Characterization of Low-Zinc Electric Arc Furnace Dust

Zhiwei Peng, Xiaolong Lin, Jiaxing Yan, Jiann-Yang Hwang, Yuanbo Zhang, Guanghui Li and Tao Jiang

Abstract Electric arc furnace (EAF) dust is an important secondary resource that should be recycled to enhance its considerable economic value and potential environmental benefit. In this study, a low-zinc EAF dust was characterized by various techniques, including chemical titration, X-ray diffraction, granulometric analysis, scanning electron microscopy and thermogravimetry. It is shown that the dust contains 2.08 wt% Zn, 23.16 wt% Fe and 19.84 wt% Ca, accompanying small amounts of Cr, Pb, etc. Magnetite, calcium ferrite and zinc ferrite are the main phase constituents. The majority (90%) of particles have size less than 137.862 μm. According to these characteristics, it is expected that the use of microwave energy for intensification of the reduction of EAF dust in the presence of biochar will succeed in the dust recycling by promoting the processing efficiency with elimination of secondary hazardous pollutants.

Keywords EAF dust · Characterization · Composition · Microstructure · Thermal stability · Recycling

Introduction

The rapid growth of iron and steel industry has led to huge increases in the use of energy and other resources. It also caused severe environmental degradation because of considerable generation of dust, waste water and exhaust gas which must be treated appropriately. Electric arc furnace (EAF) dust is an important by-product of the steelmaking industry with output accounting for approximately

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1–2% of the charge in a usual EAF operation [1, 2]. In 2014, its output reached 8.764 million tons. Because of its high contents of zinc and iron (up to 40 wt% Zn [3] and 50 wt% Fe [4]), EAF dust is often deemed to be an industrial waste having high recycling value. However, this dust also contains minor amounts of harmful heavy metals, e.g., Pb and Cr [5–8]. Hence, it is commonly categorized as a hazardous waste [5]. For disposal of the dust, it is necessary to gain a comprehensive understanding of the characteristics of EAF dust.

This paper offers a systemic study on the characteristics of low-zinc EAF dust by examining its chemical and phase compositions, size distribution, particle morphology and thermal property by chemical titration, X-ray diffraction, granulometric analysis, scanning electron microscopy and thermogravimetry, respectively. Based on the characteristics, possible approaches for treatment of this dust are discussed and a promising method involving use of microwave energy for processing of the dust is proposed.

Experimental

Material

The EAF dust, collected from Baosteel Group Corporation, Shanghai, China, was used for the characterization in this study.

Experimental Methods

The chemical composition of the EAF dust was determined by X-ray fluorescence spectrometry (XRF-Axios^{mAX}) with Rh$K\alpha$ radiation. This technique can measure the content of the elements between O^8 and U^{92} with good reproducibility, fast test speed and high sensitivity. The phase composition of EAF dust was acquired by a D/Max-2500 diffractometer at 2° min^{-1} from 0 to 90° with Cu$K\alpha$ radiation. The morphology of the sample was examined using an environmental scanning electron microscope (Quanta-200) and the particle size distribution of the dust was determined using a laser particle size analyzer (LPSA-Mastersize 2000) with the granularity range from 20 nm to 2 mm. The thermal property of the dust was characterized using a thermal gravimetric analyzer (TGA851) at a ramp rate of 15 °C min^{-1} under nitrogen atmosphere.

Results and Discussion

Chemical Composition

Table 1 shows the chemical composition of the EAF dust. Iron and calcium are the main elements of EAF dust. The contents of Fe and Ca reach 23.16 wt% and 19.84 wt%, respectively. Because the content of zinc is only 2.08%, it is categorized as a typical low-zinc dust (<4 wt%) [9, 10]. The dust also contains hazardous species, including Cr, Pb and halogens, constituting threat to environment though their contents are less than 1 wt%. Particularly, the content of Mn reaches 3.03% in the EAF dust, representing a potential manganese resource.

Phase Composition

The phase composition of the dust is shown in Fig. 1. The main phases are Fe_3O_4, $CaFe_2O_4$ and $Zn_{0.35}Fe_{2.65}O_4$. Fe is primarily enriched in the dust in the form of Fe_3O_4 and $CaFe_2O_4$ with relatively strong magnetism. This finding indicates the possibility of recovering Fe from the dust by magnetic separation. $Zn_{0.35}Fe_{2.65}O_4$ may decompose into ZnO and Fe_xO_y under certain metallurgical conditions, causing separation of iron and zinc. The other less important phases include Mn_3O_4, $CaAl_8Fe_4O_{19}$, $Mg_{0.64}Fe_{2.36}O_4$, $MgAl(SiO_4)_3$ and SiO_2.

Particle Size Distribution

The particle size distribution of EAF dust is displayed in Fig. 2. It is observed that the dust has two main size fractions, namely a very fine-grained portion (0.1–1 μm) and a coarser portion (1–138 μm). 50% of the dust particles are smaller than 19.661 μm and 90% of the particle sizes are less than 137.862 μm.

Table 1 Chemical composition of EAF dust

Element	wt%	Element	wt%	Element	wt%	Element	wt%
Zn	2.08	Cl	0.69	F	0.98	Nb	0.01
Fe	23.16	K	0.35	Ni	0.01	Mo	0.11
Ca	19.84	Mg	2.83	Cu	0.02	Ba	0.27
Al	6.21	Ti	0.15	O	30.53	Pb	0.05
Si	3.58	V	0.02	Br	0.003	loss	4.44
P	0.05	Cr	0.26	Sr	0.02		
S	1.30	Mn	3.03	Zr	0.01		

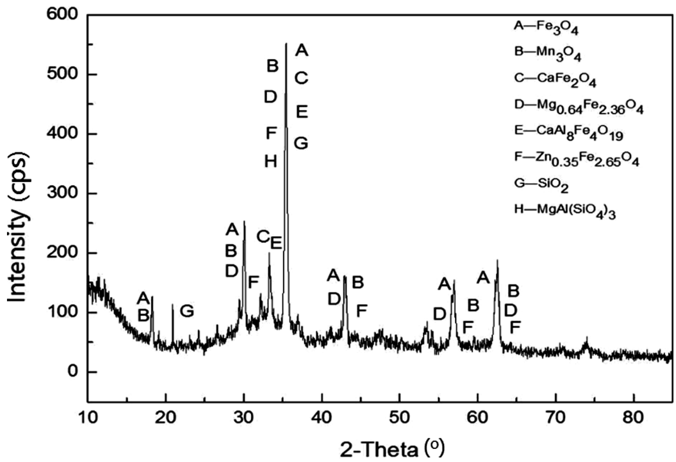


Fig. 1 XRD pattern of EAF dust

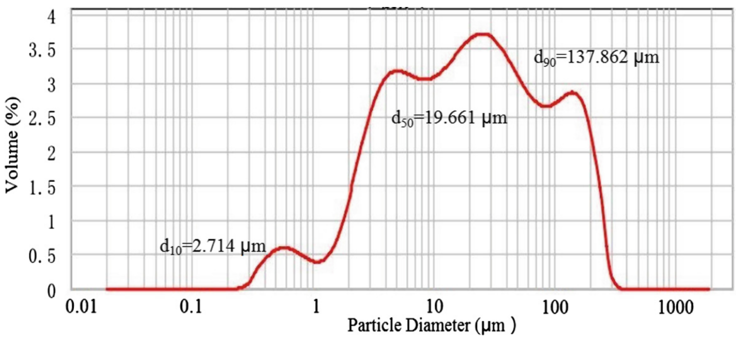


Fig. 2 Particle size distribution of EAF dust

Microstructure

Figure 3 shows scanning electron microscope images of the microstructure of EAF dust at different magnifications. It is observed that most particles appear in the sphere-like shape. The small particles accumulate together or adhere to the surface of large particles, forming large agglomerates.

Thermal Property

The thermal stability of EAF dust was revealed by the thermogravimetric analysis. Figure 4 shows the thermogravimetric profile of the EAF dust at a ramp rate of

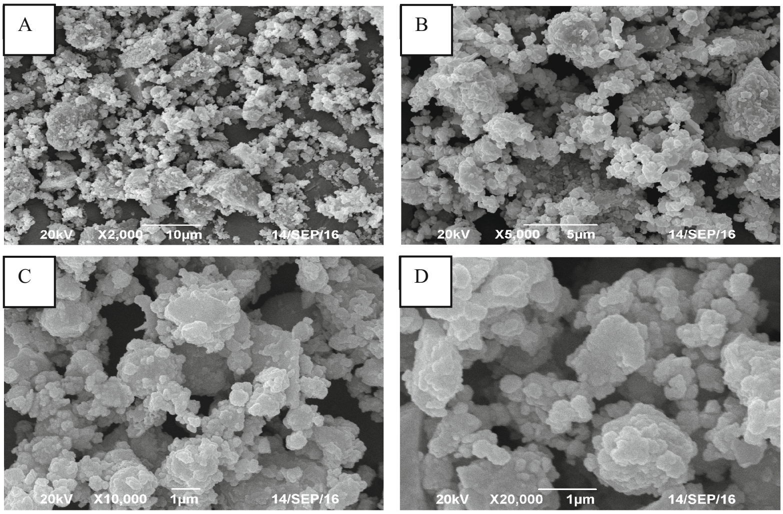
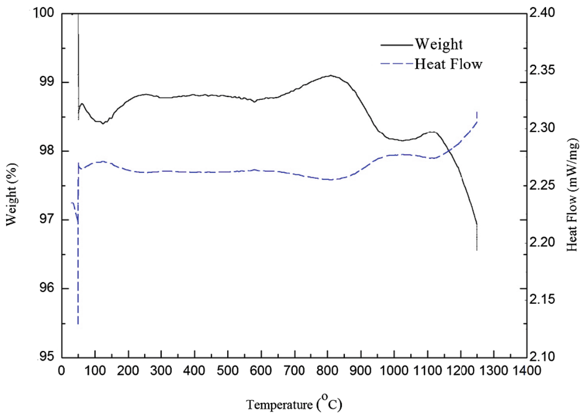


Fig. 3 Scanning electron microscope images of EAF dust

Fig. 4 Thermogravimetric profile of EAF dust



15 °C min^{-1} under N_2 atmosphere. It is seen that there exist three steps for the mass loss, consistent with the findings in literature [9]. The first mass loss event starts at 50 °C with the maximum mass loss rate occurring at 130 °C, corresponding to evaporation of entrained free water and chemically adsorbed water (e.g., water bound to the metal chlorides). The second mass loss has an onset temperature of 800 °C with the mass loss occurring in the temperature range up to 1000 °C, possibly attributed to the vaporization of halides. The final mass loss event initiates at a temperature of 1100 °C, and the loss may be assigned to the vaporization of the elements with low boiling points in the dust. It is clear that additional

characterizations of the dust are required to identify the specific reactions involved in the process.

The above results show that the dust is characterized by low content of zinc in the form of zinc ferrite, and high content of iron and calcium in the form of magnetite and ferrites. The main hazardous species include Pb, Cr and Cl. It also has small particle size and relatively low thermal stability which has been verified by the three main steps of mass loss in the temperature range up to 1250 °C. These features are in favor of use of pyrometallurgical approaches (e.g., carbothermic reduction) in separating these elements. The zinc and iron species are capable of being separated and recovered from the dust by controlling the processing temperature and atmosphere properly. When the zinc constituents are volatilized, the Fe-bearing residue can be used as a material for ferrous metallurgy after further purification by removing the major impurities, especially Ca. As the dust has high content of ferrites which have strong microwave absorption, it is anticipated that the use of microwave energy (featured by volumetric and selective heating [10, 11]) and biomass-derived char (biochar, as reducing agent and microwave absorber [12, 13]) for treatment of this dust will be highly promising from the perspectives of energy conservation and environmental protection.

Conclusions

EAF dust is an important secondary resource enriching a variety of metallic elements. In this study, a low-zinc EAF dust was characterized by a variety of techniques, including chemical and phase compositions, particle morphology, size distribution and thermal property. The dust contains 2.08 wt% Zn and 23.16 wt% Fe, accompanying a number of harmful heavy metals, e.g., Pb and Cr. Magnetite, calcium ferrite and zinc ferrite are the main phase constituents. Further, approximately 90% of particles have size less than 137.862 μm. According to these characteristics, it is anticipated that the use of microwave energy for intensifying the reduction of EAF dusts in the presence of the reducing agents originated from sustainable biomass resources, such as biochar, may succeed in the dust recycling by elevating the processing efficiency with elimination of secondary hazardous pollutants.

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