:00	33:00

C—cement.

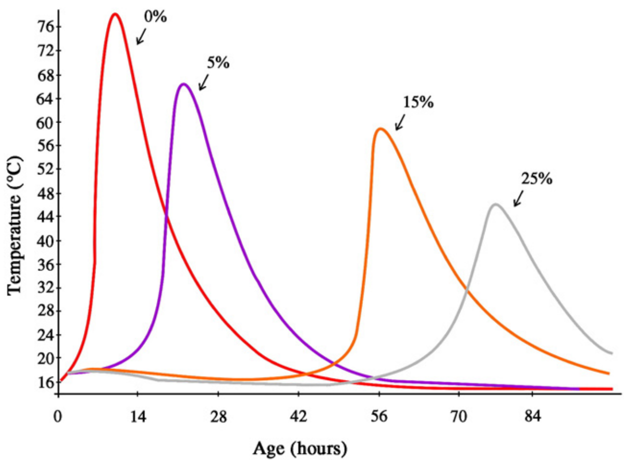

Fig. 3. Hydration heat for the reference MP cement paste (0%) and for the reference MP cement paste with 5%, 15% and 25% of EAFD addition by cement mass. 1—Calcium hydroxide ($Ca(OH)_2$); 2—ettringite (($Ca_6Al_2(OH)_{12}\cdot(SO_4)_3\cdot 26H_2O$)); 3—calcium silicate hydrate (C-S-H); 4—tridimite (SiO_2); 5—aluminum calcium hydrate oxides ($Ca_4Al_2O_7\cdot 19H_2O$); 6—periclase (MgO); 7—aluminum potassium silicate ($KalSiO_4$); 8—franklinite ($ZnFe_2O_4$); 9—magnetite (Fe_3O_4); 10—manganese silicate ($MnSiO_3$); 11—manganese oxide (Mn_3O_4); 12—calcium hydrozincate ($CaZn_2(OH)_6\cdot 2H_2O$); 13—calcium silicate (Ca_3SiO_5).

The temperature peaks for the reference MP cement paste and for the MP cement pastes with 5%, 15% and 25% of EAFD addition were at approximately 10, 22, 56 and 78 h, respectively, as shown in Fig. 3. It is possible to verify the retardant effect due to the EAFD presented in the cement pastes, which increases with increasing EAFD content. These confirm the results obtained by Al-Zaid et al. [6]. It can also be noticed that the curved shape of the reference paste shows a higher peak with a narrower base, demonstrating a higher heat release in a shorter period of time. With a higher content of EAFD, the curve decreases in height and becomes broader. This means a slower release in the hydration heat, and confirms the work of Castellote et al. [19] who classify the Portland cement/EAFD mix as a cement of low hydration heat.

3.3. Mineralogical characterization

Fig. 4 presents the compounds identified by X-ray diffraction of the reference MP cement pastes (0%) and the MP cement pastes with EAFD at the ages of 7 and 28 days.

In the reference MP cement pastes (0%) 7 phases that compose the sample were identified. Among them are: calcium hydroxide, ettringite and calcium silicate hydrate (C-S-H). There are phases with coincident identification peaks.

The MP cement pastes with EAFD, in addition to the phases of the reference cement paste, presented 5 new phases. In these pastes, there were also phases with coincident identification peaks. This is the case of the characteristic peaks of manganese oxide, franklinite and magnetite that are coincident with the peaks of the periclase phase, also identified in the reference paste. Other characteristic peaks like calcium hydrozincate are coincident with the characteristic peaks of phases already found in the reference paste, like hydrated aluminum calcium oxide and potassium aluminum silicates.

Mollah et al. [26] tried to explain the delay in cement hydration caused by Zn through a Charge Dispersal Model. However, in the literature, there is no agreement about which compound inhibits the hydration reactions by forming an impermeable layer around the cement grain. For Mollah et al. [26] the compound is calcium hydrozincate ($CaZn_2(OH)_6\cdot 2H_2O$). For Arliguie and Grandet [14] and Hamilton and Sammes [7], this layer is formed by zinc hydroxide ($Zn(OH)_2$), and it is only with the change of this layer into calcium hydrozincate that the hydration reaction would restart. The formation of calcium hydrozincate from zinc hydroxide is allowed by an excess of free ions Ca^{2+} and OH^- in the paste. This new layer, being permeable, would allow the water to reach the cement grains.

Castellote et al. [20] identified characteristic peaks of calcium hydrozincate in hardened pastes of Portland cement/EAFD. For the same authors, this compound would be the result of the reaction of ZnO in EAFD with $Ca(OH)_2$ from the hydration reactions of cement:

$$2ZnOz + Ca(OH)_2 + 4H_2O \rightarrow (CaZn_2(OH)_6 2H_2O). \qquad (1)$$

Brehm [17] presented a model for the hydration of Portland cement pastes with admixtures of ZnO. For that author, the formation of $CaZn_2(OH)_6\cdot 2H_2O$ allows the paste reactions to occur, as also stated by Arliguie and Grandet [14], Hamilton and Sammes [7] and Castellote et al. [20].

Besides, in another verification carried out by Castellote et al. [20], the X-ray diagrams of samples with Portland cement/EAFD presented less intense peaks of $Ca(OH)_2$, when compared to the reference samples (Portland cement only). These results confirm those found in this work, which can be verified in Fig. 4 ($Ca(OH)_2$ is identified as #1). Besides the reduction of peaks with the increase of EAFD contents, there is a reduction of peaks of calcium hydroxide along the aging process (7 and 28 days), suggesting that the compounds present in EAFD are reacting with $Ca(OH)_2$ through time.

Comparing the EAFD diffraction analysis (Fig. 2) with the MP cement pastes with waste (Fig. 4), it was verified that phases in chromite, iron and calcium oxides, zincite, pirolusite and manganese chrome oxides were not identified in the cement pastes with EAFD. Probably this is due to these compounds' reactions with the hydrated cement products, or due to their concentrations below 5%, not being, thus, identified by the equipment. On the contrary, tridimite phases, magnetite and franklinite were found in the EAFD samples, as well as in the pastes with the waste. Table 6 summarizes the composites identified in the MP cement pastes and the MP cement pastes containing additions of 5%, 15% and 25% EAFD.

Zinc hydroxide composites were not identified. According to Arliguie and Grandet [13], those would be in an amorphous phase. Another hypothesis is that the alkaline environment is responsible for transforming $Zn(OH)_2$ into $CaZn_2(OH)_6\cdot 2H_2O$.

Therefore, the identification of peaks which are a characteristic of calcium hydrozincate in pastes containing EAFD at 28 days (Fig. 4 and Table 6), compared to the resistance results

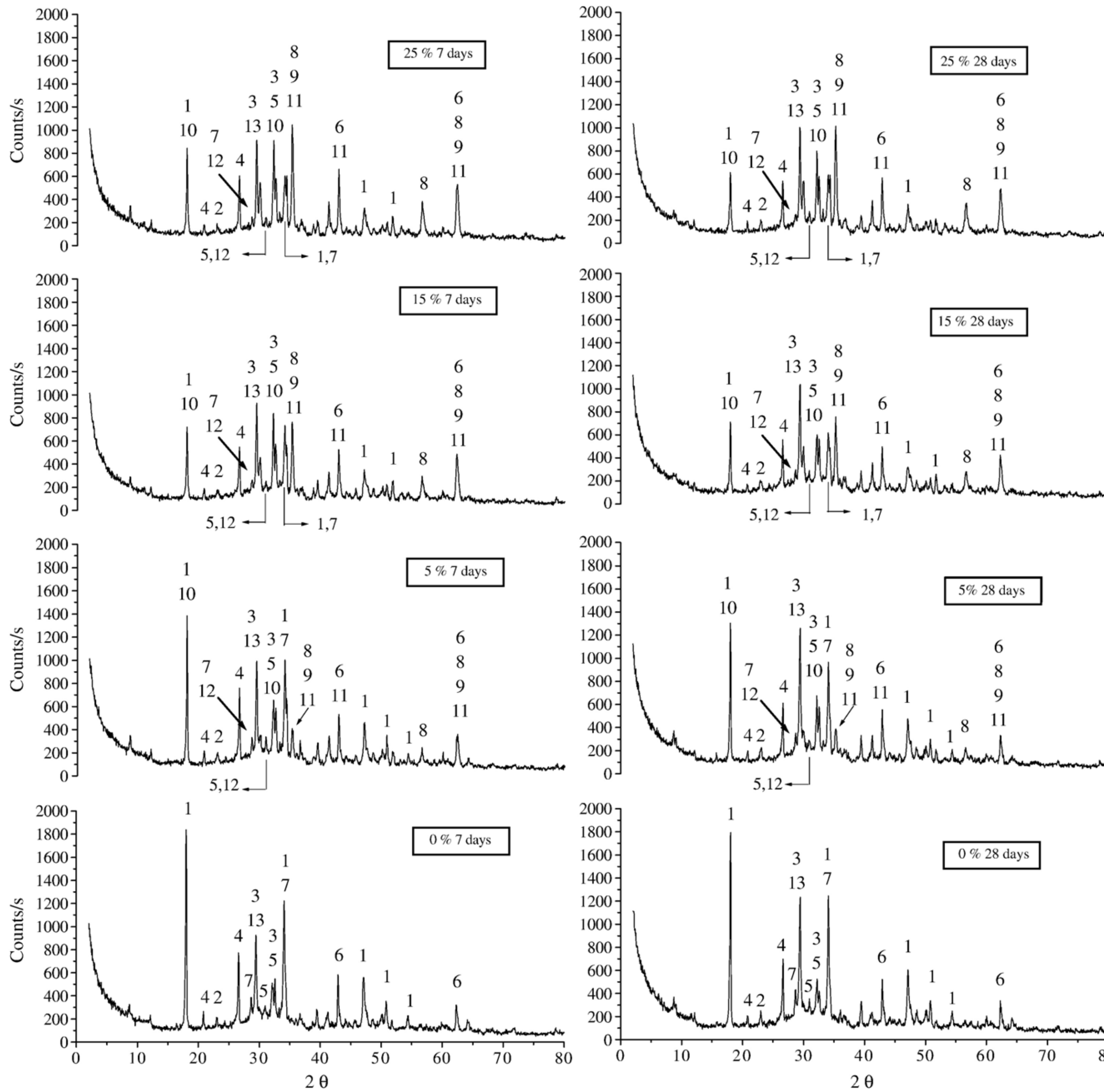

Fig. 4. Results of the X-ray diffraction of the reference MP cement paste (0%) and the MP cement paste with electric-arc furnace dust (EAFD) ratio addition of 5%, 15% and 25%, respectively, 7 and 28 days old.

to compression for these pastes at the same age (Fig. 8)–40 MPa for the pastes containing additions of PAE of 15% and 25%, and 50 MPa for pastes containing additions of 5% PAE–indicate that the calcium hydrozincate does not interfere in the cement's hydration reactions, which is in accordance with the results presented by Arliguie and Grandet [14], Hamilton and Sammes [7], Castellote et al. [20] and Brehm [17].

3.4. Microstructure characterization

Point 1 (Fig. 5) indicates where semi-quantitative EDS analysis was carried out and the corresponding results are presented in Table 7. The identified elements are common for cement hydration products, since the material analyzed is the reference MP cement paste (0%).

The microstructure of the 7 day old paste with 5% EAFD admixture is not presented because no visible microstructural differences were found regarding the reference MP cement paste (0%).

Fig. 6a and b show the microstructure of 7 day old reference MP cement pastes with 15% and 25% EAFD admixture, respectively. Points 2, 3 and 4 indicate where semi-quantitative EDS analysis was carried out, and the corresponding results are shown in Table 7.

Points 2 and 3–Fig. 6a–indicate the microstructure of MP cement paste with 15% EAFD admixture. Results obtained in

Table 6
Results of the X-ray diffraction of the reference MP cement pastes (0%) and the MP cement pastes with EAFD ratio addition of 5%, 15% and 25%, respectively, 7 and 28 days old

Chemical compound		EAFD rate (%) in cement pastes			
		0	5	15	25
(1) Calcium hydroxide	$Ca(OH)_2$	X	X	X	X
(2) Ettringite	$(Ca_6Al_2(OH)_{12}(SO_4)_3\,26H_2O)$	X	X	X	X
(3) Calcium silicate hydrate	C-S-H	X	X	X	X
(4) Tridimite	SiO_2	X	X	X	X
(5) Aluminum calcium hydrate oxides	$Ca_4Al_2O_7\,19H_2O$	X	X	X	X
(6) Periclâse	MgO	X	X	X	X
(7) Aluminum potassium silicate	$KAlSiO_4$	X	X	X	X
(8) Franklinite	$ZnFe_2O_4$		X	X	X
(9) Magnetite	Fe_3O_4		X	X	X
(10) Manganese silicate	$MnSiO_3$		X	X	X
(11) Manganese oxide	Mn_3O_4		X	X	X
(12) Calcium Hydrozincate	$Ca(Zn(OH)_3)_2\,2H_2O$		X	X	X

EAFD- eletric-arc furnace dust.
Detected X.

point 2 (Table 7) suggest the formation of a compound of Ca, O and Zn, in accordance with XRD results (Fig. 4) that identified hydrate calcium hydrozincate ($CaZn_2(OH)_6{\cdot}2H_2O$). Differently, in point 3, the main identified elements (Ca, Si, Al and Fe) suggest the formation of a cement hydration product. The presence of Zn was identified, but the authors believe that it is the influence of another region analyzed in point 2, since the scan area of EDS (pear shape) is approximately 5 μm wide.

In Fig. 6b, the microstructure of the MP cement paste with 25% EAFD admixture was identified as an EAFD grain. It can be noticed that it is apparently inert in the MP cement matrix, related with the shape and surface, when compared with Fig. 1. The results shown in Table 7–point 4–confirm the presence of mainly Fe and Zn. In this case, the rates of zinc were higher than those verified in points 2 and 3.

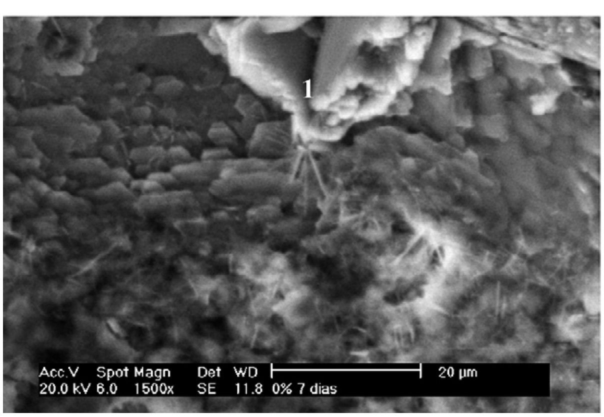

Fig. 5. Scanning electron microscopy by secondary electrons of the 7 day old reference MP cement paste (0%), 1500×. Point 1 refers to the EDS semi-quantitative analysis.

Table 7
EDS semi-quantitative analysis, indicated in Fig. 3 by points 2, 3 and 4 from the 7 day old MP cement pastes with 15% and 25% of EAFD addition

No.	Elements (%)												
	O	Mg	Al	Si	S	K	Ca	Fe	Zn	Mn	Na	Cr	Ni
1	26.6	9.3	–	22.6	–	–	29.9	11.6	–	–	–	–	–
2	32.5	–	–	–	0.9	–	61.5	1.4	2.1	–	1.5	–	–
3	35.6	1.8	3.8	10.9	1.5	1.5	36.3	6.0	2.7	–	–	–	–
4	23.5	0.7	–	1.9	–	–	2.5	55.0	9.0	0.8	–	–	2.4

Hence, until 5% of EAFD addition, no differences related to the microstructural paste with the reference MP cement paste (0%) were observed. For the 15% and 25% EAFD MP cement pastes, it was verified that the presence of products with zinc increases its levels with higher EAFD additions.

Fig. 7a–d show the microstructures of the 28 day old MP cement pastes with 0, 5%, 15% and 25% of EAFD contents, respectively. The numbers presented in Fig. 7 indicate the points where the semi-quantitative elementary chemical analysis was made with EDS and the results are shown in Table 8.

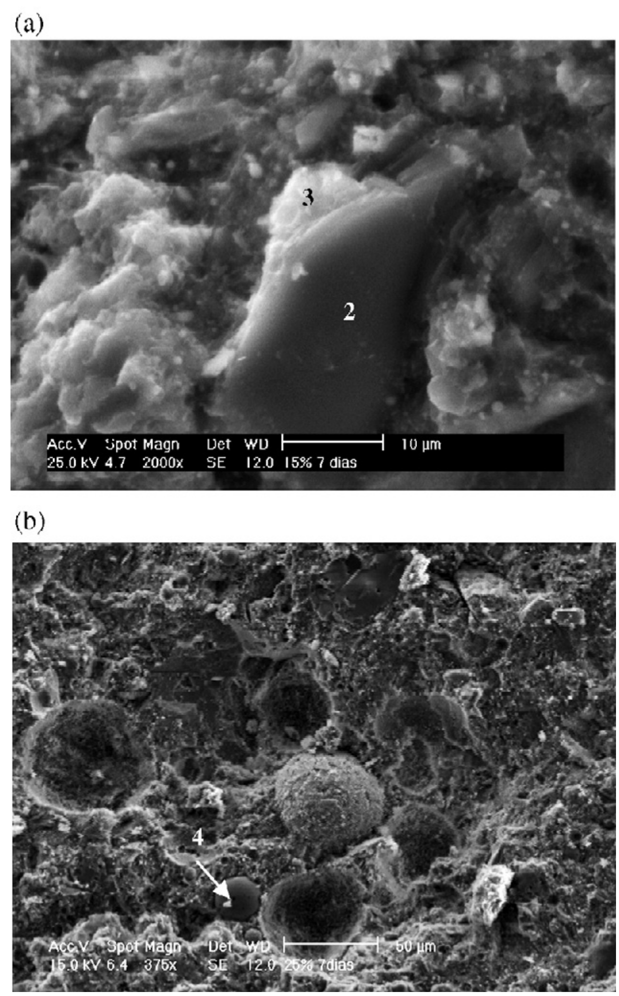

Fig. 6. Scanning electron microscopy by secondary electrons of the 7 day old MP cement pastes with EAFD addition of (a) 15%, 2000× and (b) 25%, 375×. Points 2, 3 and 4 refer to the EDS semi-quantitative analysis.

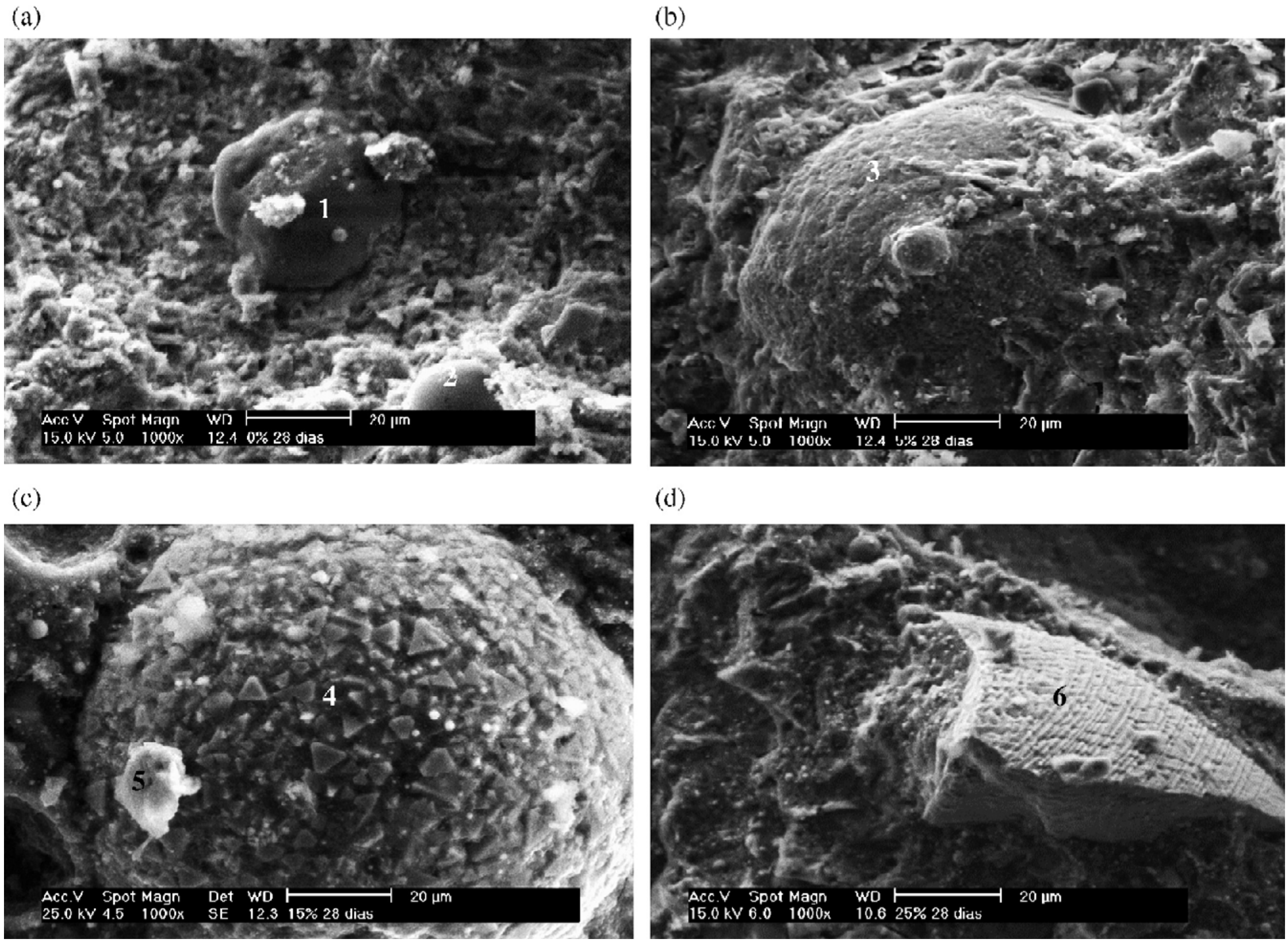

Fig. 7. Scanning electron microscopy by secondary electrons of the 28 day old MP cement pastes, 1000×: (a) reference (0%); with EAFD addition of (b) 5%, (c) 15% and (d) 25%. The points in the figure represent the EDS semi-quantitative analysis.

Common elements of cement hydration, indicated in Table 8—points 1 and 2, were identified in Fig. 7a. This is coherent because it refers to the reference MP cement paste (0%) analysis.

Fig. 7b–5% EAFD MP cement paste–shows the presence of a grain full of Fe that was identified (Table 8, point 3), apparently from the EAFD. Moreover, the calcium (22.0%) and silica (2.86%) percentages suggest a possible formation of a resulting product of the cement hydration reactions with EAFD. Nevertheless, more specified research on this subject deserve further studies.

Table 8
EDS semi-quantitative elementary chemical analysis of the reference cement paste (0%) and pastes with 5%, 15% and 25% of EAFD addition, 28 days old, and indicated in points 1, 2, 3, 4, 5 and 6 in Fig. 4

No.	Elements (%)											
	O	Mg	Al	Si	S	K	Ca	Fe	Zn	Mn	Na	Cr
1	44.9	–	12.4	34.8	–	2.90	5.02	–	–	–	–	–
2	52.6	–	3.6	13.0	–	–	30.8	–	–	–	–	–
3	32.2	–	1.55	2.86	–	1.9	22.0	35.4	–	4.09	–	–
4	10.6	–	1.5	2.0	–	–	9.9	73.7	–	–	0.9	1.4
5	22.9	3.5	1.4	9.7	1.1	1.2	56.1	4.1	–	–	–	–
6	41.4	–	1.61	1.54	–	–	2.56	52.9	–	–	–	–

Observing Fig. 7c–15% EAFD MP cement paste–and analyzing the results by EDS (Table 8, point 4), apparently, it can be verified that the EAFD grain is not inert, because its surface appears to be totally different from the EAFD observed in Fig. 1 (before of its addition into the cement pastes). In addition to this, the presence of cement product hydration has been verified, as identified in point 5, Table 8.

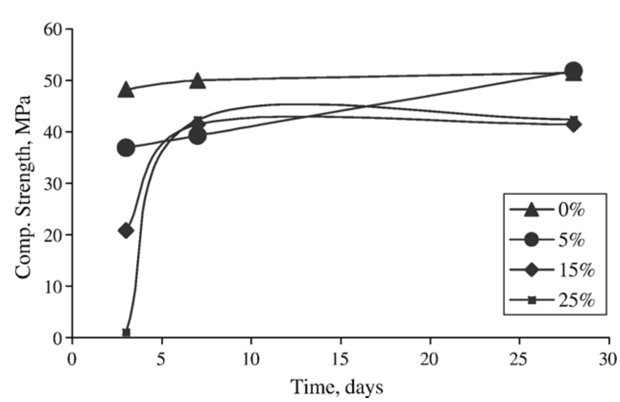

Fig. 8. Compressive strength results of reference MP cement pastes (0%) and for the MP cement pastes with 5%, 15% and 25% of electric-arc furnace dust (EAFD) addition by cement mass. Water/cement ratio in all cases was 0.31.

In point 6, Fig. 7d, the EDS semi-quantitative results indicate an Fe percentage of 52.9 (Table 8), suggesting the EAFD presence, but in a desegregated form, possibly due to the sample preparation for the microscopy test.

Thus, at the age of 28 days, apparently, reactions with the EAFD are occurring because the grain's superficial structure was not as smooth and without pores as it had been noticed in the EAFD grain micrograph (Fig. 1).

3.5. Compressive strength

Fig. 8 presents the compressive strength results in the reference MP cement pastes (0%), and in the MP cement pastes containing EAFD additions in 5%, 15% and 25%.

It can be observed that the MP cement pastes with 0% of EAFD have superior resistance, when compared to the MP cement pastes containing EAFD, independent of the amount added, until the age of 7 days. At 28 days, there is no significant difference in the resistance of the reference pastes, when compared to the pastes containing 5% of EAFD.

On the other hand, the MP cement pastes containing 15% and 25% of EAFD presented inferior resistance to the reference MP cement pastes and the MP cement pastes containing 5%, in the analyzed ages. This is related to the delay in the hydration reactions caused by the EAFD in the initial ages, as verified in the hydration heat measures—Fig. 3. In this figure, it can be observed that the hydration reactions in the samples containing 15% and 25% of EAFD began at approximately 42 and 56 h, respectively. This is why the 25% samples reached compression strength of only 1.05 MPa at the age of 3 days. Between the ages of 3 and 7 days, a significant gain in the compression strength can be observed in the 25% pastes. Nevertheless, contrary to what was expected by the authors, between the ages of 7 and 28 days, there is no significant gain in resistance in the 15% and 25% pastes. This is probably related to the EAFD particles which might be delaying new reactions in the cement hydration during this period, and probably might be elevating its resistance after this age, according to what was verified by Hamilton and Sammes [7]. These authors observed that samples containing 90% of Portland cement and 10% of EAFD only reached resistance similar to the reference samples–60 MPa–at the age of 56 days. Also, Balderas et al. [9] verified that, at the age of 42 days, the pastes that reached higher compressive strengths were those that had higher contents of Portland cement substitutes in EAFD (10%, 8%, 5% and 2%), with resistances which were superior to those reached by the reference pastes (0% EAFD). In other words, even though there is lower compressive strength in the samples with higher values of EAFD in the initial ages, in the more advanced ages, there is a tendency for them to present higher resistance, when compared to the reference samples. But this tendency will depend on factors such as the addition percentage or EAFD substitution in the cementitious materials, on the particle size and on the residue's chemical composition.

4. Conclusions

- ♦ The test for the hydration heat determination permitted a precise evaluation of the reactions of the MP cement paste hydration with EAFD, verifying that more EAFD addition result in a longer time for the cement hydration to start.
- ♦ The identification of peaks which are a characteristic of calcium hydrozincate in pastes containing EAFD at 28 days, compared to the resistance results to compression for these pastes at the same age (around 40 MPa in resistance), indicate that the calcium hydrozincate does not interfere in the cement's hydration reactions.
- ♦ Compressive strength in MP cement pastes with high quantities of EAFD is low in the initial ages. Nevertheless, in more advanced ages, there is a significant growth in resistance. It was possible to verify in this research that MP cement pastes containing 5% of EAFD presented similar resistance to the reference MP cement pastes at the age of 28 days. The MP cement pastes with 15% and 25%, in the same age, presented 80% of the reference MP cement pastes resistance and of the MP cement pastes containing 5% of EAFD.

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