American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-5, pp-46-51
www.ajer.org
Research Paper Open Access

Recycled Metal Characterization of Printed Circuit Boards

Eduarda Tobolski[1], Milena Müller Lottici[2], Alexandre Giacomin[3], José de Souza[4], Carlos Alberto Mendes Moraes[5]

[1, 2, 3, 4]*Fundação Liberato - Novo Hamburgo, Brazil*
[5]*Universidade do Vale do Rio dos Sinos - São Leopoldo, Brazil*

Corresponding Author: José de Souza, josesouza@liberato.com.br

ABSTRACT: *This paper presents the characterization of electronic components from Printed Circuit Boards (PCBs) and the comparison with the characterization of the printed circuit board without its parts. The question that guides the research is about the possibility of developing a methodology for processing that covers not only the PCBs but also its electronic components. This process is possible through the physical dismantling of the computer, printed circuit board removal, separation of their electronic components for thermal processing, grinding and particle size separation. After the mechanical processing, the chemical steps start with the analysis of x-ray Fluorescence (FRX) that determines the types of metals contained in each granulometric fraction, leaching in aqua regia, which separates the ceramic and polymeric materials of metals, and precipitation of metals using the method of reduction using laboratory, aluminum that retrieves the metals so that they can be reused. The viability of the research is indicated by the scanning electron microscopy analysis, which reveals what kinds of metals have been recovered.*

KEYWORDS: *Electronics, Reuse, Metals, Printed Circuit Board.*

Date of Submission: 28-04-2020 Date of acceptance: 11-05-2020

I. INTRODUCTION

This paper deals with methods for the recovery of metals from two different parts of the same object of study: the electronic components of printed circuit boards and printed circuit boards without their components.

The significant negative consequence of the rapid and constant evolution of technology is the inappropriate and irresponsible disposal of electronic devices. When deposited in an improper place, the simplest of electro devices can contaminate the soil, water, air, and living beings around it because it contains many metals in its composition. In 2016, the global production of electronic waste reached 44.7 million tons, and this number tends to grow, according to experts, by more than 17% by 2021, totaling 52.2 million tons [1-2]. In addition to the polymeric and ceramic composition of electronics, uniquely portable computers, the range of metals used is extensive and valuable. Among the primary metals used are copper, tin, lead, silver, and gold, among others. In addition to the environmental impact, according to a survey carried out by the UN (2018), inadequate disposal has negative economic consequences [1].

II. LITERATURE REVIEW

According to the UN (2018), around 40 million tons of computers, smartphones, and other devices are disposed of inappropriately in the world every year, which is equivalent to approximately 800 laptops every second going to landfill [1]. The disposal of these products at the end of their useful life has become increasingly common, forming a system of linear production of resource exploitation, manufacturing, and destruction. In general theory, 98 % of a portable computer is recyclable, but in practice, that number drops to around 80 %. The mixture of polymeric, ceramic, and metallic components with heavy metals makes the separation more difficult.

In Japan, it is the habit of the population to return the old cell phone to the operator's store. They usually receive several old cell phones a day. The recycling process using a type of large pressure cooker at 500 ° C, which, after 12 hours, holds a dark material for separation, where metals such as silver, gold, and copper. A Japanese mining company, for example, managed to produce a 10 kilogram bar of gold from the minerals found in cell phones. The other metals return to the market in the form of new equipment, and the plastic turns into fuel oil for the machines [3].

In Brazil, the approach and priority given in the field of social inclusion to recyclable material collectors stand out among the countries of Latin America, gaining prominence in the elaboration of State Policies and National Policies of Solid Waste [4].

However, there are still many challenges that permeate technological innovation. Researches point out significant advances in the technical area [5]. However, they are always moving in timid steps, strong support from the public authorities, and citizens' awareness in the search for sustainable management of WEEE is still necessary.

The recycling of electronics needs higher investments, as the technology is still little used in Brazil. For this reason, researchers from LAREX (Laboratory of Recycling, Waste Treatment, and Extractive Metallurgy at POLI-USP) dedicated to studying the recycling not only of silver but of several metals that make up the electronics. According to the thesis of MORAES (2011), the recovery of minerals present in electronic equipment has attracted interest thanks to different technologies that aim at the reuse of these chemical elements in new production processes [6].

Aiming at the constant evolution of technology and the improper disposal of electronic waste, research from the University of Vale do Rio dos Sinos - UNISINOS, proposes the characterization and technological development for the use and recovery of rare and critical elements from consumer electronics products. Based on this, there are several branches within the research aimed at different models and electronic equipment for the recovery of metals [7-8].

III. MATERIALS AND METHODS

From the grouping of five portable computers collected by donations of the Electronic Waste Collection Campaign carried out by the Universidade do Vale do Rio dos Sinos, the equipment disassembled by classifying its parts, isolating the printed circuit boards. The cleaning and removal of substrates and components adhered to the *PCBs* with the aid of an air blower from Toyo's TS-2850D rework station installed at LCVMat (Laboratory of Characterization and Valorisation of Materials), using hot air jets regulated in the maximum temperature that the device provided of 500ºC, reworking the SMD components.

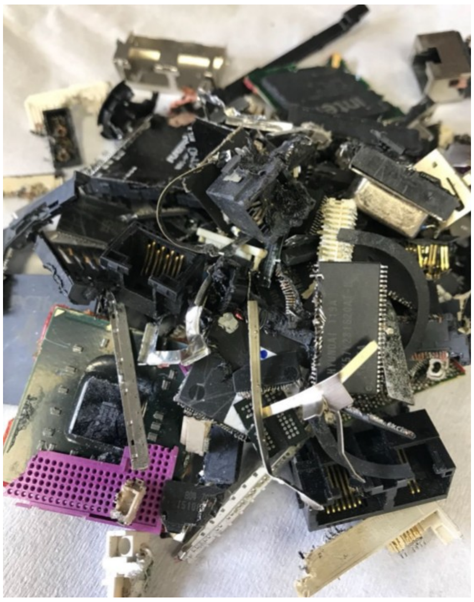

Fig. 1. Electronic waste.

To reduce the components of the printed circuit boards in fragments, leaving the necessary granulometry for the characterization tests, it is required to decrease their size. Thus, forwarding to the knife mill, WEG W22 plus located in the Laboratory of Characterization and Valorisation of Materials - LCVMat of

UNISINOS. With this process, 560 grams of the material was obtained, without distinction of grain size. After the grinding step, the granulometric separation process [8].

After grinding, at the Civil Construction Materials Laboratory (LMC), a mechanical sieve shaker and two sets of 6 hollow sieves (Fig. 2) were made available by LCVMat, following NBR 5734, with different mesh openings, in order decreasing, then, from the most widely spaced to the most closed mesh, isolating each different grain size, of sizes: 3.35 mm; 1.70 mm; 0.85 mm; 0.60 mm; 0.425 mm; 0.30 mm; 0.21 mm; 0.15 mm; 0.106 mm; 0.075 mm and 0.053 mm.

Fig. 2. Sieves used for particle size testing.

The test consisted of stacking the sieves in ascending order and depositing the material on the most significant opening sieve, shaking them for 15 minutes with the eighth level of agitation. The weighing of the retained fractions occurred on an analytical balance in the LCVMat.

Then, the grains submitted to the granulometry were evaluated by the X-Ray Fluorescence Spectrometry (FRX) assay, in LCVMat, in an X-ray fluorescence equipment by EDX 720 HS model, Shimadzu. They divided according to the mesh in which they deposited in the granulometric distribution test, thus being thirteen small samples from twelve screens and the bottom.

The next leaching process based on SILVEIRA (2016) consisted of identifying the number of metals, dividing the residue into fractions. To isolate and concentrate the metals, so that polymers and ceramics do not hinder the recovery process, 20 mL of aqua regia used for each 1g of the sample, this solution composed of 3:1 of 10 % hydrochloric acid for 6 5% nitric acid ($HCl: HNO_3$). This composition makes it possible to separate all metals retained in the samples. The material divided into fractions following separation criteria based on the results of the FRX, i) F1 = REE 4.75 mm + REE 3.35 mm; ii) F2 = REE 1.70 mm + REE 0.85 mm; iii) F3 = REE 0.60 mm + REE 0.425 mm + REE 0.30 mm; iv) F4 = 0.21 mm REE + 0.15 mm REE + 0.106 mm REE; v) F5 = REE 0.075 mm + REE 0.053 mm + REE Bottom.

The fractions materials were in contact with the solution for 24 hours, packed in closed glass bottles, inside a chapel at room temperature. Subsequently, J Prolab filter paper, with 8μm porosity, was used to filter. From that, the leachate material was filtered and then dried for 4 hours in a 60 ° C furnace. To quantify the mass of leached material.

Precipitation occurs with the redox method, based on LOTTICI & TOBOLSKI (2017) [9]. To make the metals dissolved in leaching solid using a chemical reaction. The chemical reaction that involves the exchange of electrons from both parts, material that undergoes reduction and that undergoes oxidation, using the metal reactivity table as a reference. The aluminum comes into contact with the solutions forming simple exchange reactions where the metal with NO_X zero. Able to displace the other metal that is in the salt taking its place and then creating aluminum salts and, theoretically, this metal is with NO_X zero in its state solid in its purity conditions [9]. This process lasted 1h to guarantee the effects. Then the filtering was done with J Prolab filters (porosity of 8 μm) folded in glass funnels, made available by LCVMat, and dried in a Mufla oven at 60 ° C for 4 h.

IV. RESULTS AND DISCUSSION

Five hundred sixty grams of fragmented material without distinction of grain size subjected to the granulometric separation test, and the result presented in Table 1 shows the mass value of each sample according to the mesh size and the bottom in which occurs the grain deposition.

Table 1 – Granulometry.

Mesh Opening (mm)	Mass (g)
4.80	17.75
3.50	15.91
1.70	242.34
0.85	189.69
0.60	26.94
0.42	22.48
0.30	13.81
0.21	11.50
0.15	6.41
0.10	6.02
0.07	4.66
0.05	4.88
Bottom	4.54

Subsequently, the grains classified in the granulometric separation towere analysed by the X-Ray Fluorescence Spectrometry (FRX) assay technic followed the proposed methodology. The results found the X-Ray Fluorescence Spectrometry (FRX) technic followed the proposed methodology. The results found for the FRX analysis of the components of the printed circuit boards (Table 2) in elements identified in lesser quantity (5 % - 50 %).

Table 2 - FRX results.

Sam	Smallest Quantity (5% <x <50%)	Trace Elements (<5%)
S1	Cu, Ni, Zn, Fe, Cr	Al, Ba, Br, Ca, Ce, Cr, Mn, Mo, S, Se, Si, Sr
S2	Ba, Br, Ca, Cu, Fe, Si, Sn	Ac, Ag, Au, Ba, Bi, Cr, Fr, I, Ni, Pb, S, Sb, Sn, Sr, Ti, Zn, Zr
S3	Ba, Br, Ca, Cu, Fe, Ni, Si, Sn	Ac, Ag, Au, Ba, Ca, Cr, Fr, I, Mn, Nb, Ni, P, Pb, S, Sb, Sr, Ti, Zn, Zr
S4	Ba, Br, Cu, Fe, Si, Sn	Ac, Ba, Ca, Cr, Fr, I, Mg, Mn, Nb, Ni, P, Pb, Sb, Sn, Sr, Ti, Zn, Zr
S5	Al, Ba, Ca, Cu, Fe, Si, Sn	Ag, Al, Ba, Br, Ca, Cr, Fr, I, Mg, Mn, Nb, Ni, P, Pb, Sb, Sn, Sr, Ti, Zn, Zr

Thirty-one different types of metals from the components of the printed circuit boards passed through a characterized for the quantitative determination in percentage through standards. Standards provide the calibration curves, but the laboratory does not have a standard for this material. Thus, it was only possible to make a semi-quantitative determination, which used in this work. The fractions showed different coloring from each other (Fig. 3), which represents the metal in greater quantity and the one that most reacted with the water solution ($HCl: HNO_3$).

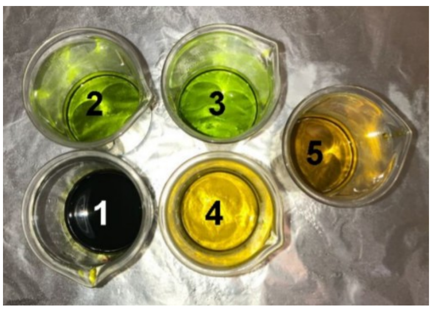

Fig. 3. Material leached in acid.

The color of the first sample defined due to the predominance of Chromium 3+. Samples 2 and 3 show a more greenish color, characteristic of Ferro. In samples 4 and 5, the orange color predominated, being able to determine the greater presence of Copper 6+. Due to the high occurrence of different types of metals, colors may vary in shade.

With reference, the amount of metal present in the samples, on average, 72.01 % of the material is a metallic compound. Table 3 shows the mass quantities of each sample, the discount made from the masses of the filters to obtain the percentage of metal present.

Table 3 - Amount of metals per sample after leaching.

S	Mass (g)	Mass F. (g)	Mass T. (g)	Mass F. (g)	% Metal Mass (g)	% Metals leachate (g)
S1	1.004	0.635	1.124	0.515	0.489	48.71
S2	1.009	0.633	1.401	0.241	0.768	76.11
S3	1.003	0.677	1.398	0.282	0.721	71.88
S4	1.000	0.679	1.441	0.238	0.762	76.20
S5	1.003	0.678	1.552	0.129	0.874	87.14

Analyzing the obtained values, it confirms the recovery potential, since there are a vast amount and variety of metals present in this type of waste, evaluating the cost-benefit of the recovery. In comparison to the values of the precipitation procedure based on the research by LOTTICI & TOBOLSKI (2017), those found in this project are smaller. However, this justified the greater variety of metals found from the FRX analysis. As the method uses the reactivity of metals as a base, aluminum does not cover all that found in electronic components. The values obtained from the precipitation procedure of metals leached with laboratory aluminum for this project, according to Table 4.

Table 4 - Amount of the leachate metals precipitation procedure.

S	Metalic mass (g)	Mass F. (g)	Mass Filtrada (g)	Massa Metais precipitados (g)	% metals
S1	0.489	0.801	1.447	0.646	132.11
S2	0.768	0.674	0.970	0.296	38.54
S3	0.721	0.892	1.380	0.488	67.68
S4	0.762	0.700	1.261	0.561	73.62
S5	0.874	0.792	1.351	0.559	63.96

The average recovery of leachate metals from the precipitation process is 60.95 %, which indicates, despite the decrease compared to other studies, that the method remains valid. In the first Sample, the value exceeded 100 %, being mathematically impossible, and this is an indicator that when the leached liquid of the polymers and ceramics is filtered, something may have been retained in the flask, so this value was disregarded when calculating the average.

V. CONCLUSION

Despite the lack of time due to unforeseen events in the research to carry out the Scanning Electron Microscopy (SEM) analysis, the validity of the method based on LOTTICI & TOBOLSKI (2017) considered. The main objective proposed by this work was the search for the characterization of the electronic components coming from printed circuit boards to prove the possibility of using the same method of metal recovery. Despite the decrease in the percentage of regeneration by the precipitation method, this difference remedied by using a more reactive metal compared to those found in the FRX analysis. However, a different metal not used in this project to precisely obtain results that could be compared.

A significant breakthrough is the variety of metals found by FRX analysis, totaling thirty-one different types, with gold in more than a fraction of material. Another value that stood out is the average amount of metals per Sample, totaling 72.01 %. This value demonstrates the importance of seeking to reuse metals from not only printed circuit boards but also, and especially, their electronic components as they contain such a large amount of metals per Sample. This results in higher viability of the project, because of having a more significant amount of reused metal with high added value. The colors found in the leachate metals precipitation process show that the metal that most reacted with the solution is copper, presented in two different ionic forms (3+ and 6+) in samples 1, 4, and 5, based on your shades. And iron found in samples 2 and 3.

As the metals isolated in the precipitation returned to their pure form, from their separation done by electrolysis or pyrometallurgy returned in the production chain. To reduce the extraction of ores to be used as raw material and to encourage the use of methods such as those presented for the correct disposal of waste from electronic equipment, based on the presentation of the values in the composition. All acids used during the research properly discarded, neutralized, and sent to the effluent treatment station at the University of Vale do Rio dos Sinos, following standards certified by ISO 14001.

ACKNOWLEDGEMENTS

This study is part of projects of a group of researchers of Teachers and Mechanics Students of the Fundação Escola Técnica Liberato Salzano Vieira da Cunha (http://www.liberato.com.br/) from Novo Hamburgo, Brazil. Thanks also to CNPq (National Council of Technological and Scientific Development— Brasília, DF, Brazil) for the PIBIC research scholarship to High School students, and Research grants for one of the authors named Technological Development Research Grant - DT2/CNPq).

REFERENCES

[1]. ONU. Lixo eletrônico representa 'crescente risco' ao meio ambiente e à saúde humana, diz relatório da ONU - 2018. Disponível em: Acesso em: 05 abr. 2018. PEREIRA, Alex. Tenho que destinar o lixo eletrônico? O que eu ganho com isso?-2018. Disponível em: Acesso em: 05 abr. 2018.

[2]. A. Hubau, A. Chagnes, M. Minier, S. Touzé, Anne-G. Guezennec, Recycling-oriented methodology to sample and characterize the metal composition of waste Printed Circuit Boards. Waste ManagementVolume 9115 May 2019Pages 62-71. DOI: 10.1016/j.wasman.2019.04.041

[3]. R. Kovalick, Japão ganha com reciclagem de celulares - 2010. Disponível em: Acesso em 05 abr. 2018

[4]. J. de Souza, D. P. F. Hadlich, T. R. Maahs, Analysis of the replacement of conventional pallets of wood for cardboard pallets [in Portuguese]. Revista Liberato Vol. 17, Issue 28, (2016) pp 01-134. DOI: 10.31514/rliberato. 2016 v17 n28. P177.

[5]. Xiang-n. Zhu, H. Zhang, Chun-c. Nie, Xin-y. Liu, Guang-w. Zhang, Recycling metals from - 0.5 mm waste printed circuit boards by flotation technology assisted by ionic renewable collector. Journal of Cleaner ProductionVolume 25810 June 2020Article 120628. DOI: 10.1016/j.jclepro.2020.120628

[6]. C. Moraes, et al. Gestão, caracterização e desenvolvimento tecnológico para aproveitamento e recuperação de elementos raros e críticos a partir de produtos de pós-consumo eletroeletrônicos. Universidade do Vale o Rio dos Sinos - UNISINOS, São Leopoldo, 2018.

[7]. T. A. Silveira, Caracterização de sucatas de Smartphones e aplicação de processamento mecânico a recuperação de materiais oriundos de placas de circuito impresso. 2016. 77f. Trabalho de Conclusão de Curso em Bacharel em Engenharia Ambiental – Escola Politécnica da Universidade do Vale do Rio dos Sinos – UNISINOS, São Leopoldo, 2016.

[8]. T. Moyo, B. H Chirume, J. Petersen, Assessing alternative pre-treatment methods to promote metal recovery in the leaching of printed circuit boards. Resources, Conservation and RecyclingVolume 152January 2020Article 104545. DOI: 10.1016/j.resconrec.2019.104545

[9]. V. T. Moraes, Recuperação de metais a partir do processamento mecânico e hidrometalúrgico de placas de circuito impresso de celulares obsoletos. Universidade de São Paulo - USP, São Paulo, 2011.

[10]. M. M. Lottici, E. Tobolski, Caracterização de sucatas de computadores portáteis e aplicação de processamento mecânico à recuperação de metais oriundos de placas de circuito impresso. 2017. 53f. Trabalho de Conclusão de Curso em Técnico em Mecânica - Fundação Escola Técnica Liberato Salzano Vieira da Cunha, Novo Hamburgo, 2017.

Eduarda Tobolski,etal. "Recycled Metal Characterization of Printed Circuit Boards." *American Journal of Engineering Research (AJER)*, vol. 9(05), 2020, pp. 46-51.