Using Mechanical Processing in Recycling Printed Wiring Boards

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As the number of electronic products in use increases, so does the need to dispose of defective and obsolete equipment, including printed circuit boards. The utilization of mechanical processing in recycling this type of waste enables recovery of the metals and allows components to be separated for proper waste disposal. Mechanical processing allows the recovery of 80% of the metals in printed circuit boards, especially copper, which represents approximately 75% of the metallic fraction.

INTRODUCTION

Around the world, obsolete electrical/electronic equipment is discarded with domestic refuse, deposited in landfills, or incinerated without any pre-treatment. Included in that waste is equipment used in the data-processing or entertainment industry, 30% of which may be printed circuit boards (PCBs). These boards are composed of isolated and integrated units and their scrap contains copper, lead, zinc, and tin, as well as the precious metals gold, silver, and platinum. Thus, the scrap represents an interesting and valuable raw material.

Treating these wastes in a way that does not harm the environment is a complex process due to the heterogeneous composition of the obsolete equipment. Electronic scrap is recycled using mechanical, hydrometallurgical,[1] and thermal processes.[2,3]

The mechanical processing of scrap is usually seen as a pre-treatment for the utilization of materials to separate compounds and components from the scrap.[4–7] Such processes as comminution, classification, and separation (by differences of density, weight, size, magnetic properties, etc.) from different compounds of the wastes are included in the mechanical processing.[8]

The processing begins with comminution.[9] After each comminution step, the resulting fraction is, in general, already enriched in a certain material that can be separated from the main stream. After the last step, concentrate and wastes can be further refined by hydraulic classification and density separation.[3,10,11]

This article will characterize PCBs and evaluate the possibilities for separating materials from scrap by different steps of comminution and size classification. Metals and materials from the substrate (plastics, ceramics, etc.) will be separated using density differences in order to obtain metals and non-metals rich fractions. This work will also show that the geometrical shape of the particles achieved after the comminution process has an influence on the separation process.

EXPERIMENTAL PROCEDURE

For this study, approximately 10 kg of PCBs containing all components were collected from old computers. Components with contaminants (capacitors, batteries, etc.) were removed.

The material was divided into two portions, one in which the PCBs were left intact and another in which the electronic components, welded to the boards, were removed. Three samples resulted from this treatment: complete PCB, electronic components only (EC), and substrate only (SB).

The samples were crushed, separated by size, and chemically analyzed. Next, they were separated by density. The different fractions obtained after the density separations were also chemically analyzed to evaluate the effective metals separation.

Comminution and Size Separation

To guarantee process efficiency, the PCB, EC, and SB samples were crushed on a cutting mill until they were smaller than 1 mm. Zhang[8] shows that after a secondary milling in a laboratory-scale mill, the degree of maximum recovery, mainly for copper, can be reached for particles below 2 mm.

The milled scraps were then classified by size through vibration screen. Three different fractions were obtained: F1 (smaller than 0.25 mm), F2 (between 0.25 and 0.50 mm), and F3 (between 0.50 and 1.0 mm). The fractions were chemically analyzed to determine mate-

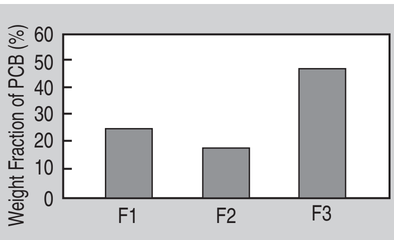

Figure 1. The results of size classification from complete printed circuit boards (PCB) after comminution in a knife mill.

Table I. Chemical Analysis of the Fractions after Size Separation

Samples	(%)	Cu	Zn	Fe	Mg	Ni	Al	Pb	Ag	Sn
PCB	F1	6.28	0.05	0.13	0.05	0.05	3.01	0.35	0.03	2.51
	F2	23.53	0.08	0.13	0.05	0.20	1.55	0.95	0.03	2.50
	F3	24.34	0.23	0.18	0.05	0.20	1.56	1.35	0.03	2.51
EC	F1	9.68	0.38	0.28	n.d.	0.40	2.06	2.34	n.d.	3.83
	F2	17.25	0.19	0.10	n.d.	0.31	1.62	3.18	n.d.	4.78
	F3	30.15	0.66	0.08	n.d.	0.60	0.92	2.78	n.d.	4.92
SB	F1	7.43	0.017	0.525	n.d.	0.22	2.34	1.01	n.d.	1.06
	F2	15.34	0.017	0.320	n.d.	0.35	2.10	1.27	n.d.	1.46
	F3	28.40	0.052	1.538	n.d.	0.41	0.45	2.3	n.d.	9.15

F1< 0.25 mm; 0.25 < F2 < 0.50 mm; 0.50 < F3 < 1.0 mm; n.d. = not determined.

Table II. Average Metal Found in Ores and PCBs

Element	Ore (%)	PCB Average (%)
Copper	0.5–3.0	12.5
Zinc	1.7–6.4	0.08
Tin	0.2–0.85	4.0
Lead	0.3–7.5	2.7
Iron	30–60	0.6
Nickel	0.7–2.0	0.7

rial concentrations, and the geometrical shape of the particles was analyzed by a scanning electron microscope with a 100x magnification.

Separation by Density Difference

As the metals have a higher density than the other components in PCBs, the separation can use this physical property, employing mineral-treatment processes.[12] After the boards were crushed and separated by size, density separation was carried out using organic liquids.[12] The organic liquids were chosen because they are simple to work with in the laboratory. The liquid utilized was tetrabromoethane (TBE), due to its reduced cost and commercial accessibility. The choice also was made because TBE has an intermediate density between metals and the other components of the PCB, and because it does not chemically react with the components of the sample. Tetrabromoethane has a relative density of 2.96 g·cm^{-3} and can be diluted with acetone [$(CH_3)_2CO$]. The fluid density, 2.5 g·cm^{-3}, was chosen because the viscosity is lower, the separation process faster, and the TBE filtration more efficient. To reduce the density from 2.96 to 2.5 g·cm^{-3}, acetone was utilized in the proportion of 1:0.27. Zhang[8] used this same relationship in density separation for electronic scrap.

The density separation was done with the three samples (PCB, EC, SB) and with the three fractions obtained by size separation. Heavy fractions (rich in metals) and light fractions (rich in plastics and ceramics) were obtained. All fractions were chemically analyzed to verify the efficiency of the density separation and to determine if there was some concentration of any element in one of the fractions.

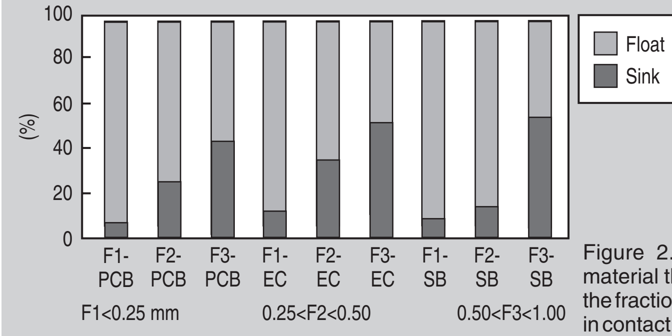

Figure 2. The percentage of material that sinks and floats of the fractions of PCB, EC, and SB in contact with TBE (with density = 2.5 g·cm^{-3}) during 2 hours.

RESULTS

Comminution and Size Separation

The results of the comminution and size classification of complete PCBs (Figure 1) show that most of the material is concentrated in the coarser fraction (F3). Similar results were obtained for the other two samples (EC and SB).

The results of the chemical analysis of the main metals from the fractions obtained by comminution and size separation are presented in Table I. It can be observed that the metals, in particular, copper, are concentrated in the coarser fraction (F3), probably due to the greater simplicity of milling polymers and ceramics than metals.

Table II presents a comparison between the average amount of metals found in PCBs and the amount of the same metal in ores. The average percentage for each element in complete PCBs was the arithmetic mean of all fractions.

Separation by Density Difference

After the separation by density with TBE, light and heavy fractions were obtained. The results for complete PCBs, EC, and SB are shown in Figure 2.

The three scrap types exhibited the same behavior (i.e., the sinking percentage increases with the increase in particle size). This was expected since the chemical analysis of the milled fractions showed that the fraction with larger particles (F3) had the greater metal concentration (see Table I).

After the density separation, the heavy and light fractions were analyzed. The results of the chemical analysis of the main metals from the three fractions obtained from milled PCBs are presented in Table III.

From the results of the chemical analysis of the light and heavy fractions (Table III), it can be observed that the metals are highly concentrated in the fraction that sinks, validating the process of separation by density. The exception is aluminum, which presented a trend for the light fractions. This occurs due to its density (2.7 g·cm^{-3}), which is very near to the used-cut density (2.5 g·cm^{-3}). Zhang[8] has also demonstrated that approximately 50% (in weight) of the floated material (mainly plastic) can be separated with densities smaller than 2 g·cm^{-3}. For the other analyzed elements, the result was very good. As a calculation exercise, one can imagine that by the treatment of 100 kg of scrap, 16.4 kg of metal would be recovered, and from that, 8.3 kg would be copper. Comparing these values with what would be possible to obtain from 100 kg of ore, one proves

Table III. Chemical Analysis of the Heavy and Light Fractions of PCB after Density Separation

(%)	Cu	Zn	Fe	Mg	Ni	Al	Pb	Ag	Sn
F1 Heavy	64.97	0.26	0.13	0.05	0.34	0.52	1.61	0.08	2.6
F2 Heavy	54.99	0.20	0.30	0.05	0.47	0.50	1.40	0.07	5.00
F3 Heavy	44.96	0.17	0.77	0.05	0.37	0.50	1.42	0.02	15.00
F1 Light	0.24	0.02	0.07	0.05	0.05	0.48	0.12	0.02	2.39
F2 Light	0.42	0.02	0.07	0.05	0.05	1.04	0.12	0.02	2.48
F3 Light	3.25	0.02	0.07	0.05	0.05	0.50	0.12	0.02	2.50

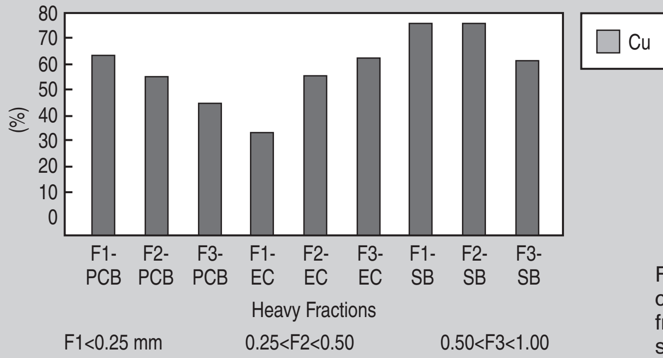

Figure 3. The copper concentration of each fraction after the density separation.

once again that PCBs are a very valuable raw material. Figure 3 presents the copper concentration of the heavy fractions obtained after the treatment of PCB, EC, and SB.

For two kinds of samples (PCB and SB), the higher copper concentration was verified for the heavy fraction with smaller size (F1). But for the EC sample, copper was concentrated in the fraction with larger particle size (F3). It was observed that the smaller the particle sizes, the greater the amount of floating material (see Figure 2). The sinking fraction was expected to be pure (i.e., to have proportionally more metals and, consequently, more copper). This is what happens to PCB and SB samples, where the fines have proportionally more copper than the coarse fractions (see Figure 3). The EC samples do not have the same tendency.

The particle shapes, which are different after milling, could explain this behavior. The EC have a rounded particle shape (Figure 4), while the PCB and SB have an elongated form (Figures 5 and 6). It is known that the particle shapes have an influence on density separation. They determine the terminal velocity and the material stratification, acting on the process efficiency.[12]

Ferrara et al.[13] have shown that plastics milling creates particles with different shapes, causing difficulties in the separation. The behavior of cubes, flakes, prisms, and mixtures of these shapes was studied. Zhang[8] studied also the shape influence on the separation processes and concluded that this is a very important parameter to be observed.

The shape of the particles is related to the milling process. Changes in the comminution process can affect the shapes and, consequently, the metals-recovery efficiency. Future works are going to deal with these parameters.

CONCLUSION

From these preliminary results it can be seen that it is possible to recover metals from PCBs using mechanical processing. Using just size separation, it is possible to concentrate 30% of the metals, and with separation by density, 65%. Considering the different metals present in PCBs, the separation method presented here seems to be particularly efficient in recovering copper, for which fractions of 55% were obtained. This work will continue with the studies of the light fractions in order to determine their toxicity and of different copper recovery possibilities.

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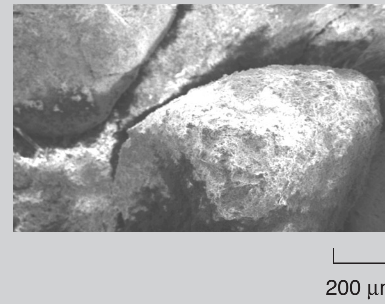

Figure 4. The EC particle shape after comminution on a knife mill (particle size: 0.5 < F < 1.0 mm).

Figure 5. The PCB particle shape after comminution on a knife mill (particle size: 0.5 < F < 1.0 mm).

Figure 6. The SB particle shape after comminution on a knife mill (particle size: 0.5 < F < 1.0 mm).

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