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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	Cement+ 15% EAFD	Cement+ 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

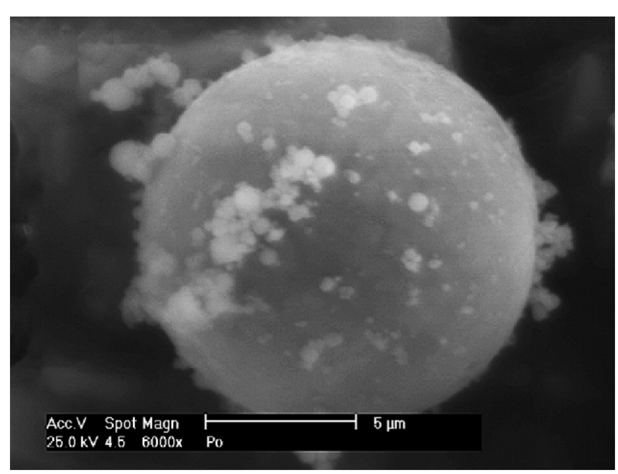

Fig. 1. Scanning electron microscopy by secondary electrons of an EAFD sample: (a) 3000×, (b) 6000×.