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Mineralogical analysis of dust collected from typical recycling line of waste printed circuit boards

Fangfang Wang [a], Yuemin Zhao [a,b,*], Tao Zhang [b], Chenlong Duan [b], Lizhang Wang [a]

[a] *School of Environment Science and Spatial Informatics, China University of Mining and Technology, Xuzhou 221116, China*
[b] *School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China*

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ABSTRACT

As dust is one of the byproducts originating in the mechanical recycling process of waste printed circuit boards such as crushing and separating, from the viewpoints of resource reuse and environmental protection, an effective recycling method to recover valuable materials from this kind of dust is in urgent need. In this paper, detailed mineralogical analysis on the dust collected from a typical recycling line of waste printed circuit boards is investigated by coupling several analytical techniques. The results demonstrate that there are 73.1 wt.% organic matters, 4.65 wt.% Al, 4.55 wt.% Fe, 2.67 wt.% Cu and 1.06 wt.% Pb in the dust, which reveals the dust is worthy of reuse and harmful to environment. The concentration ratios of Fe, Mn and Zn can reach 12.35, 12.33 and 6.67 respectively by magnetic separation. The yield of dust in each size fraction is nonuniform, while the yield of −0.75 mm size fraction is up to 51.15 wt.%; as the particle size decreases, the content of liberated metals and magnetic materials increase, and metals are mainly in elemental forms. The F, Cl and Br elements combing to C in the dust would make thermal treatment dangerous to the environment. Based on these results, a flowsheet to recycle the dust is proposed.

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1. Introduction

Being a secondary resource of valuable metals, waste electrical and electronic equipment (WEEE) has drawn increasing concern by the government as well as environmental protection organization due to its huge volume and hazardous material contents. With the advanced science and technology as well as remarkable improvement of people's living standard, it is estimated that the current global production of WEEE is expected to increase rapidly at an alarming rate of 20–25 million tons per year, China will become one of the major WEEE producers in the next ten years (Robinson, 2009), and the growth will remain due to their short lifespan (Huang et al., 2009; Hao et al., 2014). Besides, large quantities of WEEE have been exported to China for recycling by trans-boundary movement through clandestine operations or legal loopholes (Li et al., 2013). As an essential part of almost all the EEE and the base of the electronic industry, printed circuit boards (PCBs) account for the weight for about 3% (Zhou and Qiu, 2010). Compared to natural resource, it is pointed out that not only the total amount but also the concentration of metals contained in PCBs should be considered in. Waste PCBs constitute a heterogeneous mixture of metals, nonmetal, and some toxic substances. By containing many electronic components, such as resistors, relays, capacitors, and integrated circuits (Duan et al., 2011), waste PCBs have a metal content of nearly 28% (copper: 10–20%, lead: 1–5%, nickel: 1–3%) (Veit et al., 2005), especially the purity of precious metals in PCBs is more than 10 times that of content-rich minerals (Li et al., 2007; Betts, 2008). From the viewpoints of environmental preservation, it is of immediate significance to find a cautious process to recover the valuable parts of waste PCBs as well as safely dispose the harmful ones (Hadi et al., 2013).

Currently, the main options for the treatment of waste PCBs are involved physical separation processing, hydro-metallurgical processing, pyro-metallurgical processing and bio-metallurgical processing (Zeng et al., 2013, 2012; Zhu et al., 2014; Hadi et al., 2015; Duan et al., 2015). In most cases, several kinds of recycling techniques should be combined together to achieve high recovery rates of the main targeted metal species (Yang et al., 2014; Fogarasi et al., 2014; Zhou et al., 2013). In a typical recycling line of waste PCBs, physical processing operations such as grinding, sieving, magnetic, electrostatic, gravity separations and density-based separation are applied as pretreatments to liberate and concentrate the metallic fractions (MFs) and non-metallic fractions (NMFs)

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* Corresponding author at: School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China. Tel./fax: +86 51683590092.
E-mail address: ymzhao_paper@126.com (Y. Zhao).

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(Al-Thyabat et al., 2013; Guo et al., 2011; Duan et al., 2009; Zhou and Qiu, 2010; Flandinet et al., 2012). Then the preparation products will be conducted to a series of metallurgical recycling process (Zhou and Qiu, 2010; Yamane et al., 2011; Fogarasi et al., 2014).

In physical processes, a great deal of dust and poisonous gas are produced during the process of crushing, sieving, air float table separation, etc. In general, a well-designed recycling line must be equipped with dusting system and waste gases disposal system. According to the statistical data from several recycling lines of waste PCBs in China, Brazil, America, Pakistan and Canada, the dust collected from the dusting system is up to about 3.7% of its capacity. And the disposal or treatment of the dust becomes a difficult problem.

Chemical and mineralogical characterization analysis is a very useful method to provide basic information for recycling research (Zhang et al., 2014). In this study, with the purpose of obtain basic information for recycling the dust collected from the recycling line of waste PCBs, the detailed chemical and mineralogical characterizations of the dust were undertaken by coupling several analytical techniques. Based on these analysis results, a possible flowsheet for recycling this kind of dust was proposed.

2. Materials and methods

2.1. Sampling

The 20 kg dust used in our study was collected from a typical PCBs recycling plant in Anhui Province, China. In this PCBs recycling line, the dust as shown in Fig. 1 was collected by dry dust collectors from the process of crusher, vibrating screen, and air float table. The sieving test was carried out by a standard set of screens (Retsch AS200, Germany) in dry way and 6 groups of sieved products as shown in Fig. 1 were obtained, they were +1, −1 + 0.5, −0.5 + 0.25, −0.25 + 0.1, −0.1 + 0.075 and −0.075 mm respectively.

2.2. Dust chemical composition analysis

The major constituents of the dust were plenty of organic matter, a small quantity of inorganic matter and metals. For chemical characterization, the dust samples were firstly burned in plasma asher (K1050X Plasma Asher, UK) at a low temperature of 200 °C, and then the ash was frozen at −196 °C and grounded into fine powder (−0.074 mm) by a freezing grinder (Retsch Cryomill, Germany). The chemical composition of the freezing ground product was obtained with the help of an X-ray fluorescence spectrometer (XRF, Bruker S8 Tiger, Germany) using a powder pressed method to prepare the samples. The chemical composition of magnetic production and nonmagnetic production from the dust were also analyzed in the same way.

2.3. Micro-characterization

Powder structure and particle configuration of the −0.5 mm dust were analyzed by a scanning electron microscope (SEM, FEI quanta 250, America) equipped with a tungsten filament and coupled with an energy dispersive spectrometer (EDS, Bruker QUANTAX 400-10, Germany) using a silicon drift detector.

2.4. Mineral phases

Mineral phase analysis of the crushed products in −0.075 mm size fractions were carried out by an X-ray powder diffractometer (XRD, Bruker D8 advance, Germany). The setting conditions for the XRD were: Cu K a radiation, 40 keV accelerating voltage, 30 mA current, 3–90° scanning range, 0.1 s/step (0.01945°/step) scan speed.

2.5. Chemical state analysis

This experiment was carried out at room temperature in an ultra-high vacuum (UHV) system with the surface analysis system (ESCALAB 250Xi, America). The base pressure of the analysis chamber during the measurements was lower than 1.0×10^{-9} mbar. Al Ka radiation ($h\nu = 1486.6$ eV) from a monochromatized X-ray source was used for XPS. The take-off angle of the photoelectrons was 90° and the spot size was 900 μm. The spectra of survey scan were recorded with the pass energy of 100 eV, the energy step size was 1.00 eV. High resolution spectra were recorded with the pass energy of 20 eV, and the energy step size was 0.05 eV. The data processing (peak fitting) was performed with the Avantage (version 5.927) software provided by Thermo Fisher Scientific Corporation, using a Smart type background subtraction and Gaussian/Lorentzian peak shapes. The binding energies were corrected by setting the C1s hydrocarbon ($–CH_2–CH_2–$bonds) peak at 284.8 eV.

3. Results and discussion

3.1. Particle size distribution

Fig. 1 showed that the dust mainly contains tiny particles, besides some small sheets of plastics, thin-films and fibers. After

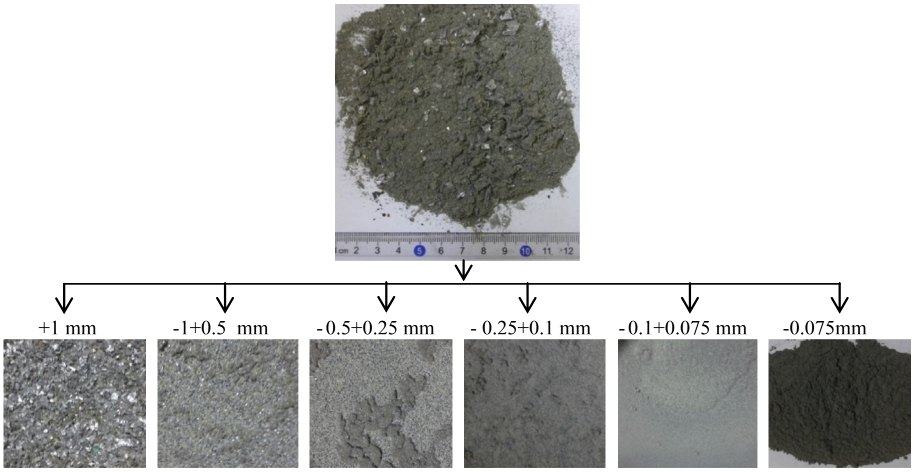

Fig. 1. The dust collected from dusting systems and sieved products.

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