- Topic: S11. Materiales para la construcción

Incorporation of industrial wastes from thermal processes in cement mortars

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A B S T R A C T

This work presents the results of the incorporation of some industrial wastes from thermal processes in cement mortars. Employed wastes were generated in electric arc furnace (EAF) steelmaking and in steel foundry production.
Namely, research with mortars containing EAF dusts and foundry sands and slags were conducted. Mechanical and environmental evaluation has been done, to compare the waste containing cement mortars samples with the normal one.
The results indicated that the incorporation of these wastes generated in thermal processes in cement mortars does not affect significantly the mechanical properties, namely the flexural and compressive strength, and does not induce any relevant environmental impact when the materials have to be considered as waste, at the end of their life cycle. As a matter of fact, the cement mortar, if becoming a residue, may be considered as an inert one.
The results of this work indicate that the incorporation of these wastes in cement mortars is an adequate waste management option.

Keywords: Wastes, cement mortars, EAF dusts, foundry sands, slags

R E S U M E N

Este trabajo presenta los resultados de la incorporación de algunos residuos industriales generados a partir de procesos térmicos en los morteros de cemento. Los residuos son los generados en hornos de arco eléctrico (EAF) de producción de acero y en la producción de fundición de acero.
Se llevó a cabo la investigación con morteros que contienen estos polvos, arenas y escorias de fundición. Se realizó una evaluación mecánica y ambiental para comparar los morteros que contienen residuos con el normal.
Los resultados indicaron que la incorporación de estos residuos en los morteros de cemento no afecta significativamente las propiedades mecánicas, es decir, resistencia a la flexión y resistencia a la compresión, y no provocan ningún impacto ambiental pertinente cuando el material tiene que ser considerado como residuo, en el final de su ciclo de vida. Efectivamente, si el mortero de cemento, se convertirse en un residuo, ello se puede considerar como un residuo inerte.
Los resultados de este trabajo indican que la incorporación de estos residuos en cementos es una vía de gestión adecuada

Palabras Clave: Residuos; morteros de cemento; polvos siderúrgicos, arenas de fundición, escórias de fundición.

1. Introduction

Industrial wastes from thermal processes, like electric arc furnace dusts (EAF dusts) and steel foundry production, as used sands and slags, are environmental problems that have to be faced by industry, implying correct management options from the environmental point of view.

Some of these wastes, as is the case of EAF dusts, are classified as hazardous wastes, due to their heavy metal contents. Other like used green sands and furnace slags from steel foundries, may, in certain cases, be classified as inert residues.

EAF dusts, due to their high zinc content, are able to be recycled to recover this metal, as well as lead and cadmium [1,2]. However, in many situations, recycling plants are not located near steelmaking units, thus becoming transportation costs of the hazardous wastes an issue that limits the recovery rate. In other situations, metal prices and administrative aspects, like legalization of export of wastes, may affect this recycling activity. Because of that, the search for alternative valorization routes may be interesting from a practical point of view.

Foundry sands and furnace slags are usually non hazardous wastes, but with few interest to be recycled, due to the low value of the contained materials. For this reason, they are often sent to landfill, as inert or non-hazardous residues, however with some environmental concerns.

In Portugal, the present situation with these types of wastes is:

- EAF dusts: generated about 30 000 ton/year. If zinc prices are high, they are recycled outside the country. If zinc prices are low, they are dumped in landfills for hazardous wastes;
- Used foundry sands: generated about 80 000 ton/year, almost all of them being sent to landfills, just a small part being incorporated in clinker production;
- Foundry furnace slags: generated around 5 000 ton/year, all of them being landfilled.

In all these situations, the possibility of incorporating the wastes in cement based materials can be a reasonable way to manage them, better, from a sustainable point of view, than landfilling.

This work presents the results of experiments that have been made at the University of Minho, Portugal, demonstrating the viability of these incorporation methods, if done under controlled conditions.

2. Experimental procedures

Employed wastes have been characterized for chemical composition by X-ray fluorescence spectrometry, using a X'Unique II equipment from Philips, and elemental analysis for carbon and sulphur, using a C-S 200 equipment from LECO, all of them available at the Laboratory of Metallurgy of the University of Minho, in Guimarães, Portugal.

Portland cement CEM 1, 42,5 R class, according to NP EN 206-1:2007 standard [3] was used for the tests. The cement was produced from SECIL - Companhia Geral de Cal e Cimento, SA, and presents a minimum of 42,5 MPa of compressive strength after 28 days [4].

Sand employed for the tests was a standard sand according to EN 196-1, produced by Societé Nouvelle du Litoral, Leucate, France.

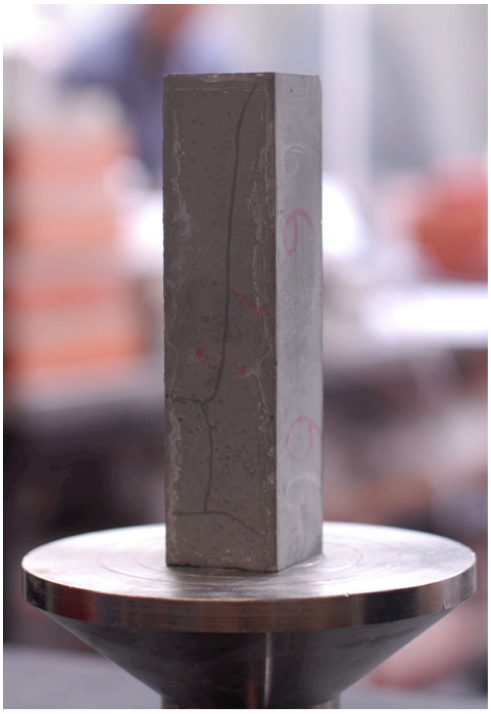

Figure 1 - Specimen of mortar with 160 x 40 x 40 mm

Mixing of the cement, inert part and wastes was done in paralelipipedic moulds with 160 x 40 x 40 mm size.

Mortar samples were prepared with 25 % weight of cement, the rest being sand and wastes, in different proportions, employing hence, always, a binder/ aggregate ratio of 1:3. Binder, wastes and water were mixed for a period of 30 minutes. A mechanical compacter was used, shaking the samples with a total of 60 strokes. After that, samples were cured under water for 7 and 28 days, after which time, flexural and compressive strength have been determined, according to BS-EN 1015-11: 1999 [5].

In all cases, the mass quantity of added water was half of that of cement. Four samples were tested after 7 days, for each condition, and another four at 28 days.

Environmental evaluation has been done on the mortars obtained after 28 day, by leaching the mortar in water, according to a relationship 1:10, for solid:liquid. Leaching was done under agitation in a rotary equipment, at 7,5 rotation per minute, during 24 hours, according to what is defined in standard EN 12457-4:2002 [6]. Then, the leachate was filtered and analyzed for parameters according to Table nº 2 of Annex IV of Decreto-Lei 183/2009, the Portuguese legislation transposing European directives, for the purpose of admission of wastes in landfills [7]. The values are compared with the limit values, to determine the acceptance in such a type of landfill, thus allowing conclude about the inertness of the material.

3. Results

3.1. Chemical characterization of materials

X-ray Fluorescence spectrometry and elemental analysis allowed determine the chemical compositions of the wastes, as indicated in Table 1.

Table 1 – Chemical composition of the wastes

Component	EAF dust	Foundry	Foundry
C	2,9	2,1	0,06
S	0,62	0,85	0,30
SiO_2	9,7	90,4	43,5
Al_2O_3	6,7	3,5	11,0
CaO	12,9	0,36	0,46
MgO	3,2	0,09	0,12
Fe_2O_3	32,1	1,45	5,8
ZnO	22,6	0,32	< 0,05
MnO	2,4	0,26	36,3
PbO	3,7	< 0,05	< 0,05
CdO	0,23	< 0,05	< 0,05

3.2. Mechanical characterization of mortars

Table 2 and Table 3 present, respectively, the results of the flexural strength and compressive strength determinations, obtained after 7 and 28 curing days. All results are present as the average of 4 specimens' determinations, the irrespective standard deviation of the results being also indicated. The percentage indicated for each experiment is the ratio of replacement when calculated with reference to the amount of the standard sand.

Table 2 – Results of the flexural strength (in MPa)

	7 days		28 days	
	Average	st. dev.	Average	st. dev.
Standard	5,32	0,27	6,23	0,46
0,5 % EAF dusts	4,67	0,29	5,48	0,32
1% EAF dusts	4,39	0,51	4,88	0,37
20 % foundry sand	4,37	0,23	4,81	0,30
40 % foundry sand	4,21	0,37	4,45	0,26
20 % foundry slag	4,58	0,19	5,32	0,25
40 % foundry slag	4,42	0,31	5,11	0,22

Table 3 – Results of the compressive strength (in MPa)

	7 days		28 days	
	Average	st. dev.	Average	st. dev.
Standard	25,3	1,6	32,5	3,0
0,5 % EAF dusts	26,3	2,2	30,8	0,9
1% EAF dusts	25,8	6,0	32,8	1,6
20 % foundry sand	21,2	3,3	28,4	0,7
40 % foundry sand	20,2	2,7	26,5	1,5
20 % foundry slag	22,6	2,6	29,5	3,0
40 % foundry slag	20,8	1,7	26,9	2,4

3.3. Environmental characterization of the mortars

Tables 4 to 6 presents the results of the leaching experiments done on the speciments, after curing for 28 days.

Table 4 – Results of the leaching tests for standard and EAF dusts containing samples (values in mg/kg of dry matter)

	Limit	Standard	0,5 % EAF dusts	1% EAF dusts
As	0,5	< 0,01	0,04	0,04
Ba	20	< 1	< 1	< 1
Cd	0,04	< 0,01	< 0,01	< 0,01
Cr total	0,5	< 0,01	< 0,01	< 0,01
Cu	2	< 0,01	< 0,01	< 0,01
Hg	0,01	< 0,001	< 0,001	< 0,001
Mo	0,5	< 0,01	< 0,01	< 0,01
Ni	0,4	< 0,01	0,08	0,05
Pb	0,5	< 0,01	0,06	0,11
Sb	0,06	< 0,01	< 0,01	< 0,01
Se	0,1	< 0,01	< 0,01	< 0,01
Zn	4	< 0,01	0,03	0,07
Chloride	800	22	38	34
Fluoride	10	< 1	< 1	< 1
Sulphate	1 000	240	200	310
Fenol index	1	< 0,1	< 0,1	< 0,1
Dissolved C	500	< 50	< 50	< 50
Dissolved solids	4 000	770	880	900

Table 5 – Results of the leaching tests for standard and foundry sand containing samples (values in mg/kg of dry matter)

	Limit	Standard	20 % sand	40 % sand
As	0,5	< 0,01	< 0,01	< 0,01
Ba	20	< 1	< 1	< 1
Cd	0,04	< 0,01	< 0,01	< 0,01
Cr total	0,5	< 0,01	< 0,01	< 0,01
Cu	2	< 0,01	< 0,01	< 0,01
Hg	0,01	< 0,001	< 0,001	< 0,001
Mo	0,5	< 0,01	< 0,01	< 0,01
Ni	0,4	< 0,01	0,03	0,06
Pb	0,5	< 0,01	0,03	0,09
Sb	0,06	< 0,01	< 0,01	< 0,01
Se	0,1	< 0,01	< 0,01	< 0,01
Zn	4	< 0,01	0,15	0,25
Chloride	800	22	45	76
Fluoride	10	< 1	< 1	< 1
Sulphate	1 000	240	350	410
Fenol index	1	< 0,1	0,2	0,1
Dissolved C	500	< 50	90	120
Dissolved solids	4 000	770	930	1 080

Table 6 – Results of the leaching tests for standard and foundry furnace slag containing samples (values in mg/kg of dry matter)

	Limit	Standard	20 % slag	40 % slag
As	0,5	< 0,01	< 0,01	< 0,01
Ba	20	< 1	< 1	< 1
Cd	0,04	< 0,01	< 0,01	< 0,01
Cr total	0,5	< 0,01	0,04	0,06
Cu	2	< 0,01	< 0,01	< 0,01
Hg	0,01	< 0,001	< 0,001	< 0,001
Mo	0,5	< 0,01	< 0,01	< 0,01
Ni	0,4	< 0,01	< 0,01	< 0,01
Pb	0,5	< 0,01	0,02	0,03
Sb	0,06	< 0,01	< 0,01	< 0,01
Se	0,1	< 0,01	< 0,01	< 0,01
Zn	4	< 0,01	0,05	0,07
Chloride	800	22	18	27
Fluoride	10	< 1	< 1	< 1
Sulphate	1 000	240	400	650
Fenol index	1	< 0,1	< 0,1	< 0,1
Dissolved C	500	< 50	< 50	< 50
Dissolved solids	4 000	770	1020	890

4. Conclusions

As conclusions of this work we can indicate that:

- the incorporation of wastes derived from thermal processes in cement mortars induce a slight decrease in mechanical properties, when compared with mortars produced solely with standard sand. However, this slight decrease is normally not relevant for industrial practical applications, as this is in the same order of magnitude as those occurring with other, non standard, aggregates;
- in all cases, the incorporation of these industrial residues in mortars, allows products that may be classified as inert if, at the end of their life cycle, they have to be considered as a waste to dispose in landfill. Even if some effects are evident

from these results, they are clearly behind the limits imposed by Portuguese and European legislation for waste disposal;

- the incorporation of these wastes in cement mortars may be a reasonable technical and environmental solution for their management, as this replace the need for virgin aggregates, with no major effects on mechanical properties or environmental issues.

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