APPLICATION OF MINERAL PROCESSING METHODS IN RECYCLING THE WASTE PRINTED CIRCUIT BOARDS

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Abstract

Recycling of the waste printed circuit boards (PCBs) is necessary from both an economic and an environmental point of view. Large amounts of waste contain significant amounts of valuable metals used as the secondary source. The PCBs can be viewed as a complicated mineral raw material on which mineral processing procedures can be applied. This work presents the mineral processing procedures used in the certain stages of recycling waste printed circuit boards.

***Keywords**: recycling, printed circuit boards, mineral processing*

1 INTRODUCTION

Development of the modern society has resulted in the production of various electronic equipment that becomes obsolete very quickly. Electronic waste contains a significant number of valuable elements, so it represents a precious resource for valorization. It also contains the harmful elements, considered as a hazardous waste and requires a space that meets the special conditions for disposal. The development of methods for recycling such materials is necessary from an economic and ecological point of view. Waste printed circuit boards (PCB) can conditionally be viewed as a complicated mineral raw material. In mineral processing, a methodology has been developed by which samples are studied to determine the concentration procedure. The same or similar approach is used during recycling.

In this work, an overview of the mineral processing methods that can be or are used in recycling waste PCB, was performed.

2 RECYCLING OF THE WASTE PCBs

It was estimated [1] that in 2019, 23.6 million tons of electronic waste were generated worldwide. Mir S. and Dhawan N. [2] describe PCB as the basis on which various electronic components such as the monolithic ceramic capacitors, tantalum capacitors, integrated circuits, and central processing units are mounted. On average, the PCBs contain 30–35% metal, 35–42% refractories, and 24–30% resin. The metal fraction of PCB consists of 8–38% Fe, 10–27% Cu, 2–19% Al, 1–3% Pb, 0.3–2% Ni, 200–3000 ppm Ag, 20–1200 ppm Au and 10–300 ppm Pd depending on plate origin. Printed circuit boards [3] make up about 3-8% of the total electronic waste.

Veit H.M. et al. [4] comminuted the printed circuit boards on a shredder to -1 mm and then sieved the material into the narrow size classes. After that, concentration was carried out on a dry magnetic separator at a magnetic field of 0.60-0.65 T. Iron and strongly magnetic amalgams were concentrated in the magnetic fraction. The non-magnetic fraction was treated on an electrostatic separator. Copper, tin, and lead were mostly concentrated in the conductive fraction, while mainly polymers and ceramics were in the non-conductive fraction. This last fraction requires processing in terms of lowering the metal content for the possible disposal of this material or some other form of recycling.

The authors Cui J. and Foressberg E. [5] performed a detailed characterization of TV waste, and it is described here because the same procedure can be applied to the waste PCBs:

- Manual separation
- Shredding on a shredder to a size of -12 mm
- Sampling by the method of quarters
- Sampling on a rotary sampler
- Grinding to fineness for a chemical analysis on a turbo-rotor mill
- Chemical analysis
- Determination of grain size composition on a series of sieves using a shaker
- Determination of grain shape using the image process system
- Grain liberation
- Sink-float test in liquids with densities ranging from 1.00 to 2.97 g/cm^3
- Identification of plastics by the FTIR spectroscopy

Good characterization is a guide for the concentration method selection.

Guo C. et al. [6] performed tests on sample of the computer PCB from different manufacturers. First, they removed the toxic parts for further use. Then they disassembled the PCB and cut them into 10 cm pieces. The material was crushed to a size of -1.25 mm. Sample was sieved into several size classes, and then the liberation was determined by observation using the digital camera and metallographic microscope. Metals were separated from material using the physical methods of concentration, namely: pneumatic, electrostatic and magnetic separation. In this way, they obtained a metal fraction with about 71% Cu.

Das A. et al. [7] describe a procedure where accessories such as cables, frames, and wires were first manually removed from the PCB. The boards are cut into 1.5 cm pieces. They were ground in a ball mill up to -0.5 mm. Sieving was done into the narrow-size classes, and the analysis of material liberation was carried out. The -44 µm class, which did not contain metal, had a pycnometer density of 1.49 t/m^3. In the initial sample, the density was 3.32 t/m^3. Based on these data, a sink-float test was performed in bromoform, which has a density of 2.81 t/m^3. This test indicated the possibility of successful separation by the gravity method.

Eswaraiah C. et al. [8] described the recycling waste printed circuit boards in an air classifier. The authors state that recycling can be considered the separation of metal and plastic from the PCB and their reuse. The lack of non-polluting methods for separating metals and plastics from these sources forces many researchers to engage in the mechanical separation methods. Air classification is a cleaner separation method that does not use any polluting separation medium. In this work, the authors presented the separation of metals and plastics from the ground PCB using an air classifier and analyzed the results of this process using the sink-float method. The authors passed the ground PCBs through an air separator and then analyzed the concentration results using the sink-float procedure. Selection of the separation medium was influenced by the density of liquid, but also by the requirements that it would be cheap, non-toxic, and non-corrosive. The density of non-metals in the PCB ranges from 1-1.8 g/cm^3. The density of present metals varies from 2.6 (aluminum) to 19.3 g/cm^3 (gold). A saturated zinc chloride solution with a density of 1.85 g/cm^3 was used for separation.

Mechanical recycling methods consist of shredding the plates to a suitable size. Then, they are treated on the eddy current separators or separators in a dense medium. In addition to the good separation of metals with these methods, the environment is also minimally polluted in this way. The authors first crushed the material to -2 mm in an impact crusher with hammers. After that, sample was sieved on a series of sieves, and each class was separated into a floating and a sinking part in a saturated solution of zinc chloride. Validation of the sink-float method was performed analyzing with the AAS method. Validation was also done by melting in a furnace at 650°C and then measuring the product. Based on the validation, it was confirmed that the sink-float method could be used as a fast method for evaluating the concentration results.

Li J. et al. [9] described the corona electrostatic concentration. Corona electrostatic separation is an efficient and environmentally friendly method for recycling metals from the PCBs. Coarseness classes from 0.6 to 1.2 mm are suitable for separation on an industrial scale.

Duan C. et al. [10] described the separation process in a water stream on the Falcon SB40 centrifugal separator. They cited the advantages of wet crushing that preceded the separation process, such as preventing the formation of dust, avoiding the heating of machine parts, no release of gases due to the pyrolysis during crushing. The process of emptying the crusher is accelerated, which further leads to the prevention of over-shredding, because the material passes through the crushing chamber faster. The water used in the process can be reused; the mean water consumption is low.

Williams J. [11] says that in the past, most discarded e-waste was destined for disposal and incineration or was taken to the developing countries despite the international agreements about limiting shipments. The paper shows the procedures used in the recycling of electronic waste:

- Decomposition processes refer to the separation of ferrous metals, non-ferrous metals, and precious metals
- Manual sorting into product groups
- Shredding on the shredder and extracting on the magnet
- Grinding in mills and extracting metals such as copper, aluminum, and others
- Mass recycling and separation of metals

In the paper [2] Mir S. and Dhawan N. state that PCBs are a central component of e-waste. They also say that the plates are very heterogeneous in composition, which makes their valorization very complicated. There is no suitable characterization technique that quantitatively assesses the distribution and liberation/association of different components that are heterogeneous without multiple comminutions. In categorization, it is necessary to perform the identification using various instrumental techniques such as the X-ray diffraction, ICP, SEM/EDS, and FTIR.

In the paper [12], an assessment of the state of PCB recycling was made. This paper analyzes related articles and covers broad areas such as characterization of the PCB waste, health hazards associated with processing, and different recycling routes to provide a comprehensive overview of this topic. In the physical separation processes, the electrostatic separation, magnetic separation, and flotation concentration are mostly described in the papers. In the paper, the authors referred to various hazardous elements, including heavy metals, and flame retardants, that pose a serious threat to the ecosystem during conventional waste treatment from disposal and incineration. Consequently, e-waste, including waste PCB, is either stored in the stores or sent to the developing countries where the poorest strata of the population engage in primitive recycling. Yard operations in Asia and Africa, particularly in China, India, and Ghana, are of concern because they involve primitive recycling techniques that result in most hazardous elements being discharged into nearby watercourses or soil. As a result, the living and working environment of the recycling population is greatly affected.

Based on the literature review, the stages of recycling and mineral raw material preparation procedures applied in those stages were systematized:

- Dismantling – manual selection
- Release of components – shredding on shredders in crushers and mills
- Characterization – comminution and sieving into narrow size classes, separation in the sink-float procedure
- Concentration or separation – sink-float method, separation in a fluid stream in cyclones, centrifugation in a fluid, magnetic separation, eddy current separation, electrostatic separation, flotation concentration
- Validation of separation results – the sink-float procedure

3 CONCLUSION

Waste PCBs can be conditionally viewed as a highly complex mineral raw material. Many are used in recycling, or the possibility of applying them at the laboratory level is being examined. Also, the well-established rules and methodology of mineral processing can be applied to recycle the electronic waste.

During the disassembly of PCBs, the unwanted parts are selected manually. To separate the components into separate grains, shredding to the required size is used. The characterization of samples takes place after sieving the crushed samples into the narrow size classes, using the classical or instrumental chemical methods. Separation of components can take place by: the sink-float process, classification in fluids, water and air, centrifugation in fluids, magnetic concentration, eddy current separation, electrostatic separation, and flotation. For rapid validation of separation techniques, the sink-float procedure can be used.

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