Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Recovery of tin from metal powders of waste printed circuit boards

Tianzu Yang, Pengchun Zhu, Weifeng Liu *, Lin Chen, Duchao Zhang

School of Metallurgy and Environment, Central South University, Changsha 410083, China

ARTICLE INFO

Article history:
Received 16 March 2017
Revised 9 June 2017
Accepted 13 June 2017
Available online xxxx

Keywords:
Waste printed circuit boards
Metal powders
Pressure oxidation leaching
Tin

ABSTRACT

To avoid the adverse effects of tin on the smelting process used to recover copper from metal powders of waste printed circuit boards, an effective process is proposed that selectively extracts tin and its associated metals. That impacts of alkaline pressure oxidation leaching parameters on metal conversion were systematically investigated. The results showed that Sn, Pb, Al and small amounts of Zn in the metal powders were leached out, leaving copper residue. By optimizing the conditions, leaching recovery of 98.2%, 77.6%, 78.3 and 6.8% for Sn, Pb, Al and Zn, respectively, were achieved. Subsequently, more than 99.9% of Pb and Zn in the leaching solution were removed as a mixture of PbS-ZnS in the purification process, which can be used as a raw material in Pb smelting. Approximately 86.2% of Sn in the purified solution was recovered by electrowinning, and the purity of the cathode tin was over 99.8%.

1. Introduction

Both technological innovation and consumption expansion continue to accelerate the replacement of waste electrical and electronic equipment (WEEE), which is becoming the fastest growing source of urban waste (Akcil et al., 2015; Wang and Gaustad, 2012). Global WEEE generation has reached 2–8 million tons every year, and it is growing at a rate of 3–5% annually (Havlik et al., 2010; Kiddee et al., 2013). In particular, waste printed circuit boards (WPCBs), which account for 3% of WEEE, may pose a serious threat to the environment because their contain hazardous materials if they are not properly pre-treated (Quan et al., 2009). WPCBs contain approximately 28% of various metals (Cu, Pb, Sn, Au, Ag, Pd etc), approximately 23% of organic resin materials, and about 49% of glass materials (Liang et al., 2013; Park and Fray, 2009). The purity of the metals in WPCBs is higher than that in conventional concentrates, and the purity of precious metals is 10 times more than that of rich-content minerals (Ping et al., 2009; Xiang et al., 2010). To alleviate the economic development bottleneck caused by a lack of resources, the recovery of metals from WPCBs has great potential for development, especially because precious metals make up more than 70% of the value and copper makes up approximately 20% (Flandinet et al., 2012; Işıldar et al., 2016).

The major methods for recovering metals from WPCBs include mechanical/physical, pyrometallurgical and hydrometallurgical processes (Birloaga et al., 2013; Huang et al., 2009). Mechanical/-physical process as a pre-treatment stage have been proposed for separating metals from WPCBs, and they include multiple crushing, magnetic separation, corona electrostatic separation, and eddy current separation. The final valuable metals are enriched in metal powders (Guo et al., 2011). The product obtained by these processes is a metal mixture that requires further separation. Thus, these processes are merely a pre-treatment before pyrometallurgical and hydrometallurgical processes (Cui and Zhang, 2008; Silvas et al., 2015).

Typical pyrometallurgical processes are used worldwide by companies, such as Umicore in Belgium, Xstrata in Canada and Boliden in Sweden (Cui and Zhang, 2008; Hagelüken, 2006). During the pyrometallurgical process, the Cu in WPCBs can be retrieved by smelting and electrorefining. However, the Sn in WPCBs is distributed between blister copper, smelting slag, and dust during the reduction smelting process for recovering copper, which not only decreases the recovery of Sn but also deteriorates subsequents copper electrolytic refining (Mecucci and Scott, 2002). Incineration and pyrolysis are the other two types of pyrometallurgical processes. Although the incineration method is a simple, low-cost process, it has been prohibited because of its serious pollution of the environment (Bi et al., 2010; Luo et al., 2011; Owens et al., 2007). Pyrolysis can be considered an alternative process for WPCB recycling because the organic material is decomposed into liquids or gases, which can be used as fuel or a chemical resource, however, the recovery of metals is low in this process(Jie et al., 2008; Li et al., 2010).

As compared to pyrometallurgical processes, hydrometallurgical processes require various steps, including a series of leaching processes, followed by separation, purification, and electrowinning (Kasper et al., 2011). Acid and ammonia-based leachings have been

---

* Corresponding author.
E-mail address: liuweifeng@csu.edu.cn (W. Liu).

http://dx.doi.org/10.1016/j.wasman.2017.06.019
0956-053X/© 2017 Published by Elsevier Ltd.

extensively studied to recover copper and precious metals from WPCBs (Petter et al., 2014; Sun et al., 2015). In recent years, bioleaching as a new extraction technology has been considered one of the most promising technologies, which does not require too much capital investment, labour, energy consumption (Xiang et al., 2010; Zhu et al., 2011). These leaching processes have advantages in terms of the efficient extraction of Cu, however, other metals (Sn, Pb, Zn, etc.) are dissolved as impurities, making subsequent processing more difficult.

Pressure oxidation, which is a clean and efficient method of leaching has been used in the pretreatment of complex materials (Flett and Antony, 2001). However, as we all know, few studies have been carried out on the recovery of metals from WPCBs by an alkaline pressure oxidation leaching process. Moreover, it is difficult to achieve selective separation of metals with conventional leaching processes, and there are few reports on the recovery of Sn from metal powders of WPCBs. In this paper, an alkaline pressure oxidation leaching-purification-electrowinning process is proposed to treat metal powders obtained from WPCBs. The process can not only recover tin effectively, but also further enrich copper for subsequent recovery by smelting. As compared to pyrometallurgical processes, this process is easily accepted because of its light pollution, simple operation, low consumption of energy and low capital investment.

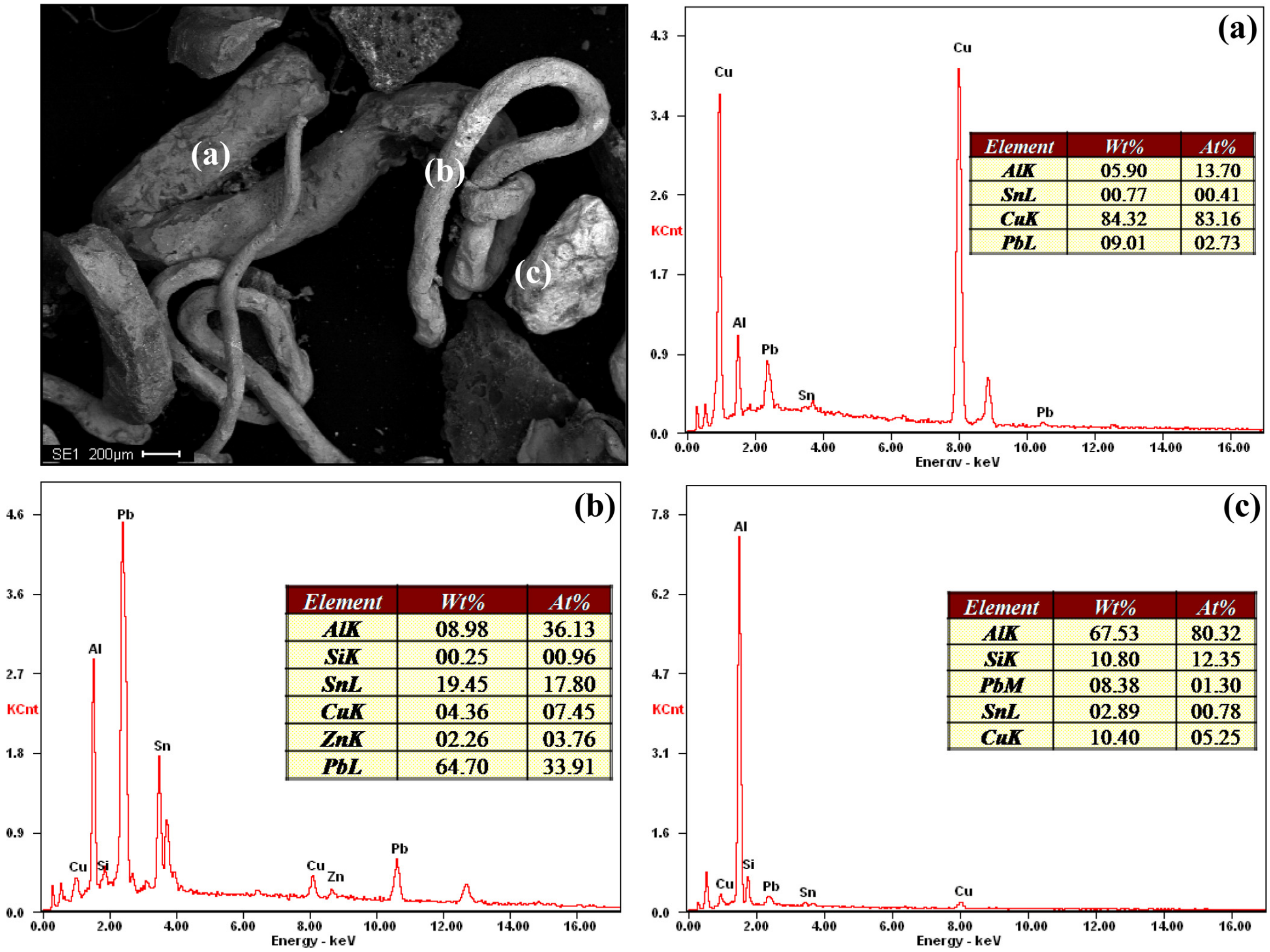
Table 1
Chemical composition of the metal powder.

Components	Cu	Al	Pb	Sn	Zn	Fe
wt.%	56.34	1.91	4.6	8.63	4.12	11.72

2. Experimental

2.1. Materials

The raw materials used in this study were metal powders that originated from waste TV printed circuit boards by crushing and separating. These powders contained many valuable metals. Table 1 shows the chemical composition of the metal powder. A scanning electron microscopy (SEM) image and the energy dispersive spectroscopy (EDS) patterns of the metal powder are shown in Fig. 1. It can be seen from Fig. 1 that the metal powder is irregular and contain valuable metals such as Cu, Pb, Sn, Al, Zn, and Si. The EDS patterns reveal that Cu [Fig. 1(a)], Sn [Fig. 1(b)] and Al [Fig. 1(c)] mainly exist in the form of elementary substances or alloys, which is consistent with the results of a related study (Ha et al., 2014). The sodium hydroxide (NaOH $\geq$ 96 wt.%) and sodium sulfide ($Na_2S{\cdot}9H_2O \geq 98$ wt.%) used in the experiment were of analytical grade, and the purity of the oxygen gas was above 99.5%.



(a)

Element	Wt%	At%
AlK	05.90	13.70
SnL	00.77	00.41
CuK	84.32	83.16
PbL	09.01	02.73

(b)

Element	Wt%	At%
AlK	08.98	36.13
SiK	00.25	00.96
SnL	19.45	17.80
CuK	04.36	07.45
ZnK	02.26	03.76
PbL	64.70	33.91

(c)

Element	Wt%	At%
AlK	67.53	80.32
SiK	10.80	12.35
PbM	08.38	01.30
SnL	02.89	00.78
CuK	10.40	05.25

Fig. 1. SEM image and EDS patterns of the metal powder.

Please cite this article in press as: Yang, T., et al. Recovery of tin from metal powders of waste printed circuit boards. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.06.019