INVESTIGATION OF ABILITY LIBERATION OF METALS FROM PRINTED CIRCUIT BOARDS BY MECHANICAL PROCESSES FOR PHYSICAL SEPARATION PROCESSES

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Received: 5 May 2016; Accepted for publication: 26 June 2016

ABSTRACT

Physical separation process was widely applied for the separation of metallic component from Printed Circuit Boards (PCBs) due to their advantages as friendly-environment, facilitated control, and low-cost. However, the efficiency of physical separation depends on a level of the liberation between the metallic and non-metallic components which is conducted by mechanical processing.

In this study, the liberation of metals from computer PCBs was conducted in detail by mechanical processes including cutting and crushing. The obtained results demonstrate the distribution metallic and non-metallic component weighs as a function of particle sizes. The separation efficiency of metals was conducted by air separation using vacuum sorter equipment. The results showed that the comminution processes using hammer mill for reach the highest efficiency with 92 % recovery and 87 % grade of metallic components in the heavy fraction with particle size 1.0 - 1.4 mm by air separation process.

Keywords: Mechanical process, Printed Circuit Boards (PCBs), metallic liberation,

1. INTRODUCTION

The products of electric and electronic equipment have rapidly increased year by year. Together with this, large amount of waste from electric and electronic equipment (WEEE) are being generated in worldwide. Globally, more than 50 million tons of E-waste was discarded in 2009 [1]. A significant proportion of WEEE is constituted by Printed Circuit Boards (PCBs) which represent about 8 % by weight of WEEE collected from small appliances [2] and 3 % of the mass of global WEEE [3]. In addition, the average distribution of these materials by weight is approximately 30 % of polymers (mainly epoxy and polyester), 30 % of refractory oxides (mainly silica, alumina, rare earth oxides), and 40 % of metals (copper, iron, tin, nickel, lead, alumina, gold, silver, etc.) [4-5]. Thus, PCBs are considered both toxic and valuable materials.

Many studies have been conducted on mechanical pre-treatment for the liberation and separation of the metallic components from wasted PCBs [6 - 8]. The research were started with cutting of the PCBs in order to reduce their size to small pieces, then the comminution were conducted to liberate metallic components and reducing the size of particles. Air separation, magnetic separation, and eddy current separation were conducted in order to separate and enrich the metallic component in the PCBs. Finally, hydrometallurgy process including extraction, separation and recovery of valuable metals were applied. In order to increase the recovery efficiency of the valuable metals, the mechanical pre-treatment processes are very important and can consider as a key of the processes. Even though, many studies have been performed on the mechanical pre-treatment process of the PCBs, the efficiency of liberation and separation is not really high.

In this study, the liberation of metals from computer PCBs was conducted by mechanical processes including cutting and crushing. The obtained results demonstrate the distribution of metallic and non-metallic component weights as a function of particle sizes. The metallic component was efficiently separated by air using vacuum sorter equipment.

2. MATERIALS AND METHODS

2.1. Materials

Approximately 15 kg of PCBs of obsolete computer from private dismantling facilities were used. The major metallic components were copper (29.16 %), zinc (2.16 %), lead (1.34 %), nickel (0.24 %), and iron (9.14 %). The total metal content in wasted PCBs was approximately 42.04%.

2.2. Methods

Schematic diagram of the physical and mechanical recycling processes for increasing efficiency of metallic liberation and separation from waste PCBs is shown in Figure 1.

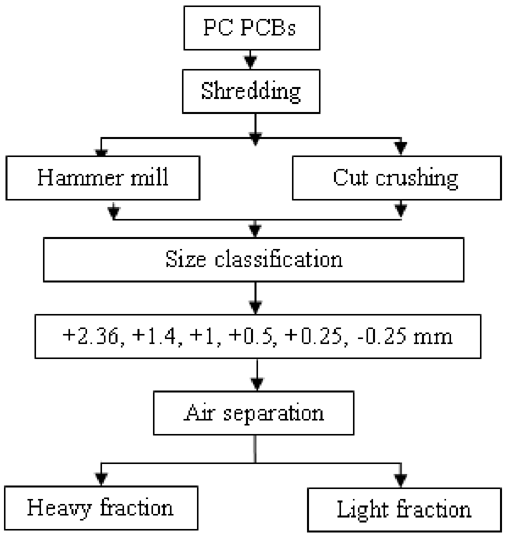

Figure 1. Flow diagram for the separation of valuable metals from PCBs by mechanical pre-treatment and physical processes.

2.2.1. Milling of PCBs

The sample of PCBs from obsolete computer was shredded into 50 mm × 50 mm size using shredder (Model: Top-10-SH, Korea) and mixed in order to ensure its homogeneous. Then, the mixture was divided into three parts. The first part was used for input sample analysis. The entire two parts were passed to hammer crusher with maximum speed of 1,800 rpm (process A, Figure 2-A) and cut crusher with electric motor of 3.75 kW – 380 V (process B, Figure 2-B) with Φ4 mm screen diameter in order to assess capacity of liberation and separation of metallic component in samples. The specifications of the crushers are as follows Table 1.

Table 1. Specifications of crushers used for PCB millings

Type of crushers	Model	Origin	Feed particle size	Product size
Hammer crusher	Top-03H	Korea	< 20 mm	< 5mm with 3 screen sizes
Cut crusher	Top-05CC	Korea	< 50 mm	

A. Hammer crusher

B. Cut Crusher

C. Vacuum sorter equipment

Figure 2. The equipments using in experiments.

2.2.2. Air separation

The samples from process A and process B were passed to vacuum sorter equipment (Air separation equipment - Figure 2-C) in order to separate heavy fraction (almost metallic compound) and light fraction (almost non-metallic compound). Several factors affect to the efficiency of air separation process such as gravity, shape, size of particles. In order to recover metal in a highly efficient sound way in heavy fraction, the requisite air velocities were adjusted through preliminary tests for each particle size of milled PCBs. In detail, air velocity of the equipment was selected at 21, 13.7, 12, 7.7 and 3 m^3/min for particle size of more than 2.36, 1.4–2.36, 1.0–1.4, 0.5–1.0 and 0.25–0.5 mm, respectively, at a constant milled PCBs feed rate of 500 g/min.

2.2.3. Chemical analysis

Samples were collected for each process in order to analyze metallic content and assess the efficiency of metal liberation and separation. It was leached by 3 mol/L nitric acid and agitated at a speed of 800 rpm in 5 hours, at a temperature of 60 ^oC using 25 g/L pulp density. The leached samples then were analyzed by Atomic absorption spectrometry (AAS) [9].

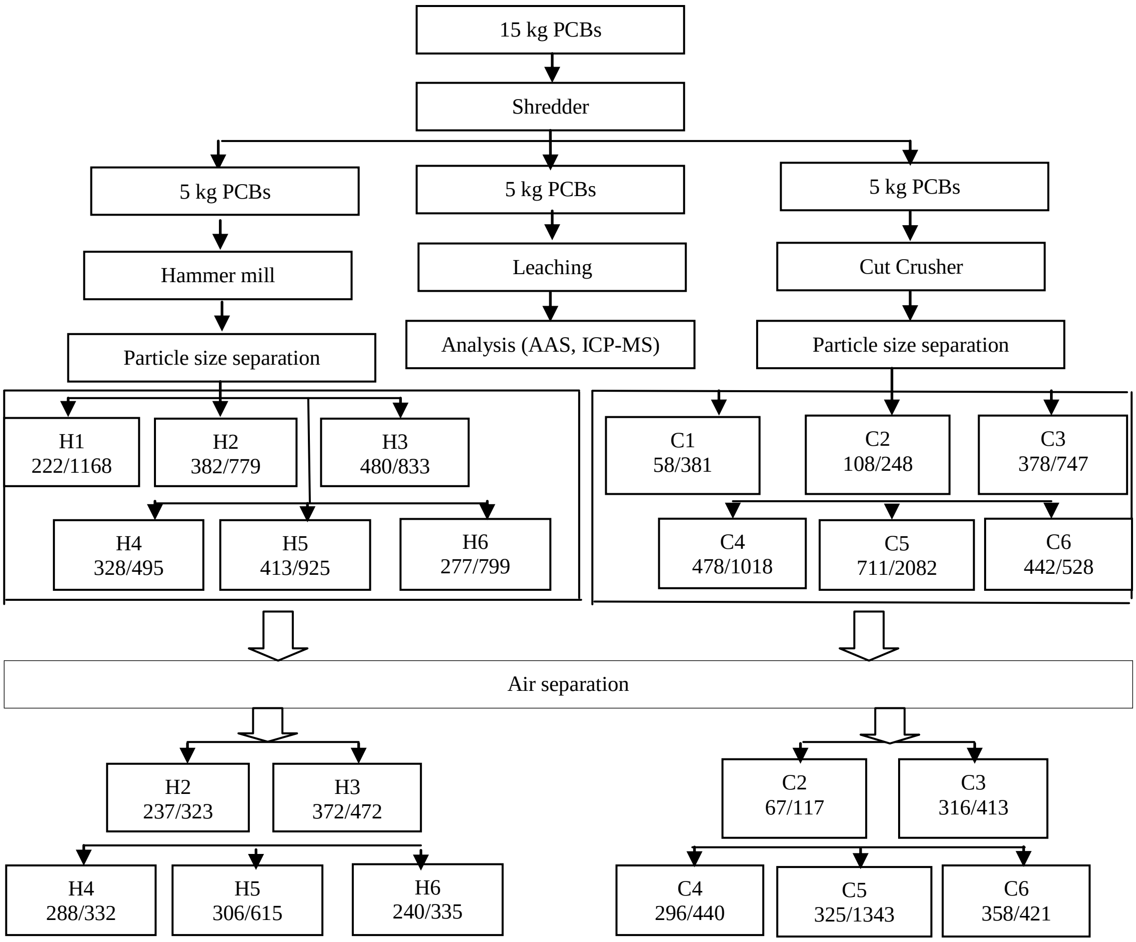

Figure 3. Flowchart of the PCBs scraps. H1, H2, H3, H4, H5, H6- the metallic weight/ total weight of the process B and C1, C2, C3, C4, C5, C6- the metallic weight/total weight of the process B- for particle size range: <0.25, 0.25-0.5, 0.5-1.0, 1.0-1.4, 1.4-2.36, >2.36 mm, respectively.

3. RESULT AND DISCUSSION

3.1. Comminution and size separation

The results of the experiments are presented in Figure 3. In order to liberate metallic components, the PCBs were milled using two separated equipment: hammer crusher (with speed of 1000 RPM and Φ4 mm screen diameter) and cut crusher (with speed of 960 rpm and Φ4 mm screen diameter). The distribution of the metallic and non-metallic components with particle sizes of PCBs is shown Figure 4 for process A and Figure 5 for process B. For process A, the distribution of weigh is evenly among the ranges of particle size. The weight is most concentrated in the smallest size part (23 %). The highest non-metallic component is about 18.9 %. It can be explained that the non-metallic components, composed of brittle ceramics and glass-fiber-reinforced epoxy resins, were milled to a smaller size, whereas the metallic components were either milled to a smaller size or become coarser.

Figure 5 shows that about 80% of weight was concentrated in particle size of between 0.5–2.36 mm. The highest weight was more than 40% and concentrated at particle size of 1.4 – 2.36 mm. This can be explained that cut crusher crushed samples to smaller size and almost evenly.

Distributions of major metals as function of particle sizes are shown in Table 2 and Table 3. For process A and process B, the major metal content after size classification was accounted for 19.0 % – 66.2 % and 15.3 % – 84.2 %, respectively.

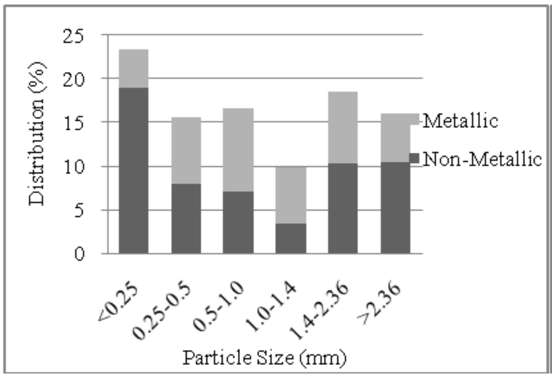

Figure 4. The distribution of weight, metallic and non-metallic components as a function of particle size of the PCBs obtained from the Hammer mill.

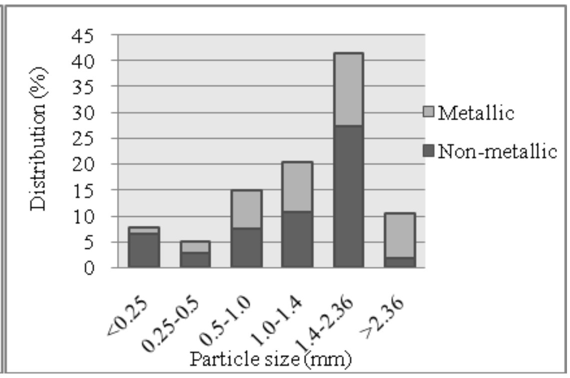

Figure 5. The distribution of weight, metallic and non-metallic components as a function of particle size of the PCBs obtained from the cut crusher.

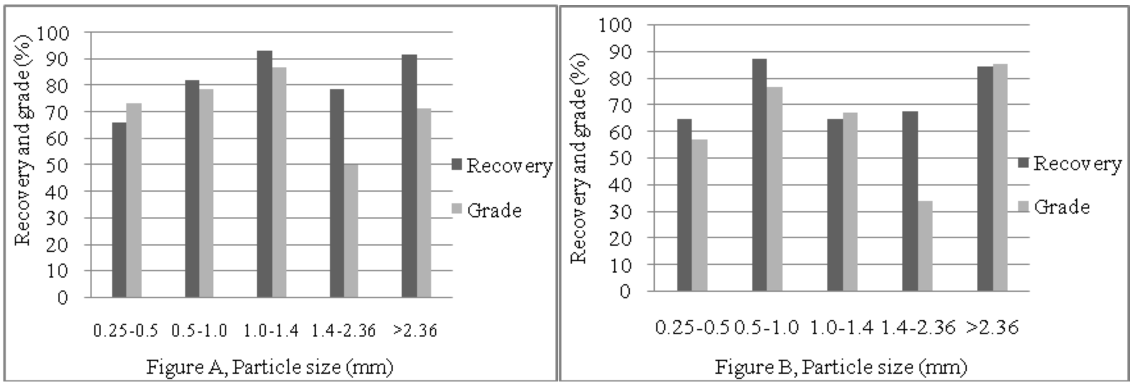

Figure 6. A- Process A, and B - Process B- Recovery and grade of metallic components in the heavy fraction from PCBs by air separation.

Table 2. Result of major metallic elements as following particle size obtained from hammer milling process and air separation

Particle size (mm)	Elements (%) after size classify					Total	Elements (%) after air separation					Total
	Cu	Zn	Ni	Fe	Pb		Cu	Zn	Ni	Fe	Pb	
<0.25	15.5	0.4	0.1	2.8	0.2	19.0	-	-	-	-	-	-
0.25-0.5	42.8	0.5	0.1	5.3	0.3	49.0	55.5	3.1	0.1	12.7	1.9	73.3
0.5-1.0	44.9	3.2	0.5	5.8	3.3	57.6	57.9	4.6	1.8	11.0	3.2	78.6
1.0-1.4	42.9	2.7	0.7	14.3	5.6	66.2	59.9	5.1	0.6	15.5	5.6	86.8
1.4-2.36	24.6	4.4	0.2	15.0	0.7	44.7	23.1	7.1	3.3	15.1	1.3	49.8
>2.36	16.3	2.4	0.1	15.7	0.2	34.7	34.9	4.8	0.1	30.1	1.5	71.4

*Table 3.*Result of major metallic elements as following particle size obtained from cut crushing process and air separation

Particle size (mm)	Elements (%) after size classify					Total	Elements (%) after air separation					Total
	Cu	Zn	Ni	Fe	Pb		Cu	Zn	Ni	Fe	Pb	
<0.25	11.3	0.6	0.1	3.0	0.3	15.3	-	-	-	-	-	-
0.25-0.5	33.4	1.5	0.1	8.0	0.5	43.5	37.8	5.2	0.2	11.0	2.8	56.9
0.5-1.0	36.9	3.1	0.3	9.0	1.3	50.6	49.0	5.0	1.9	14.9	5.7	76.5
1.0-1.4	34.5	2.7	0.4	7.8	1.6	46.9	44.1	4.6	0.8	10.9	6.8	67.1
1.4-2.36	24.3	1.5	0.1	8.1	0.2	34.1	28.3	1.0	0.3	3.5	1.0	34.2
>2.36	25.4	4.5	0.5	53.7	0.1	84.2	32.3	4.4	2.0	45.5	1.0	85.1

Symbol -: not mention

3.2. Gravity separation

Air separation using vacuum sorter equipment was applied to separate heavy fraction (almost metallic component) and light fraction (almost non-metallic component). PCBs were divided to five different fractions of particle sizes: 0.25–0.5, 0.5–1.0, 1.0–1.4, 1.4–2.36, >2.36 mm. The results of investigation showed that it is inefficient to separate sample with particle size less than 0.25 mm. The study, thus, was not mentioned to this particle size.

The results of air separation including component, recovery and grade of metals are shown in Figure 6 (A and B), Table 2 and Table 3. For samples obtaining from process A (using hammer mill), the efficiency of metal recovery and grade of heavy fraction were 66–92 % and 50–87 %. In addition, for the sample with particle size of 1.0–1.4 mm, the highest efficiency was with 92 % recovery and 87 % grade in heavy fraction.

For samples obtaining from process B, efficiency of metal recovery and grade in heavy fraction were 48 – 86 % and 24 – 77 %, respectively. And, for the sample with particle size range from 0.5–1.0 mm, the highest efficiency were with recovery and grade of 87 % and 76 %, respectively. However, the sample with particle size from 1.4–2.36 mm contains 40 % of sample weight after passing air separation process for lowest efficiency with 67.3 % of recovery and 34.2 % of grade in heavy fraction.

In addition, the major metallic components obtained from air separation in Table 2 and Table 3 are shown that the grade of the metallic components was improved from 34.7 % – 66.2 % to 49.8 % – 86.9 % (process A) and from 34.1 % – 84.2 % to 34.2 % – 85.1 % (process B). The highest efficiency for two processes concentrates to 0.5–1.4 mm of particle size range. However, for the milled PCBs of size 1.4–2.36 mm the results of recovery and grade of metallic components in heavy fraction is quite low 78% and 50% for process A; 67% and 34.16% for process B with recovery and grade, respectively. The result can be explain that amounts of non-metallic components were still introduced into the heavy fraction, which were not liberated when comminution using hammer mill and cut crusher. Especially, 40% of sample weigh contain in particle size range of 1.4–2.36 mm obtained from cut crushing process. For the problem, it can be recommended to use one milling process such as ball mill, rod mill, pin mill in order to increase the efficiency of the liberate metallic component from non-metallic component.

4. CONCLUSION

According to the study, for process A (using hammer mill) after passing air separation for higher efficiency of recovery metallic component with 81.8 % compared with process B (using cut mill) with 71.4 %. The weight of the sample evenly distributed as function of the particle size ranges obtained from hammer milling and distributed highest on the particle size range 1.4–2.36 mm is 40 % of weigh obtained from cut crushing. However, the ability of liberation of metals with particle size range 1.4–2.36 mm is not high, it can be showed the result after conducting air separation process with recovery and grade 78 % and 50 % for process A; 67 % and 34.2 % for process B, respectively.

For further study, the sample after passing hammer milling process and cut crushing process will be conducted to pin milling, ball milling, rod milling or pulverize in order to improve the efficiency liberation of metals contain in PCBs and also increasing capacity of recovery and grade of valuable metals from air separation process.

Acknowledgements. This research work was supported by Korea International Cooperation Agency (KOICA) under the project entitled: "The project for research capacity building, waste recycling technology development and transfer in Vietnam".

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