ENVIRONMENTAL FREE RECOVERY OF METALS FROM PRINTED CIRCUIT BOARDS (PCBS) OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENTS (WEEE)

R. Gopikaramanan  
Assistant Professor, Department of Electrical and Electronics Engineering  
Veltech Dr. RR & Dr. SR University Chennai, Tamilnadu.

P. Chandrakumar  
Associate Professor, Department of Mechanical Engineering  
Veltech Dr. RR & Dr. SR University Chennai, Tamilnadu.

B. Senthil Kumaran  
Assistant Professor, Department of Electronics and Communication Engineering  
Veltech Dr. RR & Dr. SR University Chennai, Tamilnadu.

ABSTRACT

This paper reviews the available technology for printed circuit boards recycling. The waste electrical and electronic devices which are mostly reaches land filling were the global issues. PCBs, the base of electronics, are essential part of almost all of the electronic products. PCBs are used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces etched from Cu sheets laminated onto a non-conductive substrate. PCBs are integral part in majority of electronic systems and are commonly found in consumer electronics. PCBs constitute at least 3% of the total electronic scraps by weight. Concentrations of precious metals such as Au and Pd in waste PCBs are richer than in natural ores, which makes their recycling important from both economic and environmental perspectives. The precious metals which is embedded on the green/yellow board and conflict circuit design makes the recovery more difficult. Waste PCBs have been paid much more attention from researchers and enterprises, not only due to their rich resource content, but also due to their potential risk for environment and human health with informal recycling. In this article, the VelTech Technology Business Incubator’s e-waste processing facility demonstrated the extraction of precious metals from mechanical processing technique, which supports the startups to venture the company by incubation and financial support. Also the recovery by Vision based mechanical system for identification and separations of shredded PCBs are also explained. The advantage of this research is to help the entrepreneurs to start venturing the PCBs extraction business under the incubation support from Vel Tech Technology Business Incubator e-waste processing unit.
1. INTRODUCTION

Increase in the development of technologies, the market demand for production of Electrical and Electronic Equipment is increasing dramatically. Smart Technology is part of people’s life. Printed circuit boards used mostly all the electronic components used by human beings. E-waste, in particular waste PCBs, represents a growing disposal problem globally. Considering that the life time of a mobile phone is approximately 1 year and of a computer 2-5 years, it is estimated that about 100 million of computers are discarded yearly in worldwide due to malfunctioning equipment or because technologies become obsolete [1-3].

Composition of printed Circuit Board in EoL

Many research works explains that composition of metals, ceramics and plastics in PCBS with ECs could reach 40%, 30% and 30% respectively. Meanwhile, the concentrations of precious metals such as Au and Pd in waste PCBs are richer than in natural ores, which makes their recycling important from both economic and environmental perspectives. Waste PCBs have paid more attention from both researchers and enterprises, due to their potential risk for environmental problem and also human health with informal recycling.

Figure 1 Material composition of PCB
2. CHARACTERIZATION OF WASTE PCBS

Considering the various nature of Waste PCBs, the characterization of Waste PCBs type, structure, components and composition is necessary to establish the process for environmental and economical feasible recycling. The base metals mainly found in PCBs are used because of their conductive properties. There are two types of PCBs (FR4 and FR2). These are normally used in PCs and mobile phones.

The FR-4 type is composed of a multilayer of epoxy resin, fiberglass coated with a Cu layer. The FR-2 type is a single layer of fiberglass or cellulose paper and phenolic coated with the Cu layer. Both resins are thermosetting (i.e. cannot be remelted and reformed). The FR-4 type is used in small devices such as mobile phones and FR-2 type is used in televisions and household appliances such as PCs (Ladou, 2006). The FR-4 epoxy resins are green in color and have high value while the FR-2 phenolic resins are yellow/brown in color and have low value. Table 2 shows the content of PCBs with ECs. PCBs without ECs contain about 30% metals and 70% nonmetals. The nonmetallic fractions consist of cured thermosetting resins, glass fiber, ceramics, BFRs, residual metals (Cu and solder) and other additives. Nonmetallic fractions composition contains 65% glass fiber, 32% epoxy resin and impurities (Cu: <3%, solder <0.1%) by weight. Resins are organic plastic polymers, high cost and low quality products. If resins are land filled or incinerated like in the past, they create potential environmental problems. Glass fibers, which are about 50–70% of PCBs, are reinforcing material in PCBs [4-5].

<table>
<thead>
<tr>
<th>Electronic components</th>
<th>Majority composition or materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistors</td>
<td>Ceramic, carbon</td>
</tr>
<tr>
<td>Capacitors</td>
<td>Aluminium, electrolyte, plastics etc., copper leads</td>
</tr>
<tr>
<td>Inductors, transformers</td>
<td>Steel, copper</td>
</tr>
<tr>
<td>Integrated circuits</td>
<td>Plastic cases, copper leads, silicon</td>
</tr>
<tr>
<td>Transistors, diodes</td>
<td>Plastic cases, copper leads, silicon</td>
</tr>
<tr>
<td>Connectors</td>
<td>Copper, plastic</td>
</tr>
<tr>
<td>Mounting brackets</td>
<td>Aluminium, steel</td>
</tr>
<tr>
<td>Heat sinks</td>
<td>Aluminium</td>
</tr>
</tbody>
</table>

Table 1 Typical PCB components and their major compositional components

3. PCBS ASSEMBLY STRUCTURE

The PCBs generally consists of two basic elements,

1. Conducting Cu substrate printed on or inside the laminate and
2. The small components attached to the substrate – chips (Ga, In, Ti, Si, Ge, As, Sb, Se and Te), connectors (Au, Ag), Capacitors (Ta, Al), etc,
Environmental Free Recovery of Metals from Printed Circuit Boards (Pcbs) of Waste Electrical and Electronic Equipments (Weee)

<table>
<thead>
<tr>
<th>Metals about 40%</th>
<th>Ceramics 30%</th>
<th>Plastics about 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>%</td>
<td>Ceramics</td>
</tr>
<tr>
<td>Cu</td>
<td>6-27</td>
<td>SiO2</td>
</tr>
<tr>
<td>Fe</td>
<td>1.2-8</td>
<td>Al2O3</td>
</tr>
<tr>
<td>Sn</td>
<td>1.0-5.6</td>
<td>Alkali-earth oxides</td>
</tr>
<tr>
<td>Al</td>
<td>2.0-7.2</td>
<td>Titanates-micas</td>
</tr>
<tr>
<td>Pb</td>
<td>1.0-4.2</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.3-5.4</td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>0.1-0.4</td>
<td></td>
</tr>
</tbody>
</table>

Depending upon the structure of the PCBs, it can be classified into single-sided or multisided. Single and multisided PCBs have the conducting layer on one or both sides of the laminates and with or without plated through-holes to interconnect the sides. The PCB boards thickness changes from 0.2 to 7.00mm.

PCBs assembly weighs in some consumer electronics are:
- CRT TVs - 7%
- Computers – 18.8%
- Mobile phones – 21.3%
- LCD Screens – 11.9%

Waste PCBs contain 33% semiconductors, 24% capacitors, 23% circuit boards, 12% resistors and 8% switches.

4. RECOVERY OF PRECIOUS METALS FROM PCBS:

4.1. Mechanical recycling technique:

The following are the optimized process of extracting precious metals from e-waste. PCB mechanical recycling can be broadly divided into two major steps. The first is the disassembly and separation of different components and materials, generally using mechanical or metallurgical processing to upgrade the desirable material content. Shredding, magnetic separation, electrostatic separation and supercritical extraction are the main technologies involved in mechanical recycling. Many methods are available to extract metals from post-processing PCBs. These technologies are very different in terms of economic feasibility, recovery efficiency and environmental impact.

The most attractive research on dismantling process is the use of robots. Unfortunately, full (semi) application of automated dismantling for recycling of PCBs is greatly frustrating. In practice of recycling the PCBs, selective dismantling is an indispensable process since: 1. The use of components has the first priority 2. Dismantling the hazardous components is essential. 3. It is also common to dismantle highly valuable components and high grade materials such as batteries in order to simplify the subsequent recovery of materials. The most recycling plants utilize manual dismantling. The below Figure we demonstrated the recycling of metal recovery from PCBs. These facilities were set up in Vel Tech technology Business incubator under the support provided by department of science and technology, Government of India. In these recovery we used raw PCBs separated from PCs, and manually separated the magnetic parts. Since PCBs further processing need to be handled in mechanical machines. The typical PCBs recovery process is as follows,
4.1.1. Physical/mechanical recycling techniques

1. Dismantling
2. Shredding / Crushing
3. Size Separation
4. Gravity separation
5. Magnetic separation for ferrous and non-ferrous
6. Electrostatic separation

Figure 2 Holistic process of Ferrous and Non Ferrous Material separation
5. VARIOUS OTHER RECYCLING TECHNOLOGIES OF PCBs:

1. Pyrometallurgy
Some techniques used in mineral processing could provide alternatives for recovery of metals from electronic waste. Traditional, pyrometallurgical has been used for recovery of precious metals from WEEE to upgrade mechanical separation which cannot efficiently recover precious metals. In the processing the crushed scraps are burned in a furnace or in a molten bath to remove plastics, and the refractory oxides from a slag phase together with some metal oxides. Further recovered metals are retreated or purified using chemical processing. The pyrometallurgical if electronic waste suffers from some limits in particular the recover as metals of aluminium and iron transferred flame retardants in the smelter feed can lead to the formation of oxides unless special installations and measures are present and precious metals are obtained at the very end of the process.

2. Hydrometallurgy
Leaching is the process of extracting a soluble constituent from a solid by means of a solvent. For electronic wastes leaching involve acid and/or halide treatment due to the fact that acid leaching is a feasible approach for removing of base metals so as the free the surface of precious metals. The solutions are then subjected to separation and purification procedures such as precipitation of impurities, solvent extraction, adsorption and ion exchange to isolate and concentrate the metals of interest. Consequently, the solutions are treated by electro refining process, chemical reduction, or crystallization for metal cover.

6. RESULTS AND DISCUSSIONS ON FEASIBLE RECYCLING PROCESS FOR ECONOMIC FEASIBILITY:
Mechanical recycling processes, such as screening, shape separation; magnetic separation, eddy current separation and electrostatic separation have been widely used in recycling industry. The advantage of physical recycling is that relatively simple and environmental free recovery can be done. The challenges are metallic and non-metallic products from waste PCBs. Significant dust collection and metal loss during shredding are the major disadvantage of physical recycling.

![Diagram of Integrated Recycling Process for Waste PCBs](image)

Figure 3 The whole process of integrated recycling for waste PCBs

The pyrometallurgy is an energy intensive and high cost process, but this is an traditional approach for metal recovery from PCBs. This technique include incineration, smelting in plasma arc furnace, blast furnace or Cu smelter, high temperature roasting in presence of selective gases to recover mainly nonferrous metals. Currently more than 70% of PCBs are treated in smelters rather than through mechanical processing. The main advantages of pyrometallurgy are accepting any forms of scraps. However pyrometallurgy process have
some disadvantages such as generation of large amount of slag, loss of precious metals and difficulty in recovery of Al and Fe and other metals.

The mechanical crushing is to strip metals from the base plates of waste PCBs. Crushing or shredding technology is intimately related to not only energy consumption of crushing equipment, but also further selective efficiency. Waste PCBs are comprised of reinforced resin and metal parts such as copper wires and joints. Mechanical – physical recycling process for waste PCBs is based on differences of materials in physical characteristics (including density, magnetic susceptibilities, electric conductivity, etc.). Due to its better environmental property (such as wastewater), high efficiency and easier operability, additional non-ferrous metals and precious metals contents have gradually decreased in concentration in PCBs.

7. CONCLUSION

The review of the available recycling such as mechanical, hydro metallurgy and pyrometallurgy were discussed. The mechanical – physical recycling process such as dismantling the waste PCBs and separating the unit components and crushing them into small pieces. The crushed small PCBs were further separated by process called screening or separation using various separators like magnetic, eddy current and electrostatic separator. The outcomes of the various separators are the metals for refineries and non-metals which directly used for Molding related products. Recycling of waste PCBs is an important subject not only from the treatment of waste but also from the recovery of valuable materials. In India in order to accelerate the pace of waste PCBs, the respective state should accelerate and motivate the startups to come with more recycling units. The Physical recycling process is the only recycling technologies will profits the e-waste business without negative impact to the environment.

REFERENCES