Information Sheet

COMPLETE TITLE OF THE PAPER: LABORATORY AND FIELD LEACHING TESTS FOR PREDICTING THE ENVIRONMENTAL IMPACT OF PORTUGUESE STEEL SLAG

SHORT TITLE WITHIN 60 CHARACTERS (If Applicable): LEACHING TESTS FOR PREDICTING THE ENVIRONMENTAL IMPACT OF STEEL SLAG

CORRESPONDING AUTHOR:

Complete Name: António José Roque

Affiliation: Laboratório Nacional de Engenharia Civil

Fax nr.: (+351) 218443021

e-mail: aroque@lnec.pt

PRESENTING AUTHOR:

Complete Name: António José Roque

e-mail: aroque@lnec.pt

Laboratory and field leaching tests for predicting the environmental impact of Portuguese steel slag

A. J. Roque
Laboratório Nacional de Engenharia Civil (LNEC), Lisbon, Portugal (aroque@lnec.pt)
F. Castro
Centre for Reuse of Waste (CVR), Guimarães, Portugal (fcastro@dem.uminho.pt)
A. Gomes Correia
Engineering School of the University of Minho (EEUM), Guimarães, Portugal (agc@civil.uminho.pt)
S. Silva
Centre for Reuse of Waste (CVR), Guimarães, Portugal (asilva@cvresiduos.pt)
A. Cavalheiro
Portuguese Iron and Steel Company (ISC), Seixal, Portugal (acavalheiro@seixal.snlongos.pt)

ABSTRACT The use of waste in the construction of Portuguese public works is feasible if there are no risks for the environment. The materials that meet these requirements in Portugal are those admissible for landfills of inert waste, their classification being done on the basis of the comparison of the leaching values obtained in standard laboratory leach tests with the leaching limit values established in the Portuguese legislation. This paper addresses the results of the leaching tests performed in laboratory and in the field with materials coming from electrical arc furnace steel slag produced in the Portuguese Iron and Steel Company.

INTRODUCTION

This paper addresses the laboratory and field studies performed with a view to assess the environmental impact of electrical arc furnace steel slag produced in Portugal by the Iron and Steel Company (ISC), at its industrial facilities of Seixal (ISC Seixal), south of Lisbon, and of Maia (ISC Maia), north of Porto.

Comparatively with the characterisation of natural granular materials, the waste must not only be characterised from a geotechnical viewpoint, but also from a geoenvironmental viewpoint, the latter aiming to consider the pollutant potential for the environment and for public health. In Portugal, waste can only be used in civil engineering works if it is classified as admissible for landfills of inert waste, their classification being done on the basis of the comparison of leaching values obtained in laboratory leach tests with the leaching limit values defined in the applicable legislation.

The present study is part of a Research and Development Project conducted at a national level between 2005 and 2009. Its main purposes were to promote the recycling of steel slag in transportation infrastructures and geotechnical works and to contribute to create an environmental and mechanical methodology ultimately intended to promote the recycling of other waste in that type of works, within the framework of a sustainable construction policy and of an appropriate management of resources.

On the basis of the work developed, the waste "steel slag" is, after processing in the industrial facilities of ISC, marketed as recycled aggregate with the designation "Inert Steel Aggregates for Construction – ISAC", which has enabled the Portuguese Company to sell the 250,000 tons produced every year. Therefore, the electrical arc furnace steel slag will be henceforth designated in this paper as "ISAC".

Despite the classification of the environmental impact of waste in the Portuguese legislation considering only the leaching values obtained in standard laboratory leach tests, the leachability of the ISAC has also been studied in the field, by taking into account that: (a) the laboratory leach test conditions are very different from the site conditions, and (b) some studies, such as the European Project ALT-MAT, performed in 1998-1999, mention that the waste leaching performed in laboratory is conservative when compared with the one performed in the field, which may render the recycling of some waste infeasible. The field leach test was performed on an trial embankment section, with about 60 m length and 3 m height, built on a National Highway, north of Portugal, about 75 km from ISC Maia.

FROM STEEL SLAG TO ISAC

Steel slag is initially separated from liquid steel and emptied in a steel slag pit (Fig. 1). It is afterwards subject to one appropriate processing so as to be recycling as ISAC in the transportation infrastructures and geotechnical works. The three phases of that processing are described below (Roque et al., 2007).

Phase A: Flow and cooling of steel slag

A.1: Transferring steel slag from the pit to an impervious zone, cooling with water, and transport to the storage/treatment zone;

A.2: Cooling to air at the storage/processing zone (may be accelerated by water). The resulting material is designated as non-processed steel slag.

Phase B: Recycling of the metallic component

B.1: Breaking up of larger steel slag plates and recovering the larger metallic components;

B.2: Separating the metallic parts from the non-metallic parts using magnetic drums. The metallic parts are to be recycling in steel production. Only a small quantity of minor metallic scraps is present in the remaining steel slag.

Phase C: Recycling of the non-metallic component

C.1: Sieving/grading in various grain-size ranges (Fig. 2);

C.2: New mechanical breaking up, with possible grinding, to produce finer grain-sizes;

C.3: Elimination of smaller metallic scraps, not eliminated in the previous phase, by passage with magnetic plate and/or re-processing, by passing again the material in the magnetic roller;

C.4: Storage and maturation by hydration to air, for the time necessary to neutralise the remaining lime.

Fig. 1 Steel slag after being separated from liquid steel.

Fig. 2 Classification of the material.

GEOTECHNICAL PROPERTIES OF ISAC

In order to assess the technical possibility of using ISAC in the construction of transportation infrastructures and geotechnical works, an extensive experimental programme was implemented in laboratory to study their chemical, mineralogical, geometrical, physical and mechanical properties. Considering the objective of this paper, it only presents the results necessary for the brief geotechnical characterisation of ISAC.

To study the chemical and mineralogical properties of the global fraction of ISAC, 5 samples were collected from a pile with a 3-month maturation and 5 samples were collected from a pile with a 6-month maturation at the storage facilities of ISC Maia and ISC Seixal. The other properties of ISAC from ISC Maia were studied on a sample collected from a pile with a 6-month maturation, and of ISAC from ISC Seixal were studied on a sample collected from a pile with a grain-size in the range of 0-40 mm diameter (the maturation time was unknown).

The contents of the chemical species were obtained by X-ray fluorescence spectrometry, for a basis of 100% in weight. The three chemical species with the highest percentages are iron oxide (Fe_2O_3), calcium oxide (CaO) and silicon oxide (SiO_2), which from the set of all chemical analyses, range, respectively, from 30.40 to 48.23%, 23.80 to 35.21%, and from 11.96 to 15.72%. As a whole, these elements represent a percentage of 81.33 to 84.44% of the chemical composition of steel slag. The chemical compositions obtained for the ISAC from the two ISC demonstrate that the variation in the intra-ISC composition is less, for the majority of the chemical species, than the variation in the inter-ISC composition. The mineralogical analysis was performed by X-ray diffraction and complemented by electron scanning microscopy. At ISC Maia, the following minerals were identified: wustite ($Fe_{0.965}O$), hematite (Fe_2O_3), kirschsteinite ($Ca(FeO_{0.69}MgO_{0.31})SiO_4$) and akermanite ($Ca_2Mg(Si_2O_7)$) and at ISC Seixal: wustite, calcium silicate (Ca_2SiO_4) and ghelenite ($Ca_2Al(AlSiO_7)$).

For assessing the geotechnical properties of steel slag, Portuguese standards/specifications have been adopted whenever possible. In fact, at the time, many known reference studies were also performed on the basis of Portuguese standards/specifications. TABLE 1 shows some of the geotechnical properties obtained for the ISAC (Gomes Correia et al., 2009), demonstrating that it is a well-graded and non-plastic material. The values obtained for the compaction parameters show that the maximum dry density is high and the optimum water content is low. The values obtained in Los Angeles and micro-Deval tests demonstrate that it is a material with a good resistance to fragmentation and abrasion.

TABLE 1 Geotechnical properties of the Portuguese ISAC

Property	Standard/ Specification	Parameter		Result	
				ISC Seixal	ISC Maia
Geometrical	E LNEC 196	Grain-size	Fine boulder (60 mm < D ≤ 200 mm), (%)	0.0	1.5
			Gravel (2 mm < D ≤ 60 mm), (%)	74.0	88.5
			Sand (0.06 mm < D ≤ 2 mm), (%)	19.5	8.5
			Fines (D ≤ 0.075 mm), (%)	6.5	1.5
Physical	E LNEC 199	Sand equivalent, SE (%)		80	100
	NF P 18-592	Methylene Blue Value, MB (%)		0	0
	NP 143	Atterberg limits		NP	NP
Mechanical	E LNEC 197	Modified Proctor	Maximum dry density, ρ_{dmax} (x 10^3 kg/m^3)	2.32	2.43
			Optimum moisture content, OMC (%)	5.0	4.8
	E LNEC 237	Los Angeles, LA (%)		23	28
	NP EN 1097-1	Micro-Deval, MD (%)		11	11

STUDY OF THE ENVIRONMENTAL IMPACT OF ISAC USING LEACH TESTS

Batch tests

The leachability potential of ISAC was only studied on samples collected from ISC Maia. TABLE 2 presents the leaching values collected from piles with 3- and 6-month maturations, respectively. The values presented by the other elements correspond to the leachability potential of a single sample, collected from the pile with a 3-month maturation.

In the period when the tests were performed, the applicable Portuguese legislation in force was the Decree-law nr. 152/2002, 23 May, and, therefore, the German standard DIN 38414-S4 was adopted rather than the European Standard EN 12457-Part 2 or Part 4, defined in the Portuguese legislation that is presently in force (Decree-law nr. 183/2009, 10 August).

Comparing the leaching values obtained with the leaching limit values established in Decree-law nr. 152/2002 for waste admissible in inert waste landfills, it is observed that all elements present lower values, sometimes significantly lower, than the leaching limit values required. Hence, ISAC is, from a leachability point of view, and in accordance with the requirements established in the mentioned legislation, a waste admissible for inert waste landfills.

TABLE 2 Results of the batch tests and environmental classification of the Portuguese ISAC

Parameter	Leachate composition of ISAC		Limiting conc. value for inert waste[b]	Classification (Decree-Law n.º 152/2002)
	3-month maturation piles[a]	6-month maturation piles[a]		
pH (—)	9.8-10.9[*]	10.3-11.0[*]	5.5<x<12	Inert
Electrical conductivity (mS/cm)	0.098-0.151[*]	0.115-0.243[*]	6<y<50	Inert
Ammonium (mg N/l)	<0.13[*]	<0.13[*]	5	Inert
AOX-Adsorbable Organic Halogens (mg Cl/l)	<0.01	—	0.3	Inert
Arsenic (mg/l)	<0.0018	—	0.1	Inert
Cadmium (mg/l)	<0.009-0.01[*]	<0.009[*]	0.1	Inert
Lead (mg/l)	<0.06[*]	<0.06[*]	0.5	Inert
Cyanide (mg/l)	<0.05	—	0.1	Inert
Chloride (mg/l)	<3[*]	<3[*]	500	Inert
Copper (mg/l)	<0.025[*]	<0.025[*]	2	Inert
COT - Carbon Organic Total (mg C/l)	3.8	—	40	Inert
Chromium VI (mg/l)	<0.05	—	0.1	Inert
Total chromium (mg/l)	<0.06[*]	<0.06[*]	0.5	Inert
Phenol (mg/l)	<0.01	—	1	Inert
Fluoride (mg/l)	0.04	—	5	Inert
Mercury (mg/l)	<0.002	—	0.02	Inert
Nickel (mg/l)	<0.04[*]	<0.04[*]	0.5	Inert
Nitrite (mg/l)	<0.04	—	3	Inert
Sulphate (mg/l)	<10[*]	< 10[*]	500	Inert
Zinc (mg/l)	<0.008[*]	< 0.008[*]	2	Inert

[a]Values with "[*]" proceed from 5 batch tests, the remaining values proceed from one batch test. [b]Established in the Portuguese legislation (Decree-Law n.º 152/2002) for waste admissible in inert waste landfills.

Lysimeter tests

The leachability study of ISAC in the field was conducted on a trial embankment section, built at km 13+600 of National Highway EN 311, linking Fafe to Cabeceiras de Basto. For the purpose, the embankment was monitored with a lysimeter. Fig. 3 shows its location in the trial section, both in plan (Fig. 3a) and in cross-section (Fig. 3b). The Fig. 3 also shows the trial embankment monitored with a lysimeter in the section built with granitic gravel, but of which the leaching results are not presented in this paper. The longitudinal cross-section of the trial embankment presented in Fig. 4 shows the different sections forming it.

The dimensions of the ISAC leaching column in the lysimeter corresponded to 2.0mx1.0mx1.4m (length, width, height), the leachate reception basin being installed in the second layer of the trial embankment.

The collected leachate was mainly produced by feeding the lysimeter with water from a joper. This was only possible due to the high hydraulic conductivity of the ISAC, which made it possible to substantially reduce the time necessary for producing a significant amount of leachate. The remaining leachate was a result of rainwater. During leaching, the leachate produced outside the lysimeter column is assumed to have poorly contributed to feeding the reception basin.

The leaching values obtained on the 11 samples collected are presented in TABLE 3, the same parameters of the laboratory tests having also been analysed. The samples ISAC 1-ISAC 5 and ISAC 7-ISAC 8 were collected during the feeding of the lysimeter by the water from the joper and samples ISAC 6 and ISAC 9-ISAC 11 during the feeding by rainwater. The water from the joper was also sampled for chemical analysis and background element concentrations. For financial reasons, a criterion was adopted, which did not involve the determination of all parameters on all samples. Therefore, we decided that all the elements with concentrations below the quantification limit of the method used would not be subject to dosage.

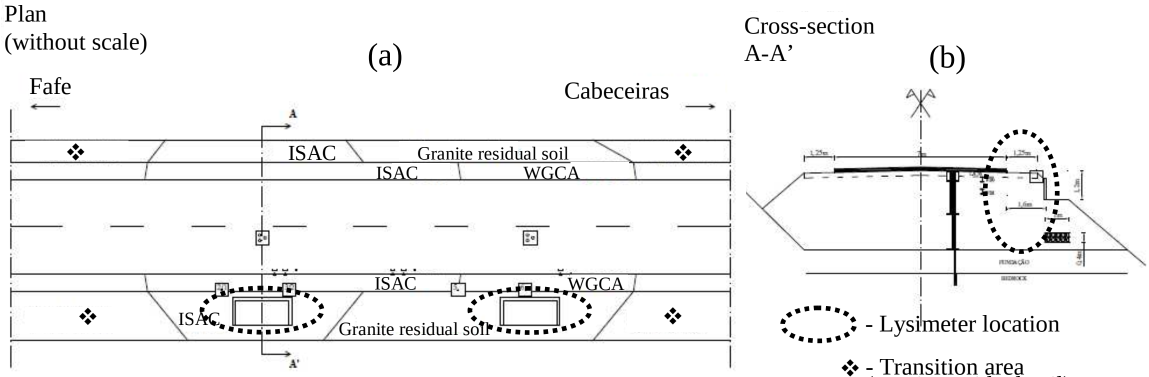

Fig. 3   Location of the lysimeters in the trial embankment road section.

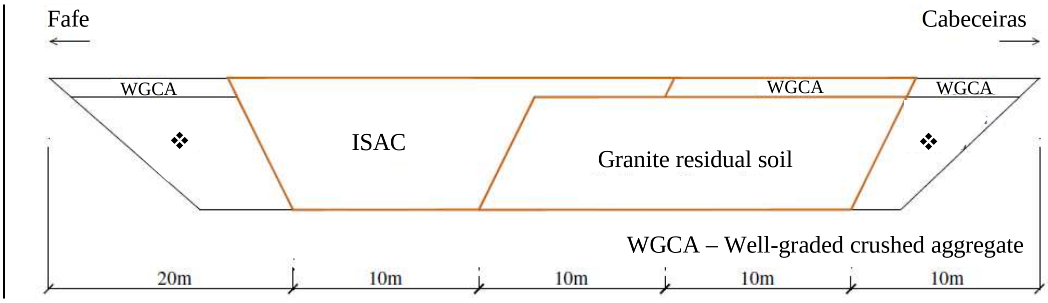

Fig. 4   Longitudinal profile of the trial embankment road section.

The results obtained were compared with the leaching limit values established by Decree-law nr. 152/2002. Nonetheless, in this analysis, it is necessary to make sure, on the one hand, that the leaching limit values laid down in the legislation have been actually defined for the leach test performed in laboratory, in accordance with the German standard DIN 38414-S4, and, on the other hand, that the liquid (L)/solid (S) ratio defined in that standard corresponds to 10 l/kg, i.e., being substantially higher than the one observed in the lysimeter.

Even in the sample with the lowest L/S ratio (i.e., ISAC 1, with L/S = 0.05 l/kg) and much less than the one of laboratory tests (L/S = 10 l/kg), it is observed that the leaching values are less or even significantly less than the leaching limit values established in Decree-law nr. 152/2002, except for nitrite, which has a value higher than the one defined in the legislation. It is also observed that the contents of elements, which initially had a higher concentration, have rapidly decreased during the leaching process. For instance, sulfates decreased from 431 mg/l to 81 mg/l, i.e., about 5 times less, and chlorides from 183 mg/l to 11 mg/l, i.e., about 16 times less. In sample ISAC 5, all elements present values less than the leaching limit values defined in the mentioned legislation. With the simplifications and considerations presented above, it can be concluded that the leaching done in the lysimeter also demonstrates that the ISAC does not involve any risk for the environment and for public health.

TABLE 3 Results of the lysimeter tests

Parameter[a]	ISAC 1[(f)] (113.5 l)	ISAC 2 (248.5 l)	ISAC 3 (408.5 l)	ISAC 4 (568.5 l)	ISAC 5 (808.5 l)	ISAC 6[(g)] (1048.5 l)	ISAC 7 (1583.5 l)	ISAC 8 (2586.5 l)	ISAC 9[(g)] (2711.5 l)	ISAC 10[(g)] (2836.5 l)	ISAC 11[(g)] (2961.5 l)
pH (—)	11.5	11.2	—	—	—	—	—	—	—	—	—
EC[b]	25.6	2.2	—	—	—	—	—	—	—	—	—
Ammonium[c]	<0.13	<0.13	—	—	—	—	—	—	—	—	—
AOX[d]	0.02	0.03	0.027	0.016	—	—	—	—	—	—	—
Arsenic	<0.002	<0.002	—	—	—	—	—	—	—	—	—
Cadmium	<0.009	<0.009	—	—	—	—	—	—	—	—	—
Lead	<0.06	<0.06	—	—	—	—	—	—	—	—	—
Cyanide	<0.05	<0.05	—	—	—	—	—	—	—	—	—
Chloride	183	136	103	51	58	66	9	7	19	20	11
Copper	0.076	0.15	0.11	0.06	0.04	0.08	<0.025	<0.025	0.03	<0.025	0.03
COT[e]	18.9	29.8	—	—	—	—	—	—	—	—	—
Chromium VI	<0.05	0.17	0.14	0.1	0.08	0.06	<0.05	<0.05	0.1	<0.05	0.1
T. chromium	0.3	0.3	0.18	0.06	0.05	0.08	<0.05	<0.05	0.08	<0.05	0.06
Phenol	0.02	0.04	<0.01	0.02	0.07	0.09	0.09	0.09	0.02	0.01	0.08
Fluoride	1.19	0.02	0.82	0.79	0.28	0.43	0.26	0.23	0.35	0.3	0.32
Mercury	<0.001	<0.001	—	—	—	—	—	—	—	—	—
Nickel	<0.04	<0.04	—	—	—	—	—	—	—	—	—
Nitrite	14	0.09	0.11	4	2	<0.04	1	1	<0.04	0.5	<0.04
Sulphate	431.28	411	170	106	135	175	58	24	98	64	81
Zinc	<0.006	<0.006	—	—	—	—	—	—	—	—	—

[a](mg/l), [b]EC-Electrical conductivity (mS/cm), [c](mg N/l), [d]AOX-Adsorbable Organic Halogens (mg Cl/l), [e]COT-Carbon Organic Total, [f]Leachate volume collected in the lysimeter. (the total volume collected was 2961.5 l), [g]Leachate produced in the lysimeter for rain water. In the remaining samples, the leachate was produced for water coming from a joper.

Obs.: The symbol < (less than) represents the limit of quantification of the method used.

CONCLUSIONS

This paper addressed the study of the leachability potential of an Inert Steel Aggregate for Construction (ISAC), which resulted from the processing of electrical arc furnace steel slag produced by the Portuguese Iron and Steel Company. The main purpose of this study was to assess the impact for the environment and for public health when it is used at the site.

The leach tests performed in laboratory have demonstrated that the leaching values of the ISAC meet the minimum requirements defined by the Portuguese legislation regarding waste admissible for landfills of inert waste. The waste included in this class has been approved by the Portuguese Environment Agency for recycling in civil engineering works. The field leaching tests also demonstrated a low leachability potential of ISAC and that its concentration has decreased very rapidly since the initial leaching stage.

ACKNOWLEDGEMENTS

The authors wish to thank the Portuguese Foundation for Science and Technology for the financial support provided to this study (File PPCDT/ECM/56952/2004), through the Operational Programme for Science and Innovation 2010 (POCI 2010) and the European Regional Development Fund (ERDF).

REFERENCES

Roque A. J., Gomes Correia A., Fortunato E., Pardo de Santayana F., Castro F., Ferreira S. and Trigo L. (2007) The geotechnical reuse of Portuguese inert siderurgical aggregate. *Proc. of XIII Pan-Am. Conf. on Soil Mech. and Geotech. Eng.*, Margarita Island, Venezuela, 6 p.

Gomes Correia A., Ferreira S., Roque, A. J. and Cavalheiro, A. (2009) Processed Portuguese steel slags. A new geomaterial. *Proc. of 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields (BCRA)*, Champaign, Illinois, USA, 8 p.