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Carbothermic Reduction of Zinc and Iron Oxides in Electric Arc Furnace Dust

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Abstract: The reduction of zinc and iron oxides from electric arc furnace dust (EAFD) by carbon was investigated at temperatures between 800 and 1300 ℃. The analytic technique employed includes chemical analysis, X-ray fluorescence spectroscopy (XRF), X-ray powder diffraction (XRD), scanning electron microscopy (SEM) equipped with X-ray energy dispersive spectrometry (EDS), and thermodynamic database FactSage 6.2. It was found that the reduction of zinc and iron oxides depends largely on Boudouad reaction. At 900 ℃, zinc exists in tested samples as ZnO, which is reduced in the temperature range of 1000—1100 ℃. At 1100 ℃, 99.11% of the zinc is evaporated. The metallization ratio of Fe is 79.19% at 1300 ℃, as the content of Fe^{2+} is still 9.40%. A higher temperature is thus required for a higher reduction degree of Fe oxides by solid or gaseous carbon.

Key words: electric arc furnace; dust; reduction; ZnO; $ZnFe_2O_4$

Electric arc furnace dust (EAFD) is generated during the production of steel in an electric arc furnace (EAF). In a typical electric arc furnace operation, approximately 1%—2% of the charge is converted to dust[1]. Due to its physical and chemical properties, the EAFD has been categorized as hazardous waste by many countries[2]. However, major components of the EAFD are iron and zinc oxides. Landfill of EAFD not only wastes the metal materials, but also poses potential threats to the environment. Therefore, many pyro-[3,4] and hydro-metallurgical[5—7] processes have been developed around the world in order to treat the EAFD and to use the EAFD as a secondary raw material for steelmaking and zinc production.

A part of zinc in EAFD exists in franklinite ($ZnFe_2O_4$), which is considerably refractory against leaching[8], giving difficulties to hydrometallurgical treatments. The franklinite problem can be solved by pyro-metallurgical treatments, such as the Waelz kiln process. However, the Waelz process operates economically only when the zinc content is higher than about 15%—20% in the EAFD[4]. Processing low grade EAFD, the EAFD with low Zn content, will increase the energy consumption and enhance the environmental impact. Subsequently, treatment processes to increase the zinc content and reduce the EAFD amount have been investigated[9—11]. Lopez et al.[9] loaded briquettes, made of EAFD, reducing agents and agglutinant agents, into an electric arc furnace to obtain dusts with zinc content of 32%. Yang et al.[11] has shown that, via EAFD recycling, Zn content in the obtained dust increased to 29.7% from 21.5% and the quantity of dust decreased by more than 40%.

In the present study, behaviors of zinc and iron oxides in the EAFD during carbothermic reduction are investigated using laboratory equipments. The results obtained may be useful to improve operations of EAFD recycling by smelting in the electric arc

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furnace.

1 Experimental

1.1 Material

The samples of EAFD and carbon powder used were obtained from Uddeholm Tooling AB, Sweden. The EAFD, with composition shown in Table 1, contains 21.50% Zn and 5.02% Cr_2O_3. The mineral phases identified by XRD analysis are franklinite ($ZnFe_2O_4$), zincite (ZnO), and magnetite (Fe_3O_4).

Table 1 Chemical composition, R_{Zn}, R_{Fe}, m_R and ζ of the treated EAFD samples

Test No.	EAFD	A01	A02	A1	A2	A3	A4	A5	A6
Temperature/℃		900	1100	800	900	1000	1100	1200	1300
w_{MgO}/%	5.83	6.07	6.13	5.37	5.31	7.12	10.10	9.99	16.20
w_{Al2O3}/%	0.35	0.39	0.37	0.34	0.32	0.43	0.61	0.59	2.05
w_{SiO2}/%	5.67	5.86	6.15	5.40	5.37	6.91	9.20	9.10	14.50
w_{CaO}/%	6.80	7.90	6.90	6.80	7.10	8.10	10.10	9.90	16.70
w_{CaF2}/%	1.60	1.00	2.20	0.90	0.50	1.70	3.40	3.50	3.50
w_{Cr2O3}/%	5.02	5.26	5.23	4.61	4.59	6.60	7.25	7.37	6.90
w_{MnO}/%	2.27	2.29	2.36	2.13	2.13	2.58	3.19	3.19	3.98
w_S/%	0.12	0.10	0.13	0.26	0.26	0.32	0.42	0.46	0.56
w_{P2O5}/%	0.08	0.08	0.09	0.08	0.08	0.11	0.16	0.16	0.10
w_{V2O5}/%	0.30	0.33	0.32	0.28	0.28	0.38	0.50	0.50	0.55
w_C/%	0.26	0.07	0.05	14.10	13.60	7.68	7.19	7.39	6.47
w_{Zn}/%	21.50	21.40	21.20	19.10	18.90	14.10	0.31	0.07	0.0014
m_{Fe}/%	<0.10	0.50	0.91	0.65	0.93	23.10	35.10	37.00	16.90
w_{Fe2+}/%	1.28	1.31	15.50	6.75	15.80	11.20	11.20	9.10	9.40
R_{Zn}/%	—	2.46	5.34	0.50	3.30	46.22	99.11	99.80	100.00
R_{Fe}/%	—	1.74	3.10	2.58	3.63	67.15	77.14	78.70	79.91
m_R/%	—	49.00	48.00	56.00	55.00	41.00	31.00	30.00	24.00
ζ/%	—	2.00	4.00	3.45	5.17	29.31	46.55	48.28	48.38

Note: R means reduction rate; m_R denotes mass of metal in EAF dust; and ζ represents mass loss of dust.

1.2 Experimental set-up and procedure

The experimental system consisted of a crucible system with an Al_2O_3 crucible inside a graphite crucible and an induction furnace of maximum 60 kW and 3 kHz, as shown in Fig. 1. For each test, a mixture of 50 g EAFD and 8 g carbon powder was contained in the Al_2O_3 crucible, which was heated by the outer graphite crucible. A thermocouple between the two crucibles measured the test temperature.

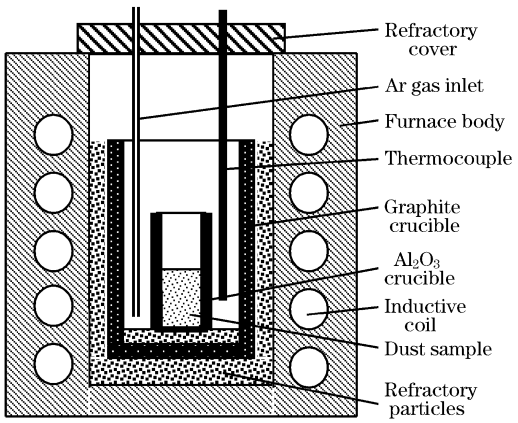

Fig. 1 Test set-up for carbothermically reducing EAFD samples

The test mixtures in Al_2O_3 crucibles were first heated for about 1 h to reach the desired test temperature and then held for 2 h in the protective atmosphere of argon. After that, the samples were cooled down in the system to room temperature. The range of test temperature was 800—1300 ℃, with an increment of 100 ℃, giving 6 test samples. Additionally, there were two reference tests carried out at 900 and 1100 ℃, using only the EAFD samples.

1.3 Analysis method and instruments

The total composition for each test sample was analyzed by Uddeholm Tooling AB (Sweden) with X-ray fluorescence spectroscopy (XRF). The total contents of zinc and iron were analyzed with flame atomic absorption spectrometric method and titanium (III) chloride reduction method, respectively. The ferric chloride-sodium acetate volumetric method and potassium dichromate volumetric method were used to determine the contents of metallic iron and iron (II), respectively. These analyses were done repeatedly in the laboratory of USTB, reporting mean values.