ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume X (XX), 2011, NR2

CHARACTERIZATION OF THE ELECTRIC ARC FURNACE DUST

Elena Chirila[1], Cornelia Ionescu Luca [1]
[1]Technical University "Gheorghe Asachi" of Iasi-Romania
cionescu@tex.tuiasi.ro

Keywords: electric arc furnace dust, chemical, physical, chemical, structural and morphological characterization

Abstract. Electric arc furnace dust, (EAFD), is a toxic waste product which results during the steelmaking process. It is a hazardous industrial waste generated in the collection of the particulate material during the process via electric arc furnace. Important elements to the industry such as Fe and Zn are the main ones in EAFD. Due to their presence, it becomes very important to know how all of these elements are combined before studying new technologies for its processing. The aim of this paper is to carry out a physical, chemical, structural and morphological characterization of the EAFD.

1. INTRODUCTION

It is already proved that the share of the electric arc furnace, (EAF) process in the world's steelmaking is increasing. This is evident from the yearly data on steel production in 1970, amounting to 595 million tons, 14% of which being produced by the EAF Technology; in 1980, the EAF accounted for 23% of the total world output 716 million tons; in 1990, the share of the EAF process in the world's steelmaking was 28% of the total of 770 million tons and in 1998, it was 34% of the total 776 million tons, [5]. During the steel-making process, major pollution that is environmental released includes solid particles, the so called "dust", carbon oxides, nitrogen oxides and volatile organic components. Trace element analysis of powdered or particulate material is often required in environmental monitoring of many industrial wastes.

The European Community Council Directive (91/156/CEE) requires control of harmful and toxic products quantity environmental concerns, among steelmakers all over the world, is treatment and disposal of dusts from the electric arc furnace. During the steelmaking process in EAF, 15...20 kg of the dust is generated per ton of steel product. The world generation of EAF dust, (EAFD) is estimated to be around 3,7 million tons per year and the shear of the European Plants is around 500,000...900,000 tons of dust per year, the greatest dust generators being Italy (about 170,000 tons per year), Germany (about 160,000 tons per year), France (about 140,000 tons per year) and Spain (about 115,000 tons per year). About 700,000...800,000 tons per year of EAFD are generated in USA and this quantity increases with 4...6 yearly, [4]. These dusts are considered toxic and hazardous products, due to their chemical and physical properties, and the disposal of these materials in landfill sited is regarded as an environmental hazard, since toxic metals may leach into drinking water supplies. These products, consisting mainly of a mixture of zinc and iron oxides contain traces elements of importance from the point of view of their impact up to the environment such as: Cr, Ni, Cu, As, Cd and Sn, but Mn, Ca, Mg, Si, Pb, S, Al and Hg, too. Being treated as hazardous waste, EAFD is partly disposed of permanently at appropriate, regulation- prescribed waste dumps, or it can be used as secondary raw material in the production of zinc, iron, lead, etc. Most of the so far developed and commercialized processes are predominantly applied to the re-cycling of EAFD and, to a lesser extent, to its inactivation i.e. its stabilization prior to permanent disposal. Collecting the EAFD while treating smoke gases in electric filters is just a partial solution to the emission problem, whereas the volumes of the produced dust as well as its composition point to the necessity to define and apply integral solutions for its complete and final disposal. The wide variability of dust compositions makes a complete analysis rather difficult. As a chemical and structural characterization of solid waste is a very important stage to evaluate the re-cycling feasibility, several analytical techniques may be used to study EAFD. Comparing the chemical analysis and the electron microscopy becomes possible to determine and to quantify the phases which are present in EAFD. So, this research involved examination of the chemical and phase composition and physical properties of samples of the EAFD for the purpose of its detailed characterization. The use of several characterization techniques is important to find two zinc oxides which have a great importance to their re-cycling as raw material: to obtain metallic zinc to zinc industry, to obtain metallic iron to iron and steel-making industry and even and for its re-cycling in the civil construct, because the depending on the presence and amount of zinc oxide, the retardation in the hydration reactions may occur, which can result in a barrier for its use in this application.

2. EXPERIMENTAL RESEARCH

In order to investigate the chemical and phase composition of electric arc furnace dust, the average monthly samples taken at the outlet of the dust suppression system were analyzed. The EAFD results from the collection of the dust generated by the arc of furnace when coal and scrap are mixed together at an approximate temperature of 1500^0C. The samples were homogenized and successive quartering provided 1000 g of each sample. All samples were dried for 2,5 hours at 120^0C and stored.

The chemical composition of EAF dust samples were investigated by means of a traditional chemical analysis (ASTM E 277 – 69/1894; ASTM E 247 – 82/1986). It is known that the chemical composition of dust varies according to the type of steel produced and the range of variation of composition is considerable.

For example, the Fe, which is the major element, can vary from 15 to 62% and represents around 43% in the EAFD from the stainless steel industry, [6]. It is also known that the chemical composition of the EAFD depends on the quality of steel scrap processed, on the technological and operating conditions and on the degree of the dust returning into the process. Reference data, [3, 8, 2], imply that the prevailing elements in EAFD vary in concentration: Fe 10...45%, Zn 2...46%, Pb 0,40...15,14%, Cr 0,2...11%, Cd 0,01...0,3%, Mn 1...5%, Cu < 3%, Si 1...5%, Ca 1...25%, Mg 1...12%, Al 0,1...1,5%, C 0,11...2,36%, S 1,5...2,5%, Na 0,5...1,8%, K 0,35...2,3%. In this EAF dust, the zinc is in the forms of zincite (zinc oxide, ZnO), franklinite (zinc ferrite) and iron is in the form of hematite and franklinite.

The authors were given a special attention to the content of heavy metals in water leached in order to find the proper solution for its disposal. The accuracy of the used analytical method was tested by analysing one EAF dust reference material. Recovery factors for all analyses identified by means of the stated method in this paper were within the range of 100±4%.

The applied method has displayed satisfactory linearity when defining the stated analyses within the selected operational area and the correlation coefficients for all analyses and the applied method were > 0,997. Granular metric composition of single samples was determined by applying sieve separation.

3. RESULTS AND DISCUTIONS

The shape of the dust particle is approximately spherical. EAF dust has contained two major sizes fraction: a very fine-grained portion and a coarser part. Particles sizes range from less than 2,8 µm to more than 176 µm. The majority, (83%), of the particles are smaller than 5,5 µm in diameter. The EAFD particles size distribution is presented in Figure 1, [1].

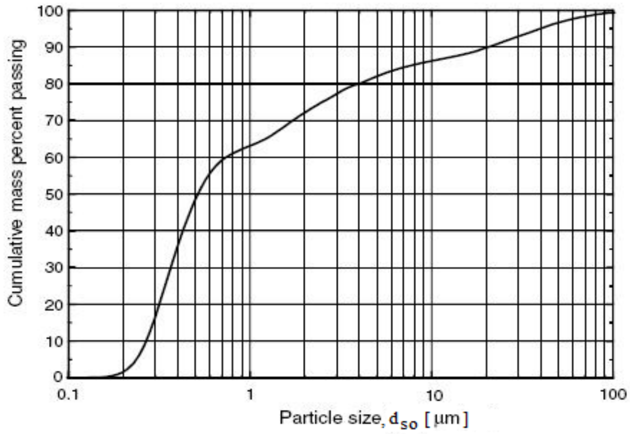

Figure 1. EAFD particles size distribution

The figure shows that only about 15% of the particles are coarser than 10 µm and the median particle size, (d_{50}), is around 0,5 µm. This fine size distribution indicates that the physical concentration methods, like gravity or magnetic separation, are not suitable to treat such a material. Further, its size distribution suggests that the material would be difficult to handle dry, if no previous agglomeration is used.

On the other hand, reaction kinetics involving this dust should be fast, due to the prevailing fine particle sizes, which suggests that leaching may be an attractive route to treat this material, when zinc recovery is of interest. All the chemicals used were analytical grade, unless indicated otherwise. Usually, the chemical analysis is expressed in the most stable oxides forms. The samples of 5g (dust or leaching residue) were digested in 30ml of concentrated nitric acid, heated nearly to the boiling point (95^0C) for 30 minutes, and then, the water was added to dilute the acidity and the heating was continued for another 60minutes. A small portion of samples can not be dissolved.

Table 1 presents the chemical composition of the major oxides of the EAFD tested.

Table 1. Chemical composition of the major oxides of the EAFD tested

Oxides, mass [%]	CaO	SiO_2	MgO	Al_3O_3	MnO	Fe_2O_3	K_2O	TiO_2	Na_2O	P_2O_5	LOI*	Total
EAFD	6,58	5,77	4,26	0,73	5,88	39,55	0,47	0,18	1,03	0,03	3,66	68,14

*LOI – Loss on ignition

The analyzed samples of the EAFD had the following concentration ranges: Fe 41,06…48,58%, Zn 3,75…8,3%, Pb 0,92…2,3%, Cr 0,19…0,35%, Cd 0,01…0,028%, Mn 5,2…5,93%, Cu 0,21…0,33%, Si 1,79…2,24%, Ca 3,62…4,97%, Mg 2…2,83%, Al 0,22…0,26%, C 0,26…0,46%, S 0,54…1,5%, Na 0,38…0,68%, K 0,49…1,28%. No pretreatment was conducted in the study. Scanning electron microscopy was performed to gain further knowledge of the EAFD particles structure, morphology and their chemical composition. The samples were subjected to the element distribution analysis (O, Fe, Zn, Mg, Ca, Cr, Si and Mn). Figure 2 shows a general distribution of EAFD particles where most particles are spherical.

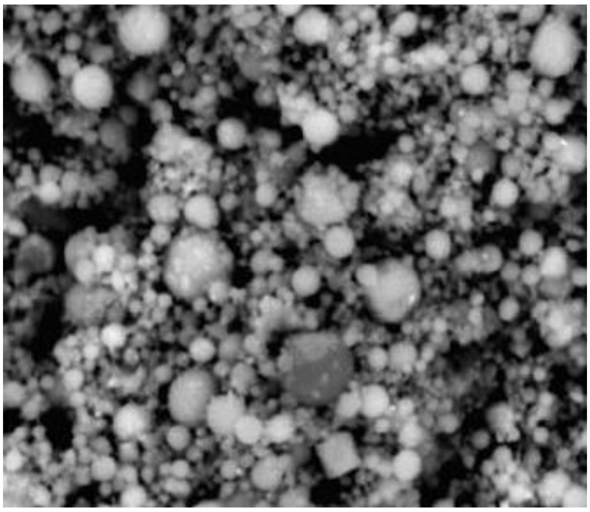

Figure 2. Metallographic structure of the EAFD particles, (x 7500)

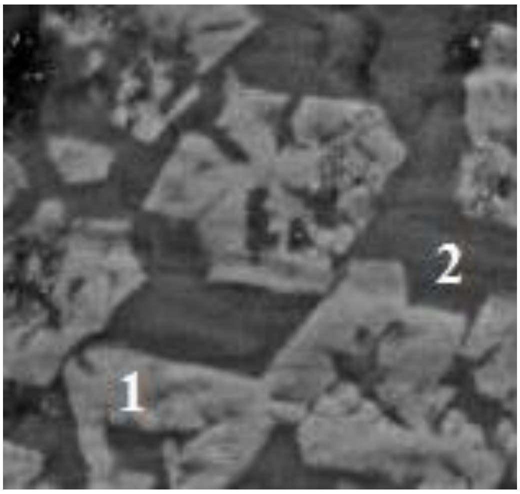

Figure 3. Metallographic image, (x1500), showing a dendrite structure of the EAFD

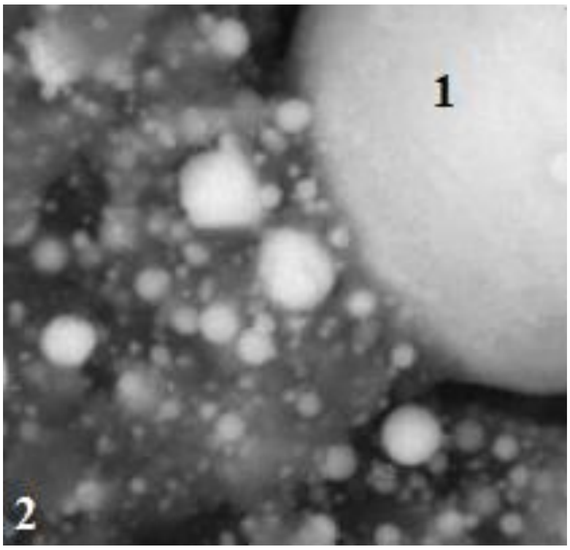

Figure 4. Metallographic image of the EAFD, (x8000), showing two regions: 1 – rich in Fe and O; 2 – rich in Fe and Zn

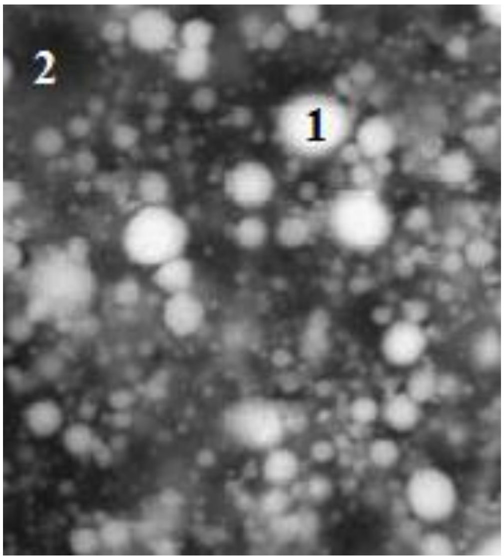

Figure 5. Metallographic structure of the EAFD, (x8000), showing two areas: 1 – rich in Fe and O; 2 – rich in Fe and Zn

This shape is in agreement with the main generation mechanism, i.e, ejection of the slag and metal particles by bobber-burst, [7]. Figure 3 shows a typical morphology of the EAFD containing a dendrite structure, and Table 2 shows the result of the analysis of areas 1 and 2 identified in Figure 3. It can be seen that the higher contributions are due to Fe, Cr and O in the clearer region and to Fe, Ca, Si and O in the darker one. Figure 4 and Figure 5 show a typical metallographic image of the EAFD. Table 3 and Table 4 give the results of the analysis of areas 1 and 2 identified in Figure 4 and Figure 5. It can be said that area 1, in both figures, is probably magnetite, (Fe_3O_4). In area 2, in both figures, it was observed that the particles are very fine and iron and zinc are present in a high amount. We have considered that it is the region where the franklinite phase ($ZnFe_2O_4$) is present.

Table 2. Energy dispersive spectrometry EDS, of area 1 rich in Fe, Cr and O and area 2 rich in Fe, Ca, Si and O showed in Figure 3

Element	Area 1, [%]	Area 2, [%]
Fe	39,83	34,96
Cr	33,63	3,37
O	10,14	13,49
Al	2,53	2,57
Si	0,62	10,91
Mg	5,27	0,40
Mn	5,49	1,48
Ca	2,52	32,78

Table 3. Energy dispersive spectrometry EDS, of area 1 and area 2 presented in Figure 4

Element	Area 1, [%]	Area 2, [%]
Fe	90,32	59,57
Zn	-	22,61
O	8,39	2,85
Cl	-	2,90
Si	0,25	2,74
Mg	-	1,57
K	-	2,10
Ca	0,39	1,90
Cr	0,62	2,63
S	-	1,22

Table 4. Energy dispersive spectrometry EDS, of area 1 and area 2 presented in Figure 5

Element	Area 1, [%]	Area 2, [%]
Fe	72,56	58,08
Zn	12,62	22,39
O	5,66	2,47
Cl	1,11	3,85
Si	1,78	2,58
Mg	1,47	1,76
K	-	1,64
Ca	1,09	2,11
Cr	-	0,72
Mn	3,62	2,76
S	-	1,64

Analyzing the behavior of the EAFD after hydrolysis, a given ratio of dust and water was stored in glass bottles and mixed by an orbital shaker for a given time (15rot/min). Filtered, the cake was washed by half amount of water used for hydrolysis.

The hydrolyzed dusts were dried for the coming studies. It was found that the compositions of dusts were kept unchanged after hydrolysis.

4. CONCLUSIONS

The characterization of a solid waste, like EAFD, using many techniques increases the reliability in the results and also gives more conditions to decide about the best feasible re-cycling method. Scanning electron microscopy was performed to gain further knowledge of the EAFD particles structure, morphology and their chemical composition. Scanning electron microscopy and the micro-analysis show a general distribution of the EAFD particles, where most particles are spherical.

The electric arc furnace dust has a heterogeneous distribution of particles, where the majority of 83% of the particles are smaller than 5,5µm in diameter. Iron and zinc are the main components of the dust, which also presents small amounts of very toxic heavy metals which include chromium, cadmium and lead.

The compositions of dusts were kept unchanged after hydrolysis. Zinc content in the dust is considered low for a successful pyrometallurgical treatment for zinc recovery which leads to the greater interest in the hydrometallurgical treatment.

References

1. Chirilã E., Ionescu Luca C., Gheorghiu, D. A. (2009). “Modern Tendencies in the Designing, Construction and Exploitation of the Electric Arc Furnace”. B.I.P. Iasi, Tom LV (LIX), Fasc. 2, pp. 75-80, ISSN 1453 – 1690.
2. Doutra, A.J.B., Paiva, P.R.P. & Tavares, L.M. (2006). “Alkaline Leaching of Zinc from Electric arc Furnace Steel Dust”. Mineral Engineering, no.19, pp 478 – 485, ISSN: 0892-6875.
3. Laforest, G. & Duchesne, J. (2006). “Characterization and Leachability of Electric Arc Furnace Dust Made from Remelting of Stainless Steel”. Journal of Hazardous Materials B135, pp 156 – 164, ISSN: 0304-3894.
4. Néstor, G.G. & Borja, G.E.V. (2003). “The situation of EAF dust in Europe and the upgrading of the Waelz process”. Waste Treatment and Clean Technology, no. 99, vol. 2, pp 1511 – 1520, ISSN: 0210-5621.
5. Sofilić, T., Rastovčan – Mioč, A., Cerjan – Stefanović, Š., Novosel – Radovič, V. & Jenko, M. (2004). “Characterization of steel mill electric arc furnace dust”. Journal of Hazardous Materials, B109, pp 59 – 70, ISSN: 0304-3894.
6. Stegermann, J.A., Roy, A., Caldwell, R.J., Schilling, P.J. & Tittsworth, R. (2000). “Understanding environmental Leachability of Electric Arc Furnace Dust”. J. Environ. Eng. no.126, vol.2, pp 112 – 120, ISSN: 0733-9372.
7. Takano, C., Mantovani, M.C., Cavallante, F.L. & Mourão, M.B. (1999). “Electric Arc Furnace Dust Characterization and Re – cycling by Self Reducing Pellets”. First Japan – Brasil Symposium on Dust Processing – Energy – Environment in Metallurgical Industries, São Paulo.
8. Youcai, Z. & Stanforth, R. (2000). “Integrated Hydrometallurgical Process for Production of Zinc from Electric Arc Furnace Dustin Alkaline Medium”. Journal of Hazardous Materials B80, pp 223 – 240, ISSN: 0304-3894.