Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 14	No. 1	pp. 145-148	2015

Original Research Paper

Process for Copper Recovery from E-waste: Printed Wiring Boards in Obsolete Computers

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 5-1-2015
Accepted: 7-2-2015

Key Words:
Printed wiring boards
E-waste
Copper recovery
Shaking table

ABSTRACT

The printed wiring boards (PWBs) in obsolete computers as a type of e-waste are also a resourceful metal mine hidden in cities. Along with the intensified shrinkage of mineral resources, recovery of metals from e-waste such as obsolete PWBs becomes an inevitable trend and also a requirement for adaptation to circular economy. In this study, copper was recovered from PWBs in obsolete computers via the process of "crush-screen-shake". Copper was fully separated from other components at the crushing and grinding speeds of 3100 r/m. Then after screening, the materials with a grain-size level of 0.12-0.3 mm contained the highest copper content and were also separated well. After shaking-table separation, the copper grade was up to 78.64%.

INTRODUCTION

With the rapid development of microelectronic technology, the emergence of various electronic products such as high-tech products (especially computers) has brought about new changes to the world. However, 20-50 million tons/year of obsolete electrical-electronic equipment and 4000 tons/hour of e-waste are generated worldwide, and such figures are increasing by 3-8% annually (Shi et al. 2006, Gu & Qi 2004, Cui & Forssberg 2003, Ruan 2007). These electronic wastes contain heavy metals and other bio-toxic components, such as poly-brominated biphenyls (PBB), polybrominated diphenyl ether (PBDE), Pb, Hg, Cr and Cd (Ren & Xia 2004). Direct disposal or inappropriate treatment of electronic waste will cause severe pollution to the atmosphere, soils and groundwater.

In fact, any garbage is a misplaced resource. The printed wiring boards (PWBs) in obsolete computers as a type of e-waste contain noble metals (e.g. Au, Ag, Pd) and non-ferrous metals (e.g. Cu, Al, Zn, Ni) (Lehner 1998). Specifically, PWBs contain 26.8% Cu (Table 1), 80 g/t Au and 3300 g/t Ag, which are all far higher than the grades in natural ores. Table 2 shows the comparison of metal contents between obsolete PWBs and ores (Lehner 1998, Zhu et al. 2006). Apparently, e-waste is a resourceful metal mine hidden in cities.

The commonly used methods to recover metals from obsolete PWBs include heat treatment, chemical treatment, biological treatment, mechanical treatment, or the combination of two or several of them (Li & Song 2008). In particular, mechanical treatment is increasingly popular owing to its low cost, low investment, low environmental pollution, high adaptability, and satisfaction of current market requirements (Li & Song 2008, Hong et al. 2006, Liu et al. 2011).

In this study, we collected PWBs from some disassembled obsolete computers and investigated the process for separation and extraction of Cu from PWBs. We aim to achieve the recovery and reuse of Cu from obsolete PWBs with the double purpose of waste utilization and pollution reduction.

MATERIALS AND METHODS

Materials: The PWBs disassembled from obsolete computers were provided by a local company.

Instruments: The major instruments used in this study included a primary crusher, a fine crusher and a grinding machine (all Shicheng Metallurgical Equipment Factory, Jiangxi) for crushing PWBs; an LY1100 500 430 hydraulic shaking table (Xichang Metallurgical Equipment Factory, Jiangxi) for separation; 6 sieves (200, 120, 80, 60, 40 and 30-mesh) (Shangyu First Sieve Factory, Zhejiang); a digital camera (8.1 mega pixel, Sony Corporation, Japan) and an XL30W/TMP scanning electron microscope (SEM, Philips, the Netherlands).

Experimental methods: Since the breaking points of metals and nonmetals are different, the Cu contents after crushing of PWBs will change with the grain-size level. Therefore, classification of grain-size will help to understand the optimal breaking degree that maximizes the recovery rate. The metals in PWBs can be enriched via shaking-table separation, which depends on the density differences between metals and nonmetals (e.g. glass fibres and resins). Thus, Cu can be separated from nonmetals via the combined screening-shaking process. The experiments were finished via four steps:

Step 1: The PWB materials were crushed into lumps (2cm × 2cm) using a shear crusher.

Step 2: The lumps were ground using the grinding machine, while the revolution speed was adjusted in accordance with the crushing performance.

Step 3: The grinded materials were air-dried, and then sieved for analyses of grain sizes copper grades with the digital camera and SEM.

Step 4: The materials as prepared were sent into the hydraulic shaking table for copper separation and analysis.

RESULTS AND DISCUSSION

Effects of crushing methods and revolution speed on crushing granularity: The changes of grain sizes were tested by adjusting the revolution speed, and the results are showed in Fig. 1. The crushed PWBs were grinded by the grinder. Then the changes of grain-size in the PWB powder were tested by adjusting the revolution speed, and the results are shown in Fig. 2.

The mean grain-size after shear crushing is 0.41-0.51 mm, and it decreases with the increase of revolution speed, but not very obviously (Fig. 1). The mean grain-size after grind crushing is 0.1-0.3 mm, and it decreases significantly with the increase of revolution speed (Fig. 2). However, too large or too small crushing fitness is not favourable for metal extraction. Thus, the materials with the average grain size of 0.26 mm (crushed at 3100 r/m) were selected and used in the subsequent experiments.

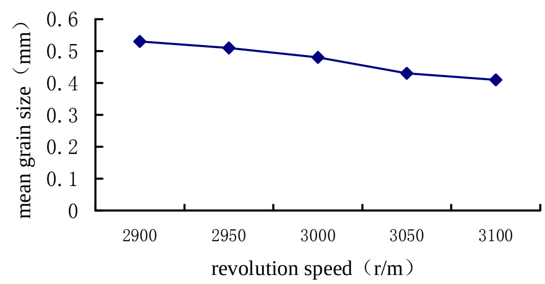

Fig. 1: Effects of revolution speed on shear crushing performance.

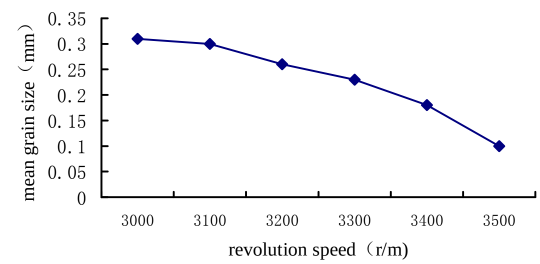

Fig. 2: Effects of revolution speed on grind crushing performance.

Grain size distribution and metal contents with different grain-size levels: The crushed PWB powder was successively screened using the 30, 40, 60, 80, 120, and 200-mesh standard sieves. Table 3 lists the pore diameters of these sieves. The materials after screening were weighed, and the grain size distributions and Cu contents were analysed (Table 4). To further determine the occurrence state of Cu and the relation of dissemination between metals and nonmetals in the powder, we analysed the screened grains using the camera and SEM (Figs. 3a-3e).

Clearly, the major component in the powder in the +30 mesh material (Fig. 3a) is plastics; the contents of both rod-like and sheet-like plastics in -40+60 mesh material (Fig. 3b) and -80+120 mesh material (Fig. 3c) decrease significantly, while the contents of spheric and lumpish metals increase. The Cu (bright) content is the highest in the -120+200

Table 1: Element composition in computer PWBs (percentage by weight).

Element	Ag	Al	Liquid Al	As	Au	S	Ba	Be
Content	3.3%	4.7%	1.9%	<0.01%	0.008%	0.10%	0.02%	0.00011%
Element	Bi	Br	C	Cd	Cl	Cr	Cu	F
Content	0.17%	0.54%	9.6%	0.015%	1.74%	0.05%	26.8%	0.094
Element	Fe	Ga	Mn	Mo	Ni	Zn	Sb	Se
Content	5.3%	0.035%	0.47%	0.003%	1.47%	1.5%	0.06%	41g/t
Element	Sn	Te	Ti	I	Hg	Sr	Zr	SiO_2
Content	1.0%	0.0001%	3.4%	0.02%	0.0001%	0.001%	0.003%	15%

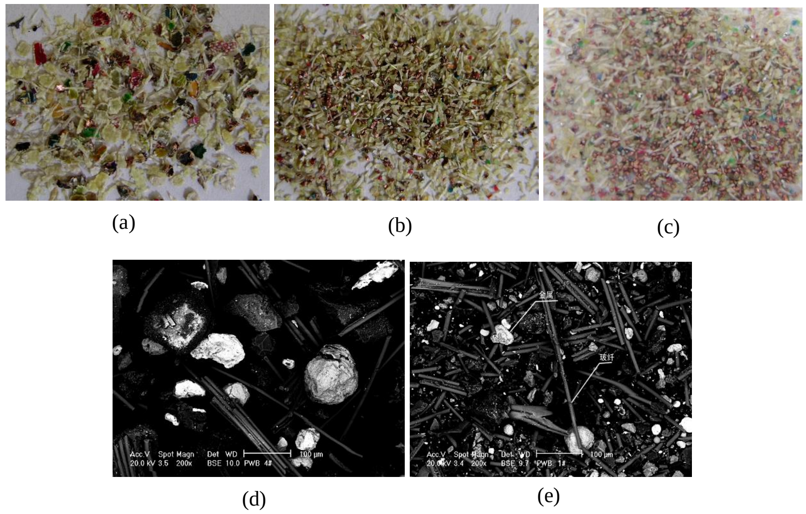

Fig. 3 Photos of materials with different grain-size levels after screening. (a) +30 mesh; (b) -40+60 mesh; (c) -80+120 mesh; (d) -120+200 mesh; (e) -200 mesh; (+ = oversize; - = undersize).

mesh material (Fig. 3d), while the content of rod-like glass fibers is the highest in the -200 mesh material (Fig. 3e).

When the PWBs were crushed, various materials connected via confluence or adhesion were partially cracked along the interfaces, or were separated into single-component monomer dissociated grains. The crushing undersize of all components will lead to inadequate dissociation and finally to low product grade in the subsequent separation. Nevertheless, the crushing oversize will lead to adequate dissociation and also to the generation of inseparable fine grains. This phenomenon called “over crushing” is unfavourable for the subsequent separation, since it will reduce the grade and recovery of Cu and raise the costing. Thus, an appropriate crushing fineness is necessary for economic and efficient separation between metals and nonmetals.

The above photos and grade analysis show that Cu content is the highest in the crushed materials with grain-size level of 0.2-0.3 mm, followed by grain-size level 0.12-0.2 mm. Then a smaller grain size corresponds to a lower grade. With grain size larger than 0.3 mm, a larger grain size corresponds to a lower grade. Clearly, the crushing effect and the yield are both maximized with grain-size level of 0.12-0.3 mm. Therefore, the optimal grinding revolution speed is 3100 r/m.

Shaking-table separation: The PWB powder after grinding was used in reselection test on the fine shaking table with the following conditions: stroke, 9-17 mm; punching

Table 2: Average contents of minerals in ores and PWBs.

Element	Average content in ores %	Average content in PWBs %
Cu	0.5-3.0	12.5-26.8
Zn	1.7-6.4	0.08-1.5
Sn	0.2-0.85	1.0-4.0
Pb	0.2-0.85	2.7-3.0
Fe	0.3-7.5	0.6-5.3
Ni	0.7-2.0	0.7-1.47

Table 3: Pore diameters of the six sieves.

Sieve size (mesh)	30	40	60	80	120	200
Pore diameter (mm)	0.6	0.45	0.3	0.2	0.12	0.074

Table 4: Grain size distributions in PWB powder and Cu grades with all grain-size levels.

No.	Granin size (mm)	Weight (g)	Yield α (%)	Cu grade β (%)	α × β	Recovery ε (%)
1	>0.45	54.35	14.07	37.70	530.44	10.50
2	0.3-0.45	73.46	19.01	40.00	760.40	15.06
3	0.2-0.3	72.11	18.66	71.43	1332.88	26.41
4	0.12-0.2	60.72	15.71	66.85	1050.21	20.80
5	0.074-0.12	57.55	14.90	52.83	787.17	15.59
6	<0.074	68.18	17.65	33.30	587.75	11.64
Total		386.37	100		5048.85	100

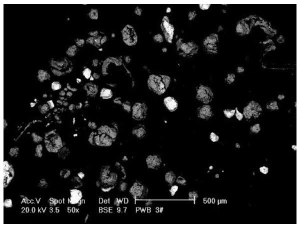

Fig. 4: Shaking-table separated PWB material × 50.

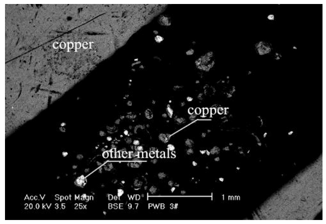

Fig. 5: Shaking-table separated PWB material × 25.

Table 5: Results from shaking-table separation.

Cu in crushed powder %	Heavy products per g	Cu in heavy products (%)	Light products per g	Cu in light products (%)	Yield of heavy products (%)
50.49	22.2	78.64	67.3	30.29	24.1

number, 280-460 r/m; test material, 92.1 g; feeding grain size < 0.2 mm; material feeding speed, 100 g/min; water feeding speed, 6 L/min; and transverse slope of shaking table: 2°. Heavy and light products were separated on the shaking table, while Cu was enriched in the heavy products (Table 5).

To further determine the occurrence states of Cu and the relation of dissemination between metals and nonmetals in the powder, we analysed the screened grains using SEM (Figs. 4- 5). Fig. 5 shows the comparison between Cu and the materials. The gray photos in the upper left and the lower right corners indicate Cu, and the homochromatic materials on the black strips are Cu, and the other more white and bright materials are other metals, which can be deduced to be the welding materials (mainly Zn) on the PWBs. These photos do not show any rod-like glass fibers, indicating that the shaking-table separation process is able to separate the light-weight glass fibers and plastics.

The results indicate that the shaking-table process is very effective for separation of PWB mixed materials with grain size < 0.45 mm, and increases the Cu grade from 50.49% to 78.64%. The image effect indicates that light-weight materials such as glass fibers have been almost all separated out. The light-weight products after shaking-table separation still contain 30.29% Cu, which is probably left in the large-size materials and thus cannot be fully separated from the plastics. Therefore, further fine-grinding is needed.

CONCLUSIONS

PWBs with crushing properties different from regular minerals can be appropriately crushed via shear crushing and grind crushing. The metals and nonmetals in PWBs were fully dissociated at the crushing and grinding speed of 3100 r/m, which also facilitated the subsequent reselection.

The combined screening and shaking technique is effective at separation and enrichment of Cu. During screening tests, metal contents (mainly Cu) are the highest in the materials with the size level of 0.12-0.3 mm, which indicates the highest separation effect. During shaking table tests, the dissociation degree between metals and nonmetals is very high in the PWB mixed materials with grain size < 0.45 mm, which yields a Cu grade of 78.64%.

The crush-screen-shake process is able to effectively recover valuable metals from obsolete PWBs, and thus will bring about many social and environmental benefits.

ACKNOWLEDGEMENTS

This research was financed by the National Natural Science Fund Projects (41362003) of China and the Twelfth Five-Year National Science and Technology Support Program (Serial number 2012BAB10B03).

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